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RESEARCH ARTICLE

REVISED Coexistence Analysis of 5G C-Band Indoor Deployments and Fixed Satellite Service (FSS) in Malaysia

[version 2; peer review: 2 approved]

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Abstract

Several satellite services, including the Fixed Satellite Service (FSS), rely on the C-Band (3. 4 – 4. 2 GHz), which provides wide coverage and high availability despite weather effects. As a mid-band spectrum ideal for 5G, its allocation to cellular networks raises interference concerns, potentially disrupting satellite services and causing a significant economic impact. This study presents an empirical, measurement-based 5G propagation assessment and an interference investigation with 5G cellular networks operating below the 6 GHz band in the optimization of exclusion zones for 5G and FSS scenarios, with the aim of fine-tuning the exclusion zone and identifying better coexistence conditions between the two systems. We provide an extensive 5G-cellular downlink analysis that discusses, as part of the coexistence context, the potential for Low-Noise Block (LNB) saturation at the FSS Earth station receiver. Moreover, we deployed a real indoor 5G cellular network for measurement, in which high-gain receiving antennas

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version 2 (revision) 19 Aug 2026	✔ view	✔ view
version 1 11 Jun 2026	? view	? view

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were positioned at various indoor and outdoor locations to capture the downlink signal radiated by the 5G base-station transmitter within the proposed site. Additionally, a spectrum analyzer was used to examine the power signal received in contrast to the data signal acquired for the proposed projects. Across the indoor measurement points, the received power decreased with distance, reaching approximately −74.02 dBm at 40 m, and no measurable elevation of the FSS signal was observed at the MEASAT earth station located 3 km away. The results of this research indicate that spectrum regulators and other relevant parties will be affected by the potential implementation of 5G cellular networks in C-band operational FSS Earth station receivers. The research additionally proposes and evaluates methods that could facilitate the harmonious coexistence of both systems, like disabling significant emitters or diminishing their transmission capacity.

Keywords
5G NR (New Radio) frequencies, Fixed Satellite Service (FSS), C-Band, Indoors measurements

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REVISED **Amendments from Version 1**

This revised version responds to the comments of both reviewers. The most substantive change is one of framing rather than of data: the abstract and introduction no longer describe a "5G propagation model" but instead an empirical, measurement-based propagation assessment so that the manuscript accurately reflects what was performed—an indoor measurement campaign characterizing received power against distance under LOS and NLOS conditions.

The scope of the central finding has been tightened. The no-interference conclusion is now explicitly bounded to the single indoor RekaScape C-band scenario and the specific conditions tested, and a new "Study limitations" paragraph has been added to Section 4 identifying the constraints on generalization: one building, one base-station configuration, bounded Tx–Rx distances, and limited propagation diversity. A clarifying statement now also indicates that the ~100 m separation and 50–100 MHz guard band are practical planning considerations inferred from the measured behavior, not derived regulatory limits.

Several clarifications improve replicability and readability. Ambiguous phrasing in the abstract and results has been rewritten, duplicated RBW/VBW/SWT text has been removed, and the LNB-saturation mention has been reworded to match the body. The abstract now reports a quantitative outcome. An unrelated reference 16, has been replaced with an appropriate spectrum-analysis source, the MEASAT frequency notation has been corrected, and the reference list has been extended.

The experimental setup, measured values, and openly available Figshare dataset are unchanged. Formal link budget, exclusion zone derivation, and building loss modeling are signposted as future work.

Any further responses from the reviewers can be found at the end of the article

1. Introduction

5G refers to a fifth-generation mobile network. Furthermore, the following standards were adopted and published approximately every nine years since the establishment of the first mobile network in 1982: GSM, the second generation of cellular networks, was first released in 1992, and rival 3G specifications were introduced in 2001.[1,2] Service providers used the 4G LTE cellular standards in 2010. To create new mobile devices, technology companies and mobile operators worldwide are now using 5G technology. These 5G implementations are followed by LTE transformation technologies such as LTE Advanced and LTE Advanced Pro, which allow network operators to deliver faster speeds on mobile devices.[3] Ericsson published its 2017 "5G Readiness Survey." The operators sped up preparations for the new technology, and 78 percent of the respondents were conducting trials. In addition, 28 percent expect the fifth generation to be deployed in 2018. App interactions are evolving rapidly. Cisco VNI Mobile data show that mobile data traffic is expected to reach 11 exabytes per month in 2017, double that in 2015, reaching 49 exabytes by 2021. As of July 25, 2019, 5G was introduced into commercial use on 27 worldwide networks wished to deploy more than 150,000 base stations of 5G.[4] The mobile telecommunications sector is seeing significant changes on a daily basis.[5] Innovative generations and benchmarks have been instituted to deliver registered users with enhanced voice, data, and multimedia services at accelerated speeds. The introduction of new wireless technologies and the rising demand of consumers have enabled the mobile industry to transition from the second to the fourth generation. A decision was taken at the 2015 World Radio Communication Conference to designate 3.3 GHz – 4.2 GHz (3.5 GHz C band) to future mobile broadband, 5G beamforming, and 5G multi-antenna structure. This motivates service providers to utilize this frequency band for forthcoming 5G systems to facilitate seamless implementation.[1] For this paper was focus on indoor frequency 3.5GHz band, especially from 3.4 GHz to 3.6 GHz, as shown in Figure 1. This mid-band spectrum (<6 GHz) is taking shape as the core band for 5G worldwide because of the technical feature that affords an optimal balance of large capacity (amount of supported traffic) and coverage (distance of travelled signal).[6,7]

There is a possibility for adverse frequency interference with the planned allocation of 5G networks and FSS systems owing to the technological complexity of the FSS service within the 3.5 GHz range.[8] This is reflected by permitting unnecessary signals from 5G base stations and mobile terminals to interfere with FSS earth stations receiving signals in the 3.5 GHz band.[9–11] Technical studies were performed to evaluate the feasibility of the deployment of 5G within the range of the FSS system. This scientific study aims to determine the appropriate guard band, emission power limits, and distance separation. It is necessary to reduce interference and allow the coexistence of the two systems. Such approaches are recommended for testing by theoretical research and field trials based on global best and current practices, as these strategies can be used as a solution to interference management for both local and cross-border scenarios. In particular, Kristiadi et al. (2024) examined the protection-zone requirement for 5G–FSS coexistence in the C-band for the case of Indonesia; the present study complements that work by contributing direct indoor field measurements for a Malaysian deployment scenario rather than a computed protection-zone framework.[9]

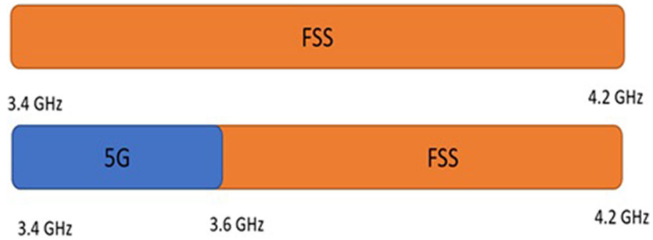

Figure 1. Proposed frequency arrangements for C-Band in Malaysia.

2. Experimental setup

The measurement component content of essential high-quality devices provides the best results without any errors. A new beamforming antenna for the 3.5 GHz band (3.3 to 3.8 GHz) was released by radio frequency systems (RFS). The ability to support 3.5 GHz applications is critical as operators worldwide are trying to meet the growing demand for LTE, deploy new small cells, and plan for 5G rollout. The 3.5 GHz band is the preferred sub-6 GHz spectrum for 5G networks worldwide rollout. The base station designed by ZTE is shown in Figure 2. It has the following description of the range of power transamination between (35–10) dBm (3–0.25) watts and the propagation of the signal is approximately 75 m. The purpose is to ensure that the base station operates indoors. Fifth-generation (5G) technology relies primarily on high-capacity transmission that utilizes short-range high-frequency radio waves.[12] This makes the 3.5 GHz band ideal for delivering high data rates with stable indoor coverage. In addition, the beamforming capability enhances the signal strength and minimizes interference, thereby ensuring a more reliable communication performance.

2.1 Location of measurement for received signal

This section describes indoor measurement scenarios. As shown in Figure 3, the location of the indoor scenario was in the RekaScape building and parking. There are also two paths: result line-of-sight propagation (LOS) and non-line-of-sight propagation (NLOS). On the other hand, the interference effect with various distances in parking and crossing the road with a distance (130) meters nearest the building of Cyberview and the other distance was nearest to the MEASAT station with a distance of 3 km. The FSS signals used in this study are shown in Figures 4 and 5.

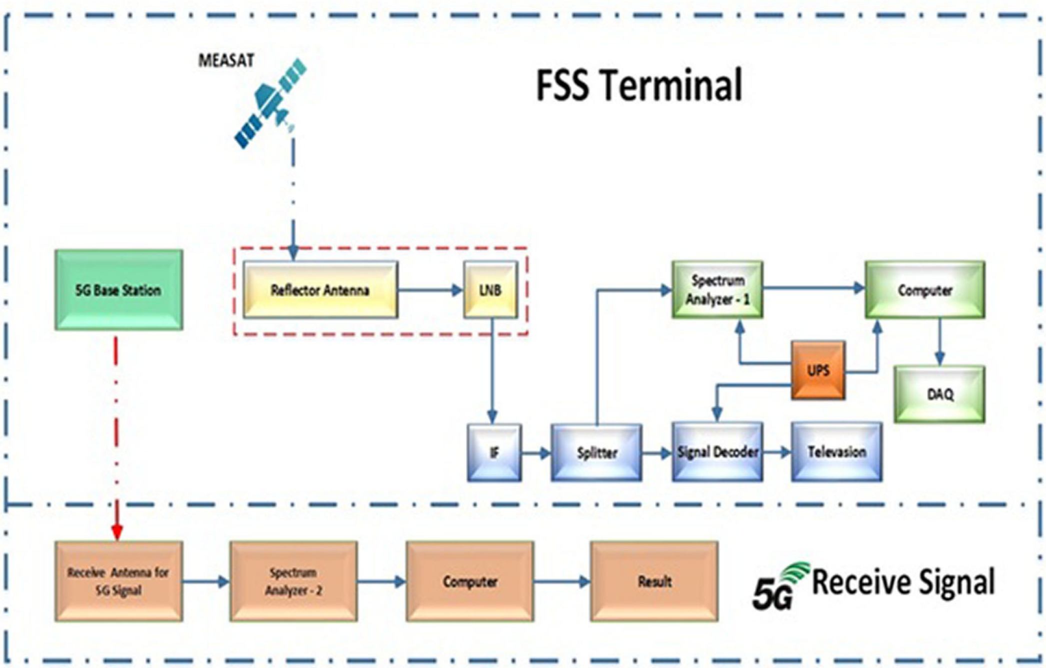

Figure 2. Experimental setup scheme.

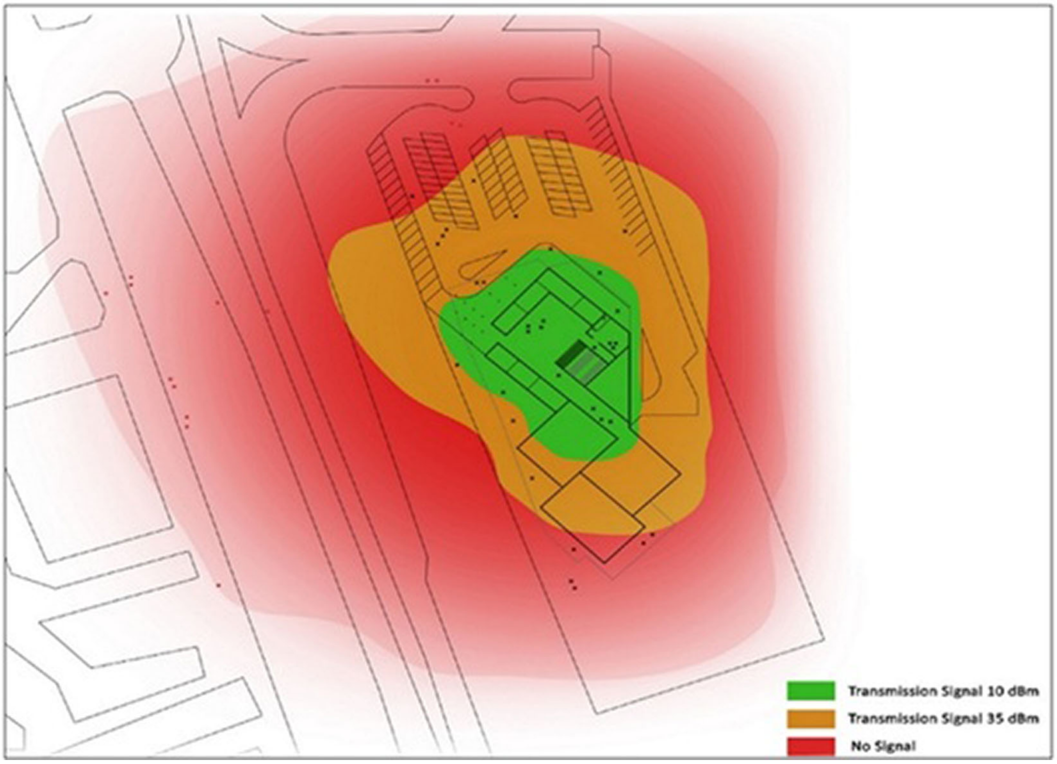

Figure 3. Map 1 for RekaScape building.

Figure 4. The distance of received signal (130 m), from RekaScape to Cyberview.

2.2 Receiver antenna parameters

The description is shown in Table 1, where the linear polarized Periodic Broadband Antenna Logarithmic (aluminum tubing) for receiving and transmitting applications.[13,14]

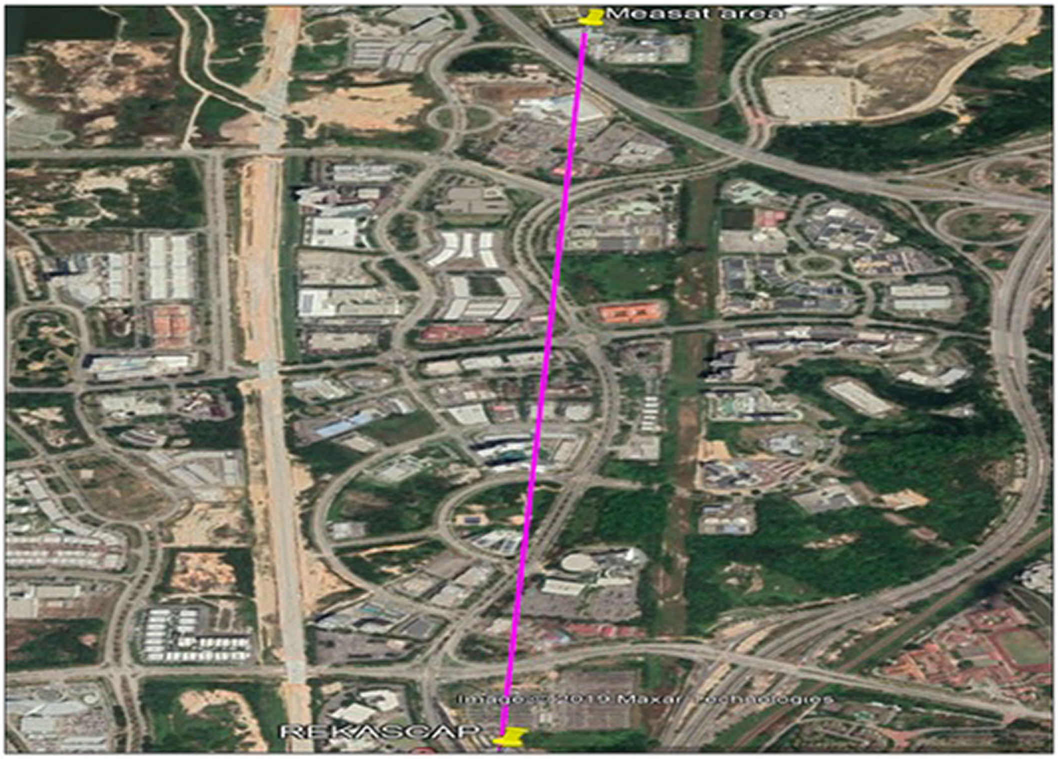

Figure 5. The distance of received signal (3 km), from RekaScape to MEASAT.

Table 1. The specification of receiver antenna.

Specifications	Typical
The nominal spectrum of frequency	800 MHz-5 GHz
The frequency spectrum can use	650 MHz-8 GHz
Gain isotropic	4–7 dBi
The factor of the antenna	23–38 dB/m
Typical SWR standing wave ratio	<1.5
Front to Back Ratio	20 dB
Cross-polarization	>20 dB (800 MHz-2 GHz)
Input max power	300 W @ 1 GHz \ 150 W @ 5 GHz

Moreover, the signal intensity variation was close to the location. In addition, the indoor radio transmission system varies significantly from the conventional cellular radio channel in terms of defended lengths. Relevant features, such as the building structure and positions of the antennas, affect propagation inside buildings. The location of the 5G base station inside the ZTE organization hall is 2 m higher from the ground, polarization vertical, and a transmit power of 35 dBm, as shown in Figure 7, and the yellow area covers the position of the points receiving the signal from the 5G station with a range distance between 1 m to 40 m.

Otherwise, as shown in Figure 6, the gap between the 5G base station and receiver antenna sites is approximately 5 m, with a special symbol (■). The display block settings were as follows: RBW =1 MHz, VBW = 1 MHz, and SWT = 100 ms. The received-power traces presented in Figures 7–12 correspond to max-hold detector readings captured directly from the spectrum analyser, rather than instantaneous single-sweep samples or externally averaged values. The resolution bandwidth (RBW) specified as the frequency range of the final filter that extends to the input signal. Relatively small

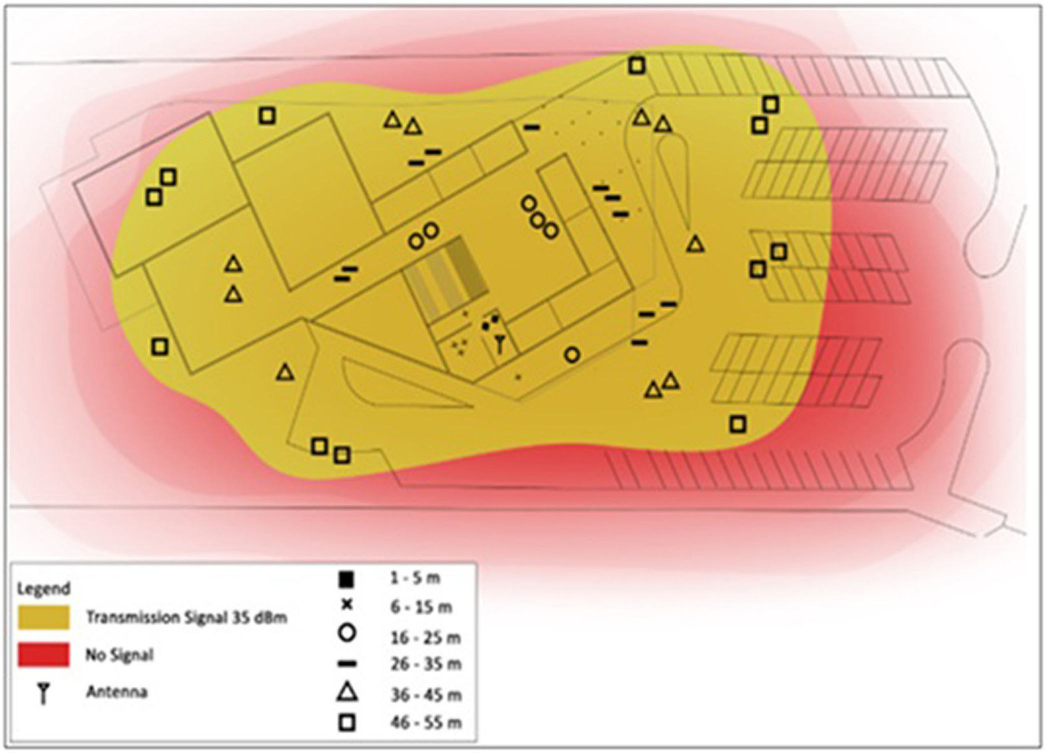

Figure 6. Map 2 5G points locations in RekaScape building Cyberview.

RBWs provide more natural frequency resolution and the ability to separate signals with closer frequencies.[15] Another aspect influencing a spectrum analyzer is that trace efficiency is the video bandwidth (VBW). This noise makes it difficult to detect tiny signals when VBW is high. As we lower the VBW, the small signal is even more evident. The sweep time (SWT) is the amount of time it takes from the start to the stop frequency from sweeping the detector. This noise makes it difficult to detect tiny signals when VBW is high. As we lower the VBW, the small signal is even more evident. The sweep time (SWT) is the amount of time it takes from the start to the stop frequency from sweeping the detector. The (SWT) value can be determined from the following equation: $SWT = \frac{K_T + SPAN}{RWB^2}$; the time required affects the RBW and VBW ratio. The VBW is typically set to a value greater than or equal to the RBW when we do not rely on noise, whereas the principal effect of the VBW and RBW detectors is to smooth the tracing and noise.[16] Moreover, innovations in RF receiver front-end design, encompassing rectifier technologies and energy harvesting architectures for simultaneous wireless information and power transfer (SWIPT) systems, have illustrated that shared-spectrum environments necessitate meticulous attention to receiver sensitivity, multi-band operation, and power conversion efficiency to guarantee dependable coexistence among diverse wireless services.[17]

3. Experimental results

In comparison, the frequency ranges start at 3 GHz and end at 4 GHz with a duration width of 1GHz at the middle scale of 3.5 GHz.

3.1 Measurement result

The first results, as shown in Figure 7, indicate that the particular range in the received power has the highest signal, with frequency of 3.49 GHz, −54.34 dBm, at the same location as the 5G transmission station, where the gap between the two sites is approximately 1 to 5 meters.

Figure 8, the signal is smooth and relatively flat from 3 GHz to 4 GHz with −50 dBm power level. The first peak received at the frequency 3.4 GHz with power − 30 dBm, and at the 3.48 the system received the highest peak in the −13.41 dBm from the received power signal with distance 10 m from the antenna of 5G station.

Figure 9, demonstrates that the first three pulses received starts from 3.4 GHz to 3.5 GHz. The highest peak of the received power signal from the 5G station antenna at −28.41 dBm, with a distance of 20 m.

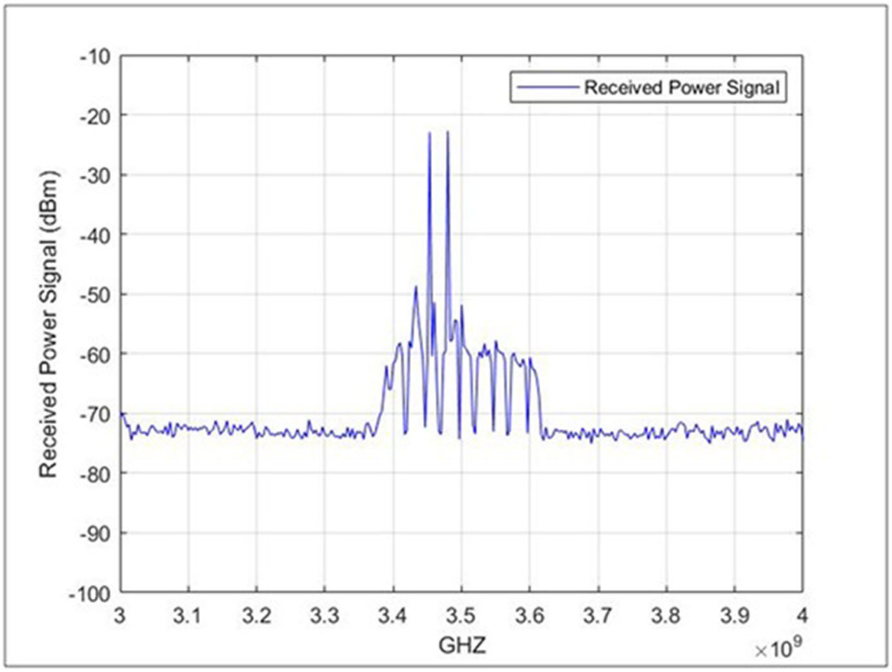

Figure 7. **Experiment result with distance 1 to 5 m.**

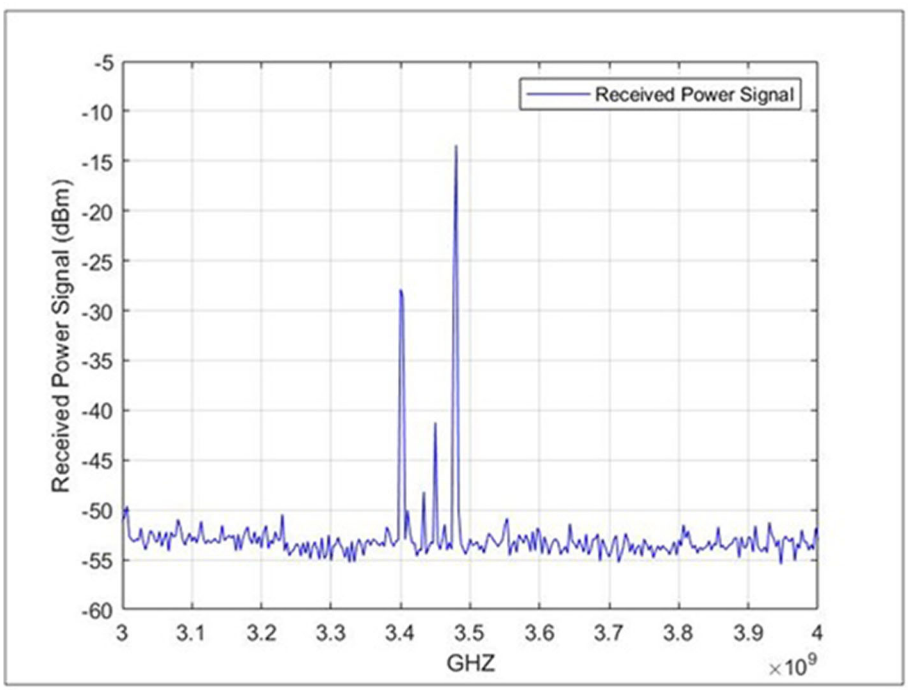

Figure 8. **Experiment result with distance 10 m.**

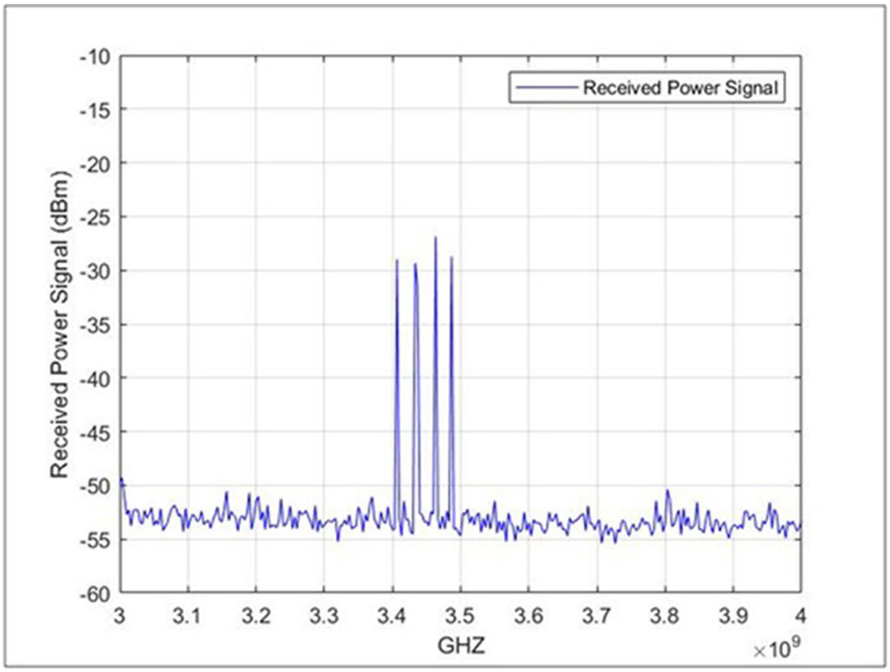

Figure 9. Experiment result with distance 20 m.

Figure 10, at a frequency of 3.42 GHz, indicates the maximum hold that will be obtained from the 5G station antenna at −54.61 dBm at the 30 m distance.

Figure 11, at a frequency of 3.41 GHz, shows the highest control received from the 5G station antenna at −52.34 dBm over a distance of 35 m.

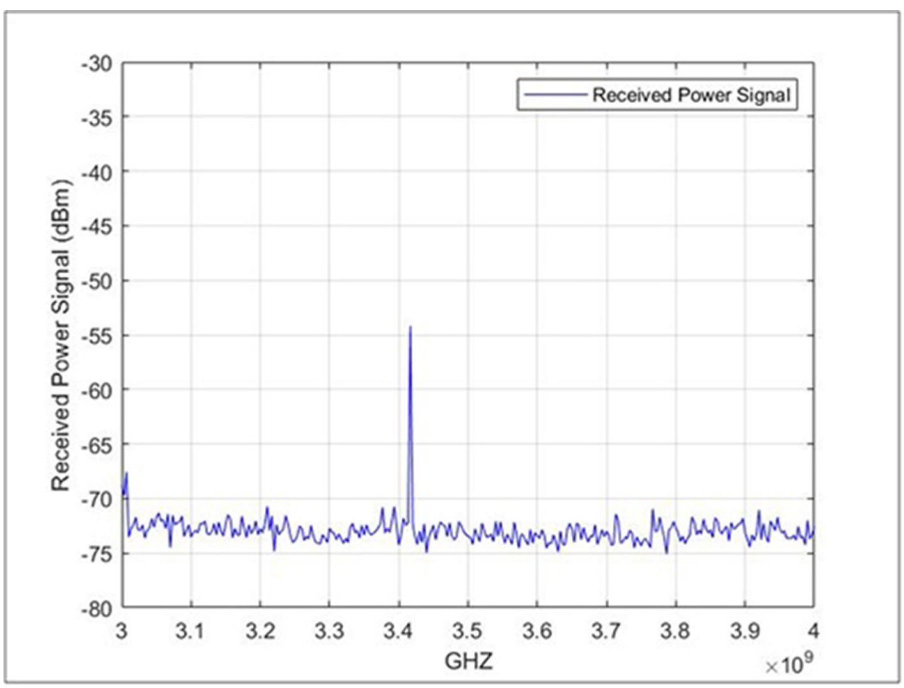

Figure 10. Experiment result with distance 30 m.

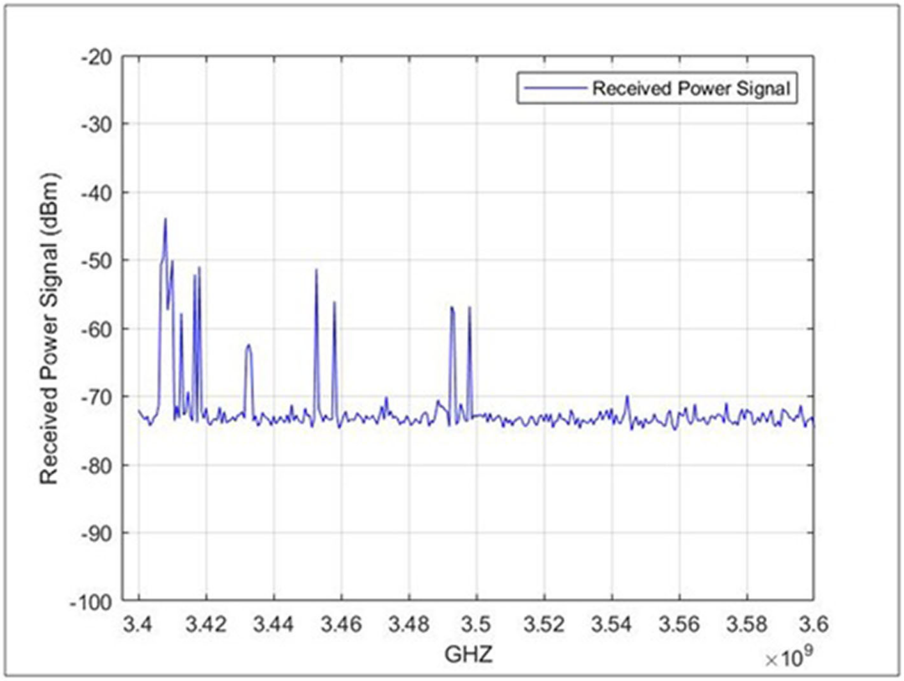

Figure 11. **Experiment result with distance 35 m.**

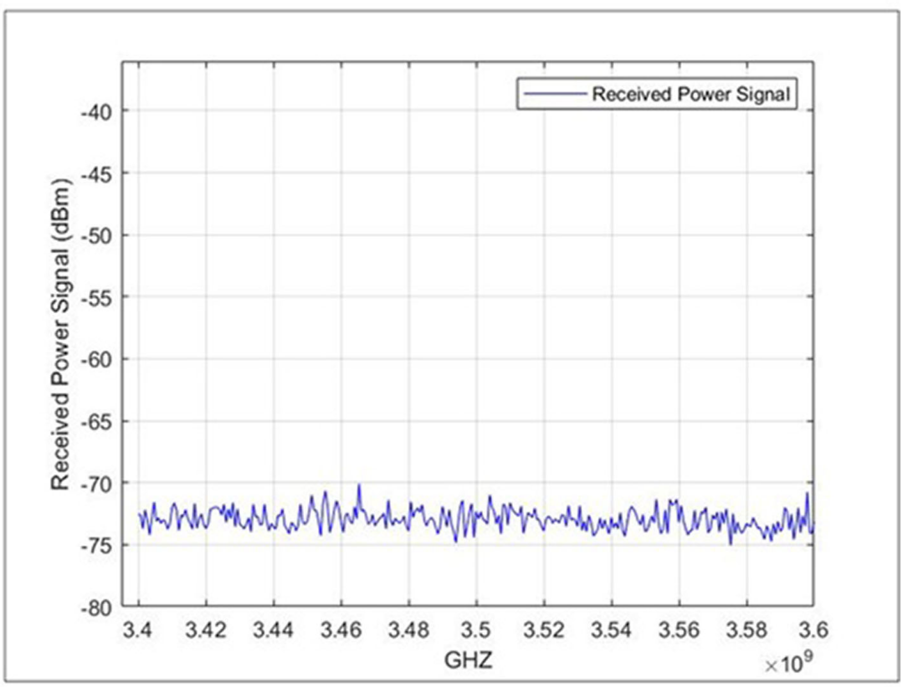

Figure 12. **Experiment result with distance 40 m.**

Figure 12 indicates that the signal is prevented by the cement wall between Tx and Rx. This point was collected from the 5G antenna at the highest distance. The first peak appeared within the initial range of 3,456 GHz at a power level of −74.02 dBm.

3.2 The distance model between Tx and Rx antenna

This section explains the comparison between the received power signals and propagation length (m). Figure 13 shows the maximum receiving power transmitted by the higher 5G antenna transmission approximately at 0.43 m with approximately 35 dBm.

Figure 14 indicates the highest signal at 10 m with −13 dBm, while at the 20 m the power received was less than approximately −30 dBm.

Figure 15 shows the received signals at different distances and antenna transmissions, where the transmission power approximately is −32 dBm to −54 dBm, at 20 m.

Figure 16 shows that the receiving signal is low at approximately − −55 dBm to −74 dBm at 30 m.

Figure 17 shows that the received power signal transmission by the service antenna signal is exceeded. Moreover, at 35 m the power received was approximately −63 dBm to −72.19 dBm.

The optimal exclusion zone between the 5G indoor model and FSS Inter-cell interference proved to be the most significant restricting factor at high altitudes; therefore, many industries and researchers are seeking to use less congested radio components in the total spectrum. The 3.4–3.8 GHz (C-band) is one of the world's most significant pioneer frequencies for the early launch of 5G networks. However, this band is already being used for fixed satellite services (FSS) in Malaysia and is not significantly affected by rain. The coexistence of mobile broadband networks should be investigated to better define the business conditions in specific environments. This section examines and demonstrates the numerical and measurement results for 5G indoor locations. It is notable from the last received data that there is no interference between the 5G signals and FSS spectrum. This study considers the following parameters, as explained in Table 2.

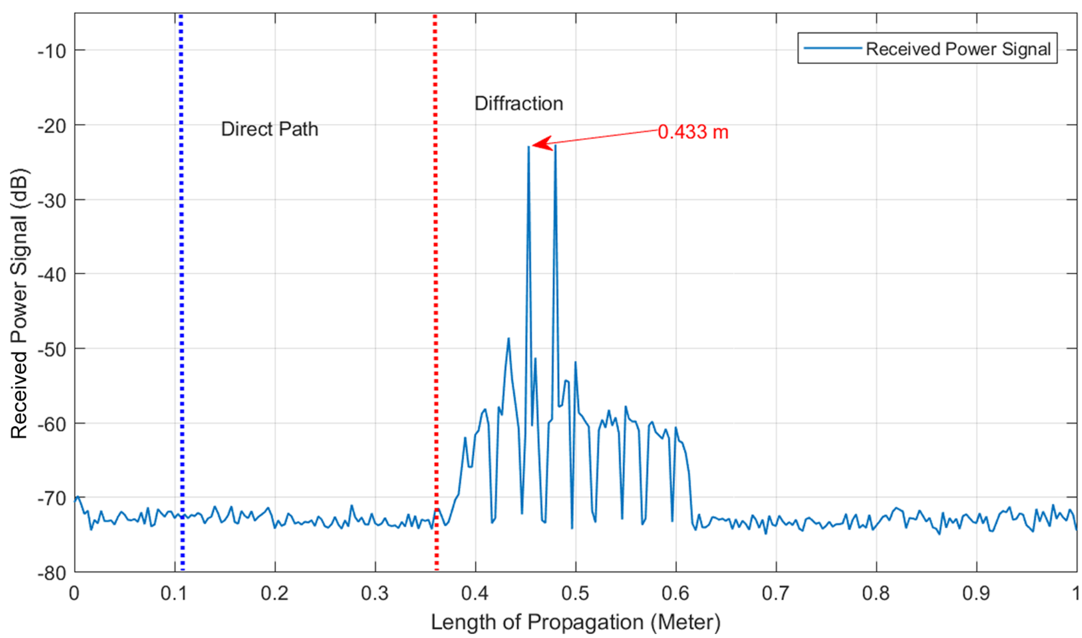

Figure 13. Distance of 1 m (Tx to Rx) Antenna.

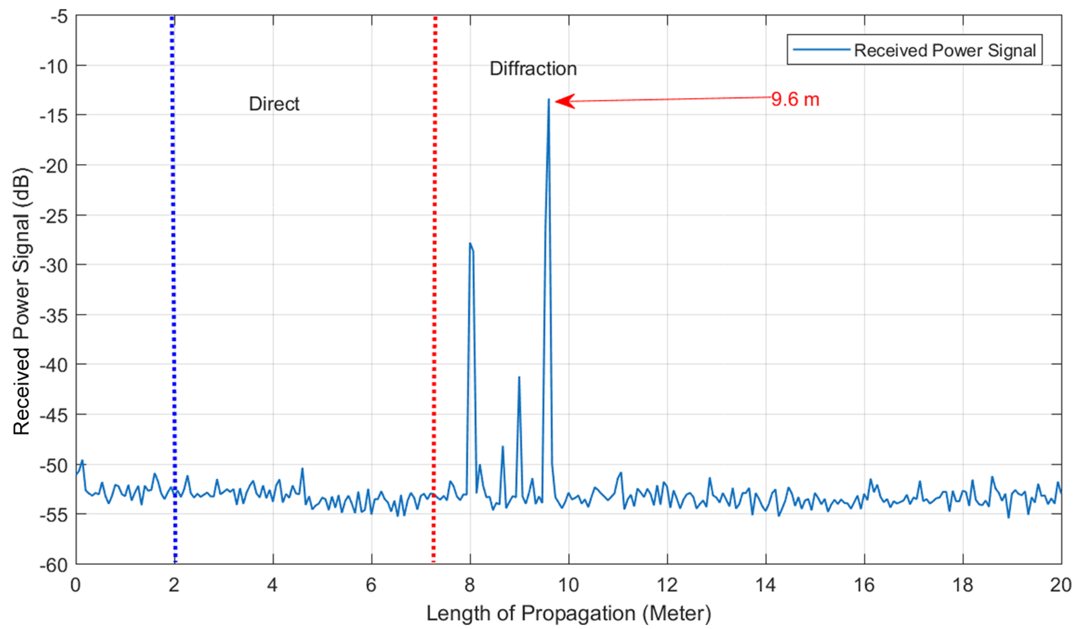

Figure 14. **Distance of 10 m (Tx to Rx) Antenna.**

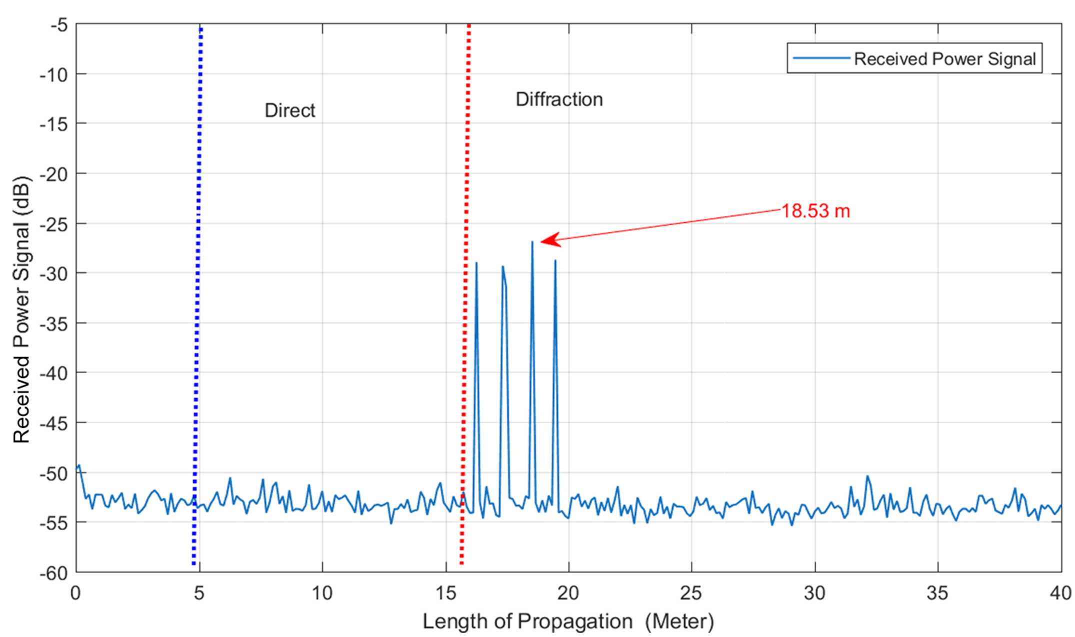

Figure 15. **Distance of 20 m (Tx to Rx) Antenna.**

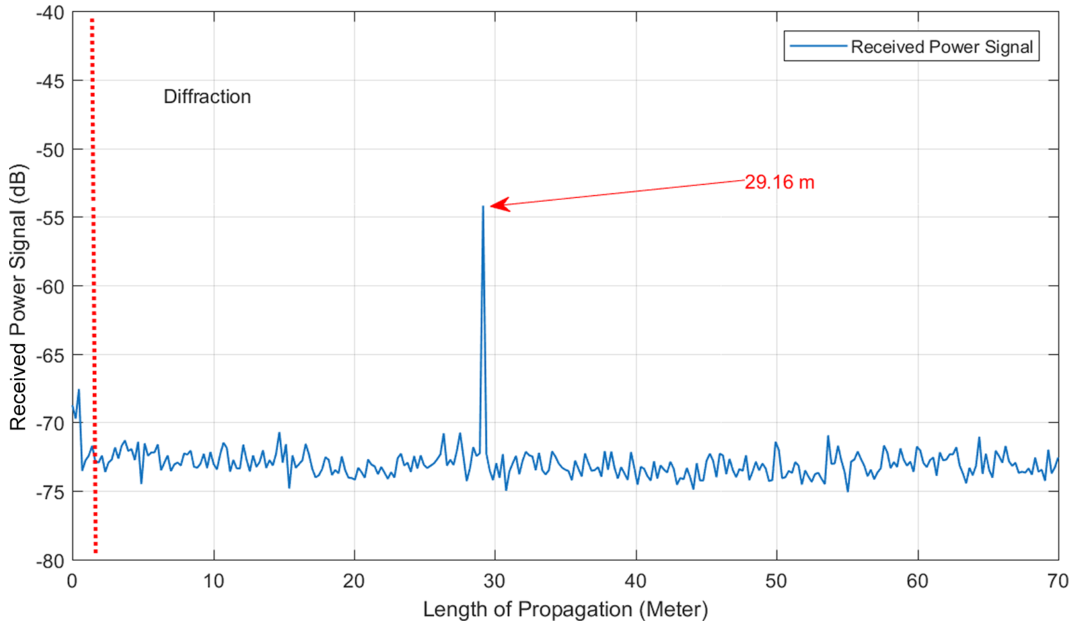

Figure 16. **Distance of 30 m (Tx to Rx) Antenna.**

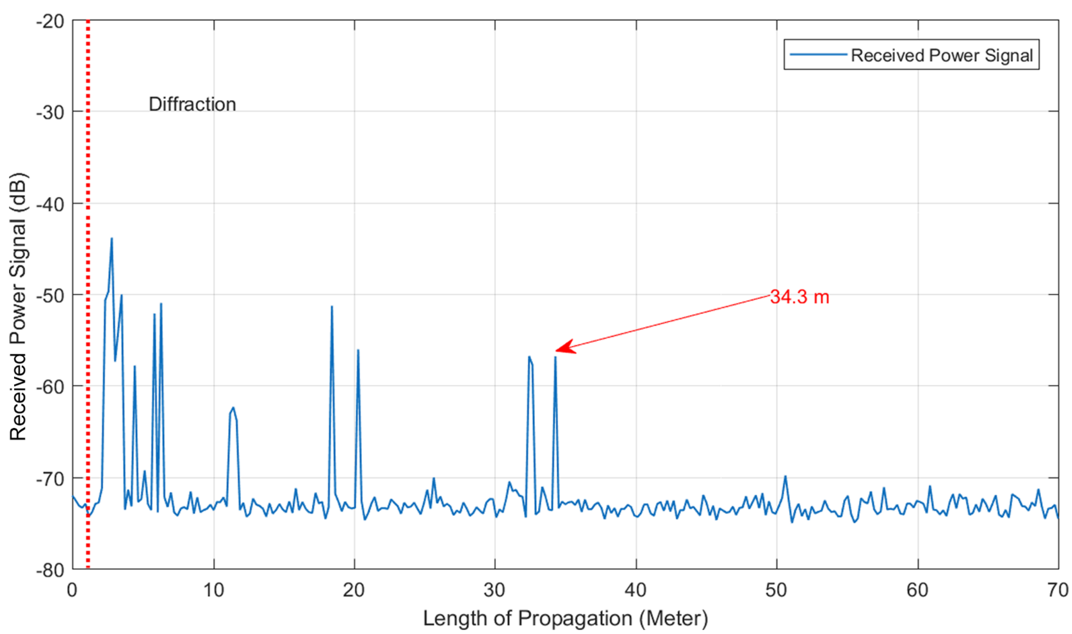

Figure 17. **Distance of 35 m (Tx to Rx) Antenna.**

Table 2. Typical parameters values.

Parameters	Values
Power transmission for 5G station	10 dBm, 35 dBm
Location of the 5G station	Inside the RekaScape building and parking
Frequency bandwidths	3.4–3.6 GHz
The max distance the signal receives	35 m
RekaScape closing site using FSS (MEASAT)	3 Kilometers
MEASAT frequency bandwidths	≥ 3,700 MHz (3.7 GHz)

It is notable from Table 2 that the best optimization exclusion zone for the indoor scenario, the distance between the 5G indoor station and FSS station should be approximately 100 m and the forbidden band from 50 to 100 MHz should be between the usage frequency. These separation and guard-band figures are practical planning considerations inferred from the measured indoor signal behaviour in this specific scenario; they are not proposed as universal regulatory limits, and their formal derivation against FSS protection criteria (for example, ITU-R I/N thresholds) is identified as an item for future work.

4. Conclusions

This study achieved all the stated objectives. The results obtained from the study and observations are described and analyzed in this study. Initially, the performance evaluation of 5G transmission with a power equal to 35 dBm resulted in higher data receiving widespread power recording. The power output of the 5G indoor base station decreased to 10 dBm owing to a reduction in the scatter size. The range of power received started from −3.53 to −57.88 dBm when the power transmission was high. The nearest center using the FSS transmitted and received signals was the MEASAT. The lowest frequency used by MEASAT is 3.7 GHz, and the distance from the indoor antenna in Rekascape is approximately 3 km. Finally, there is no interference between the 5G indoor signal and FSS signals in the scenario measurements. It should be emphasized that these findings apply specifically to the single indoor RekaScape C-band deployment scenario and the particular measurement conditions tested in this study, and they should be interpreted within that context rather than generalised to other building types, outdoor deployments, or aggregated multi-cell configurations.

4.1 Study limitations

The present results are based on a single indoor environment (the RekaScape building and its adjacent parking area) and therefore reflect limited spatial and propagation diversity. Only one building structure, one 5G base-station configuration, and a bounded set of Tx–Rx distances (approximately 1–40 m indoors, with adjacent 130 m and 3 km reference distances) were examined. Consequently, the reported coexistence behaviour should not be generalised to other building types, outdoor macro-deployments, or aggregated multi-cell scenarios without further measurement campaigns. Future work will extend the study to additional environments and incorporate formal path-loss fitting together with a regulatory link-budget analysis.

Data availability

The data supporting the findings of this study are openly available in Figshare at: [DOI: 10.6084/m9.figshare.31872805].[18]

The dataset includes radio-frequency measurement data collected during on-site indoor measurement campaigns, along with the processed data used for analysis and figure generation. Additional metadata describing the measurement setup, environmental conditions (e.g., building structures, terrain characteristics, and weather conditions), and experimental parameters are also provided to support interpretation and reuse.

The dataset is made available under a CC0 Public Domain Dedication/CC-BY 4.0 license, permitting unrestricted use, distribution, and reproduction in any medium, provided appropriate credit is given.

References

1. Al-Jumaily A, *et al.*: **Evaluation of 5G coexistence and interference signals in the C-band satellite earth station.** *IEEE Trans. Veh. Technol.* 2022; **71**(6): 6189–6200.
Publisher Full Text

2. Al-Jumaily A, *et al.*: **Evaluation of 5G and fixed-satellite service earth station (FSS-ES) downlink interference based on artificial neural network learning models (ANN-LMS).** *Sensors.* 2023; **23**(13): 6175.
PubMed Abstract | Publisher Full Text | Free Full Text

3. Patzold M: **5G readiness on the horizon [mobile radio].** *IEEE Veh. Technol. Mag.* 2018; **13**(1): 6–13.
Publisher Full Text

4. Biswas A, Gupta VR: **Multiband antenna design for smartphone covering 2G, 3G, 4G and 5G NR frequencies.** *Proc. 2019 3rd Int. Conf. Trends Electron. Informatics (ICOEI).* 2019; pp. 84–87.

5. Al-Jumaily A, Sali A, Riyadh M, *et al.*: **Machine learning modeling for radiofrequency electromagnetic fields (RF-EMF) signals from mmWave 5G signals.** *IEEE Access.* 2023; **11**: 79 648–79 658.
Publisher Full Text

6. Gozalvez J: **5G tests and demonstrations [mobile radio].** *IEEE Veh. Technol. Mag.* 2015; **10**(2): 16–25.
Publisher Full Text

7. MCMC 5G Task Force: *5G Task Force Findings and Recommendations to the Government.* Malaysian Communications and Multimedia Commission; 2019.

8. Fan YL, Lin XQ, Yang X: **An FSS-based shared-aperture antenna for 5G/Wi-Fi communication and indoor 5G blind compensation.** *Int. J. Microw. Wireless Technol.* 2023; **15**(8): 1373–1381.
Publisher Full Text

9. Kristiadi ID, Raharjo ARH, Nasir K: **Protection zone requirement of FSS for the coexistence of 5G–FSS in the C-band (case study of Indonesia).** *Proc. 2024 IEEE 35th Int. Symp. Pers., Indoor Mobile Radio Commun. (PIMRC).* 2024; pp. 1–6.

10. Arnaoutoglou DG, Empliouk TM, Kaifas TN, *et al.*: **Perspectives and research challenges in wireless communications hardware for the future internet and its applications services.** *Future Internet.* 2025; **17**(6): 249.
Publisher Full Text

11. Bukhari J, Mérida W: **5G interference with aviation altimeters: technology and policy recommendations for coexistence.** *Transport Policy.* 2024; **153**: 1–11.
Publisher Full Text

12. SalarRahimi M, Geurts M, Vandenbosch GA: **Realizing the E-Wall concept for indoor 5G.** *Proc. 2019 12th Global Symp. Millim. Waves (GSMM).* 2019; pp. 69–71.

13. Mess-Elektronik S: **USLP 9142 Log-Periodic Antenna – Product Specification.** 2020.

14. Bertrand M, Ettorre M, Valerio G, *et al.*: **A broadband low-profile circularly polarized radial line slot antenna.** *IEEE Trans. Antennas Propag.* 2022; **71**(1): 140–150.
Publisher Full Text

15. Chambwa W: **Frequency Reuse in 3GPP-LTE Downlink Cellular System.** 2017.

16. Keysight Technologies: *Spectrum Analysis Basics.* Application Note 150, 5952-0292E. Keysight Technologies; 2023.

17. Khalaf QM, Sali A, Ismail A, *et al.*: **Enhancing SWIPT systems: A systematic review of rectifier technologies, efficiency, and integration strategies.** *IEEE Access.* 2025; **13**: 201802–201831.
Publisher Full Text

18. Hussein Y, Hussein YS: DataSet for the paper Coexistence Analysis of 5G C-Band Indoor. Dataset. *figshare.* 2026.
Publisher Full Text

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✔ **Dr. Abdulaleem Al-Othmani**
School of Computer Science and Informatics, De Montfort University, Leicester, England, UK

I am happy with the revised article and the corrections made. Happy to accept/approve this submission.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cyber Security, Mobile Communication, Signal Processing, and Machine Learning

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 05 Sep 2026
Qasim Khalaf

Dear Dr. Abdulaleem,

On behalf of the authors, Thank you very much for your positive feedback and approval. We sincerely appreciate your time, valuable comments, and careful review of the revised manuscript. We are grateful for your recommendation to accept the submission.

Qasim

Competing Interests: No competing interests were disclosed.

Reviewer Report 20 August 2026

https://doi.org/10.5256/f1000research.208155.r512584

Assistant Prof. Ali Al-Juboori
School of Theoretical and Applied Science (TAS), Ramapo College of New Jersey, Mahwah, New Jersey, USA

I reviewed the revised version of the manuscript, and the authors addressed all my concerns very well. I recommend accepting the paper as it is.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Data Communication, Computer Networking, Wireless Communication.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 05 Sep 2026

Qasim Khalaf

Dear Dr. Ali,

On behalf of the authors, Thank you very much for your positive feedback and approval. We sincerely appreciate your time, valuable comments, and careful review of the revised manuscript. We are grateful for your recommendation to accept the submission.

Qasim

Competing Interests: No competing interests were disclosed.

Version 1

Reviewer Report 17 July 2026

https://doi.org/10.5256/f1000research.193483.r493151

Dr. Abdulaleem Al-Othmani
School of Computer Science and Informatics, De Montfort University, Leicester, England, UK

This is a really timely and relevant experimental study. The focus on real-world 5G and FSS coexistence in Malaysia, particularly using actual indoor measurements rather than just simulations, is a definite strength. The structure is logical, the measurement-based approach is appropriate, and making the data open is a great move that adds significant value to the community. The work contributes useful empirical data for practical deployment contexts.

That said, I do have a number of corrections and suggestions for enhancement that I believe would help strengthen the manuscript's clarity, presentation, and completeness. My detailed corrections and suggestions for enhancement are as follows:

Corrections:

1. To ensure replicability of the measurement, it is essential to add brief methodological details (Section 2: Experimental Setup, pp. 3-4) to:

- Clearly describe the measurement procedure, including whether measurements were repeated (number of trials per location), duration of each measurement, and sampling approach.

- Clarify data processing steps, e.g., whether values shown in Figures 7-12 (pp. 7-10) are instantaneous readings, averaged values, or smoothed outputs from the spectrum analyser.

2. Revise ambiguous or unclear sentences (Abstract, p. 1; Results, pp. 6-11)
- The Abstract (p. 1) contains unclear or disjointed sentences (e.g., incomplete statement on "fine-tuning exclusion zones").
- The Results section (pp. 6–11) includes unclear phrasing such as "in the same lap as the 5G transmission station" and "smooth mode"
- The explanations around RBW and VBW are repeated in the last section of p. 4. you could easily remove these repeated statements.

3. Revise the conclusion to reflect that findings apply to the specific indoor scenario and measurement conditions tested.

Recommended Enhancements

1. A general comment is that the English language and technical writing quality should be revisited throughout the manuscript. The structure of the paper is sound, however, there are recurring issues with grammar, sentence construction, and inconsistent terminology.

2. Consider adding a short note on study limitations (end of Section 4: Conclusions, p. 13) to acknowledge single indoor environment and limited spatial/propagation diversity.

In summary, this manuscript provides a useful and relevant contribution to the study of 5G-FSS coexistence. The work is technically sound, and the conclusions are generally supported by the results. The issues identified are minor and primarily relate to clarity, completeness, and presentation of results.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cyber Security, Mobile Communication, Signal Processing, and Machine Learning

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 06 Aug 2026

Qasim Khalaf

Reviewer 2: Dr. Abdulaleem Al-Othmani (De Montfort University)

We are grateful to the reviewers for their constructive and encouraging assessments and for recognizing the value of a real, measurement-based coexistence study with openly released data. Both reviewers judged the study design appropriate and the work technically sound, and neither identified an error in the measured data itself. We have accepted every comment that concerns clarity, language, presentation, framing, or a clearly editorial correction, and these are now implemented as tracked changes.

R2 · Correction 1: Methodological detail for replicability
Reviewer: Add procedure detail (repetitions/trials per location, duration, sampling) and clarify whether Figures 7–12 are instantaneous, averaged, or smoothed.
Response: partially accepted (clarification). A single clarifying sentence has been added in §2 stating that the traces in Figures 7–12 are max-hold detector readings taken directly from the spectrum analyzer, rather than instantaneous single-sweep samples or externally averaged/smoothed values—consistent with the text already present for Figure 10. The measurement location, base station and transmit-power settings, receiver-antenna

specification (Table 1), LOS/NLOS geometry, distances, and analyzer settings (RBW = VBW = 1 MHz, SWT = 100 ms) are already reported, and the complete raw and processed datasets with setup/environment metadata are openly available on Figshare (DOI: 10.6084/m9.figshare.31872805). We have documented the existing procedure rather than altering the practical campaign.

R2 · Correction 2: Ambiguous sentences

Reviewer: Incomplete abstract “fine-tuning exclusion zone” statement; results phrasing “in the same lap as...” and “smooth mode”; repeated RBW/VBW text on p.4.

Response: accepted (all three). The abstract fragment is completed: “in the same lap as the 5G transmission station” → “at the same location as the 5G transmission station”; “in the smooth mode” → “smooth and relatively flat”; and the duplicated RBW/VBW/SWT sentences are deleted, leaving a single clear explanation. All shown as tracked changes; no measured value is affected.

R2 · Correction 3: Conclusion scope

Reviewer: Revise the conclusion so findings apply to the specific indoor scenario and conditions tested.

Response: accepted. A caveat has been added (tracked) to §4 stating that the no-interference finding applies specifically to the single indoor RekaScape C-band scenario and the measurement conditions tested and should not be generalized without further campaigns.

R2 · Enhancement 1: Writing quality

Response: Accepted and applied conservatively. Clear grammatical/typographical errors are corrected as tracked changes (e.g., "transamination"→"transmission," "puls"→"pulses," “3,456 GHz”→“3.456 GHz”). Edits were deliberately limited so that no measured value, parameter, or technical statement changes; a full professional copy-edit will follow at the proof stage.

R2 · Enhancement 2: Study limitations

Response — accepted. A “Study limitations” paragraph has been added (tracked) at the end of §4: single indoor environment, limited spatial/propagation diversity, one building and base-station configuration, bounded Tx–Rx distances, and the need for further campaigns before generalization.

R2 · “Conclusions supported: Partly."

Response. The added scope caveat and limitations frame the conclusion strictly within the measured evidence, so the no-interference finding is now fully supported by the presented results rather than overgeneralized.

Competing Interests: No competing interests were disclosed.

Reviewer Report 29 June 2026

https://doi.org/10.5256/f1000research.193483.r493144

? **Assistant Prof. Ali Al-Juboori**
School of Theoretical and Applied Science (TAS), Ramapo College of New Jersey, Mahwah, New Jersey, USA

The manuscript addresses the problem of interference potential between 5G indoor deployments in the 3.4–3.6 GHz C-band and existing Fixed Satellite Service (FSS) operations in Malaysia. The experimental approach, using a ZTE 5G base station inside the RekaScape building with a spectrum analyzer to measure received power at multiple distances, is sound in its basic conception, and the finding that no measurable interference was detected between the indoor 5G signal and the MEASAT FSS station at 3 km is a useful empirical contribution. The work focusing on exclusion zone optimization is directly relevant to regulators and spectrum planners.

Major Comments

1. The abstract and introduction promise "a 5G propagation model," yet the body of the paper presents no formal propagation model. The results consist of raw spectrum analyzer readings at discrete distances. There is no path loss equation, no comparison to standard indoor propagation models (e.g., ITU-R P.1238, 3GPP TR 38.901, WINNER+), and no curve-fitting to the measured data. The authors should either (a) explicitly derive or adopt a propagation model and fit it to their measurements, report model parameters and goodness-of-fit statistics, or (b) revise the abstract and introduction to accurately describe the study as an empirical measurement campaign rather than a propagation modeling study.
2. The core claim, that no interference exists between the 5G indoor system and FSS, is supported only by the observation that signal levels at the MEASAT station were not visibly elevated. However, the manuscript does not provide: (a) the ITU-R threshold for interference into FSS receivers (I/N or C/I criteria), (b) any calculation of the aggregate interference power that would arrive at the FSS earth station from the indoor 5G emitter at 3 km, given the building attenuation and free-space path loss, or (c) any link budget. Without these, the "no interference" conclusion lacks a quantitative basis. The reader cannot determine how far below the interference threshold the measured levels were, which is the most practically important result. A formal interference link budget should be written.
3. Table 2 recommends an exclusion zone of approximately 100 m between the 5G indoor station and FSS station, and a forbidden guard band of 50–100 MHz. These values appear without derivation, simulation, or citation. How were they determined? Are they based on measurements, a regulatory recommendation, or a prior publication? The authors must either derive these values from their data and the relevant FSS protection criteria or clearly attribute them to an existing regulatory or technical source.
4. While the experimental description is reasonably detailed, it omits several parameters that would be needed to reproduce the study. For instance, the exact model of the spectrum analyzer used (referenced as "Spectrum Analyzer - 1" and "Spectrum Analyzer - 2" in Figure 2 but not named), the calibration procedure for the measurement equipment, and the number of measurement repetitions or averaging used at each distance point. Without this information, the measurement uncertainty cannot be estimated, and the study is not fully reproducible. These details should be added to Section 2.
5. The study measures signals inside the building (LOS and NLOS) and at distances up to 40 m, but the interference scenario of primary concern is leakage from indoor 5G to an outdoor

FSS earth station 3 km away. The paper does not discuss building entry loss (or exit loss) for the 3.5 GHz band, which is the critical attenuation factor in this scenario. Standard values from ITU-R P.2109 or 3GPP specifications should be cited and applied to estimate the actual out-of-building signal level, and this should inform the exclusion zone derivation.

Minor Comments

1. The abstract contains an awkward sentence structure in the passage beginning "Prior to the power signal transmission ceasing the network..." This should be rewritten for clarity. The abstract should also explicitly state the main quantitative finding (e.g., the received power range across distances, and the measured signal level relative to FSS protection thresholds).
2. The introduction covers 5G history in considerable detail (mobile network generations from 1982 onward, Cisco VNI traffic projections), which does not directly motivate the study. This background can be compressed substantially, with space redirected to a more thorough review of prior coexistence studies in the 3.5 GHz band, particularly the work of Kristiadi et al. (2024, reference 9), which addresses an almost identical problem for Indonesia and should be directly compared to the present findings.
3. Figures 7 through 12 use axis labels that are difficult to read at publication resolution. The x-axis label "GHz × 10^9" is redundant (GHz already implies ×10^9 Hz); this should be corrected to simply "GHz." Also, Figures 13 through 17 (propagation length plots) would benefit from explicit annotations indicating the LOS-to-NLOS transition point.
4. Reference 16 (Ellis et al., "On the maximal strength of a first-order electroweak phase transition...," J. Cosmol. Astropart. Phys.) appears to be a citation error, it concerns particle cosmology and has no connection to spectrum analysis or VBW/RBW. The authors should replace this with the appropriate technical reference for the SWT equation and VBW/RBW relationships.
5. The entry "MESAT frequency bandwidths ≥ 3.700 MHz" is almost certainly a typographic error and should read "≥ 3,700 MHz" (i.e., 3.7 GHz). Please verify and correct.
6. The abstract mentions analysis of "potential Low-Noise Block (LNB) saturation," but this analysis does not appear in the body of the paper. Either the LNB saturation analysis should be included as a distinct section, or the reference to it should be removed from the abstract.

Recommendation:

Major revision is required. The study addresses a valuable and policy-relevant question, and the empirical measurements are a genuine contribution. However, the manuscript needs a formal propagation model or an accurate characterization of what was actually done, a quantitative interference link budget relative to FSS protection thresholds, a derivation of the exclusion zone recommendation, correction of sign errors in the reported power values, and resolution of the LNB saturation omission.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Data Communication, Computer Networking, Wireless Communication.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 06 Aug 2026
Qasim Khalaf

Reviewer 1: Assistant Prof. Ali Al-Juboori (Ramapo College of New Jersey)

We are grateful to the reviewers for their constructive and encouraging assessments and for recognizing the value of a real, measurement-based coexistence study with openly released data. Both reviewers judged the study design appropriate and the work technically sound, and neither identified an error in the measured data itself. We have accepted every comment that concerns clarity, language, presentation, framing, or a clearly editorial correction, and these are now implemented as tracked changes.

R1 · Major 1: "Propagation model"
Reviewer: The abstract/introduction promises a 5G propagation model, but the body presents measured readings; either derive/fit a model with goodness-of-fit or reframe it as an empirical measurement campaign.
Response: accepted via option (b). We have reframed the claim: the abstract now reads "an empirical, measurement-based 5G propagation assessment" rather than "a 5G propagation model," so that the manuscript describes exactly what was performed—a measurement campaign characterizing received power versus distance under indoor LOS/NLOS conditions. We have deliberately not fitted a formal path-loss model to the data, as that would convert this empirical study into a different type of paper; such model fitting is noted as future work.
R1 · Major 2 — Quantitative interference link budget
Reviewer: The "no interference" claim lacks ITU-R I/N or C/I thresholds, aggregate interference power at the FSS earth station, and a link budget.
Response: Respectfully declined as beyond the empirical scope; the observation is retained and now scenario-bounded. The no-interference statement is an empirical observation: at the MEASAT earth station 3 km away, no measurable elevation of the FSS signal was detected under the tested indoor 5G operation, and the 5G band (3.4–3.6 GHz) is separated from the MEASAT operating range ($\geq$ 3.7 GHz). A full regulatory link budget

requires proprietary site-specific FSS receiver parameters and deployment assumptions, which were outside this study's objective and cannot be provided without unverified assumptions. We have therefore bounded the conclusion to the measured scenario (§ 4) and signposted the formal I/N link budget as future work, rather than change the practical result.

R1 · Major 3: Exclusion zone and guard band
Reviewer: The ~100 m separation and 50–100 MHz guard band appear without derivation, simulation, or citation.
Response: clarified (no change to the values). A sentence has been added after Table 2 stating explicitly that these separation and guard-band figures are practical planning considerations inferred from the measured indoor signal behavior in this specific scenario, not universal regulatory limits, and that their formal derivation against FSS protection criteria (e.g., ITU-R I/N thresholds) is future work. This addition resolves the framing concern without altering the reported values.
R1 · Major 4 — Reproducibility (instrument detail)
Reviewer: The spectrum-analyzer model, calibration procedure, and number of repetitions/averaging are not given.
Response: partially accepted (clarification). As with Reviewer 1's Correction 1, we have clarified in §2 that Figures 7–12 are max-hold traces read directly from the analyzer. The reported analyzer display settings (RBW = VBW = 1 MHz, SWT = 100 ms) and the openly available Figshare dataset (with setup and environmental metadata) allow the measurement scenario to be reproduced in principle. We have not added a full instrument-metrology and uncertainty-budget section, as that is a different (metrological) study scope; the measured campaign itself is unchanged.
R1 · Major 5: Building entry/exit loss
Reviewer: Building entry/exit loss (ITU-R P.2109 / 3GPP) for 3.5 GHz should be cited and applied to estimate out-of-building leakage toward the FSS earth station.
Response: Respectfully declined, as it is beyond the empirical scope. This work is a field-measurement study: the walls and indoor environment are physically part of the measured scenario, so their attenuation is already embodied in the recorded received-power behavior. Applying a generic building-loss model would be appropriate for a simulation-based extrapolation across many building types, which is precisely the future-work extension we now signpost; it is not required to validate the empirical observation reported here.
R1 · Minor 1: Abstract clarity and quantitative finding
Response: accepted. The awkward sentence beginning "Prior to the power signal transmission ceasing the network…" has been rewritten for clarity, and the abstract now states a measured finding: the received power decreased with distance to approximately −74.02 dBm at 40 m, with no measurable elevation of the FSS signal at MEASAT Station 3 km away.
R1 · Minor 2: Introduction focus
Response: Partially accepted. A direct comparison to Kristiadi et al. (2024, ref. 9) has been added to the Introduction, noting that the present study complements their Indonesian protection-zone analysis by contributing direct Malaysian indoor measurements. We have retained the historical context for readers new to the band; further trimming can be applied at the proof stage in agreement with the editor.

R1 · Minor 3: Figure axis labels and LOS/NLOS annotation

Response: accepted for the figure files. Figures 13–17 have been regenerated as propagation-length plots in which the direct (LOS) and diffraction (NLOS) paths are explicitly marked, directly implementing the requested LOS/NLOS annotation; the redundant "GHz × 10^9" label on Figures 7–12 will be corrected to "GHz" in the revised figure set. These are figure-image corrections and do not change any reported value or interpretation.
R1 · Minor 4: Reference 16
Response: accepted. The unrelated cosmology citation has been replaced (tracked) with an appropriate spectrum-analysis reference (Keysight Technologies, "Spectrum Analysis Basics," Application Note 150) supporting the SWT/VBW/RBW discussion.
R1 · Minor 5: MEASAT frequency notation
Response: accepted. Corrected (tracked) in Table 2 to "MEASAT frequency bandwidths ≥ 3,700 MHz (3.7 GHz)." This is a typographical/units correction; the physical value (3.7 GHz), already stated in the Conclusions, is unchanged.
R1 · Minor 6: LNB saturation
Response: accepted. The abstract has been reworded so that LNB saturation is presented as part of the coexistence-risk context discussed in the paper, rather than implying a dedicated LNB saturation experiment. This makes the abstract consistent with the body; a dedicated LNB compression study is noted as future work.
R1 · Recommendation: alleged sign errors in power values
Response: respectfully declined; values verified. We re-checked the reported received-power values against the publicly available Figshare dataset. The negative dBm figures are correct as measured; received power at the spectrum analyzer input is naturally expressed in negative dBm, and the per-figure peak values are consistent with distance (for example, −13.41 dBm at 10 m in Figure 8 decreasing to −74.02 dBm at 40 m behind a cement wall in Figure 12). Prompted by this comment, we also reviewed the overall received-power range summarized in the Conclusions and have ensured it is reported consistently with the values shown in the figures. No change to the underlying measured data is warranted.

Competing Interests: No competing interests were disclosed.