Huawei response to the Ofcom public consultation:
Hybrid sharing – enabling both licensed mobile and Wi-Fi users to access the upper 6 GHz band

Summary

We thank Ofcom for the opportunity to comment on this consultation on the application of hybrid sharing between licensed mobile networks and Wi-Fi in the upper 6 GHz band.

In this document we use the CEPT term “mobile/fixed communication network” (MFCN) to refer to licensed mobile (IMT) networks, and the CEPT term “radio local area network” (RLAN) to refer to networks which use technologies such as Wi-Fi.

We have modelled the potential for mutual co-channel interference between RLANs and MFCNs, both indoors (where we see that a large majority of locations would benefit from MFCN coverage in the upper 6 GHz) and outdoors. The results indicate that in the absence of any additional mitigation measures, there is a **substantial risk of mutual harmful interference** between RLANs and MFCN downlink in the upper 6 GHz. The potential for interference between RLANs and MFCN uplink is for further study.

We have analysed two mitigation measures, namely, **sensing** and **database-assisted access**. We outline how these techniques can be used to potentially enable co-channel operation of MFCNs and RLANs through geographic separation or separation in time, and discuss some of the challenges which these techniques may present in the implementation of hybrid sharing in the upper 6 GHz band.

We consider that a **simple demarcation** between MFCNs and RLANs along the lines of **outdoor vs. indoor** use is **not appropriate**, on the basis that in our view outdoor-to-indoor coverage can play an important role in the provision of mobile services in the upper 6 GHz band, as evidenced by the results of recent field trials, and that its exclusion would substantially reduce the utility of the band for MFCNs.

Furthermore, we consider that the placing of **restrictions** on the **power of MFCN base stations** is **not appropriate** as a mitigation measure for facilitating hybrid sharing. This is because such restrictions would effectively preclude the use of the existing grids of macro-cellular MFCN sites for the provision of citywide capacity coverage, and would thereby effectively **reduce the value** of the upper 6 GHz band for MFCNs to near zero.

We also present our views in relation to the important matter of **prioritisation** between MFCNs and RLANs, and the need for a broad impact assessment to establish whether hybrid sharing between MFCNs and RLANs in the upper 6 GHz would actually bring any net benefits compared to the case where the band was made available for use by either MFCNs or RLANs alone.

We consider that access by **licensed MFCNs to the upper 6 GHz band must be prioritised over licence-exempt RLAN at all locations where the signal power from the MFCNs in the band is sufficiently high to provide services to users**. We consider this to be an essential pre-condition to incentivise mobile operators to investment in infrastructure, and that this would also have a substantial impact on the performance and utility of RLANs in areas served by MFCNs.

Nevertheless, we note that in certain circumstance, e.g., **deep indoors**, it might be possible for RLANs to operate co-channel with MFCNs. This can be achieved via sensing and if the energy detection threshold of RLANs is reduced appropriately. The technical feasibility of such reduced thresholds, their impact on RLAN performance, and risk of potential interference to indoor (non-deep) use by MFCNs are for further investigation.

Huawei's comments in response to Ofcom's questions

Question 1: Hybrid sharing could mean that the upper 6 GHz band will be used for mobile outdoors, and Wi-Fi indoors. What are your views on the priorities for each of these two services, assuming that suitable coexistence mechanisms are developed?

As Ofcom itself acknowledges in its consultation, MFCNs (IMT networks) provide wider area coverage both outdoors and indoors. And while it is certainly true that the provision of outdoor-to-indoor coverage is not readily feasible at high frequencies such as mmWaves (due to excessive building penetration loss), the same cannot be said of the upper 6 GHz.

On the contrary, MFCNs are expected to provide not only **outdoor-to-outdoor**, but also **outdoor-to-indoor** coverage in the upper 6 GHz band[1].

Furthermore, field trials[2] undertaken to date indicate broadly similar spectral efficiencies for both outdoor-to-outdoor and outdoor-to-indoor (shallow indoor) scenarios in the 6 GHz and 3.5 GHz bands, with throughput only materially affected when deep indoors. This is due to the higher-order MIMO implemented in the 6 GHz base station, and the fact that glass (unless it has special coating) presents little or no signal attenuation at these frequencies[3].

Accordingly, we do not consider that a simplified demarcation between MFCNs (IMT) and RLANs (Wi-Fi) along the lines of outdoor vs. indoor use is appropriate in the context of sharing in the upper 6 GHz band. We consider that outdoor-to-indoor coverage can play an important role in the provision of mobile services in the upper 6 GHz band, and that its exclusion would reduce the utility of the band for MFCNs.

In our view, access by licensed MFCNs to the upper 6 GHz band should be **prioritised** over access by licence-exempt RLANs at **all locations where the signal power from the MFCNs in the band is sufficiently high to provide services to users.** We elaborate on our reasoning in our response to Question (7).

Question 2: Hybrid sharing could mean that the upper 6 GHz band will be used for mobile in some locations, and Wi-Fi in others. We would like feedback on the priorities for each of these two services, assuming that suitable coexistence mechanisms are developed.

a) From the point of view of mobile, is the upper 6 GHz band most useful to provide outdoor coverage, or indoor coverage? Is it most useful in urban areas, or in those base stations that are currently carrying more traffic, or some other split?

b) Similarly, what are the priorities from the point of view of Wi-Fi deployments?

Priorities for IMT

As emphasised by the mobile industry[4], the upper 6 GHz band is primarily considered for the deployment of MFCNs (IMT networks) for the provision of **capacity layers** in cities, larger towns, and other high-traffic areas, as opposed to the deployment of wide-area/national coverage layers.

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[1] See a presentation by Orange at the MWC 2023 here and here, and a presentation by Deutsche Telekom at the European 5G Conference 2023 here.

[2] See details in Huawei's response to Ofcom's consultation in on "Enabling spectrum sharing in the upper 6 GHz band, shared licences for local, low-power indoor use of the upper 6 GHz band (6425-7070 MHz)," Feb. 2022. See here on trials at the Politecnico di Milano in Oct. 2022. See here and here on trials by Deutsche Telekom at the upper 6 GHz in Nov. 2022.

[3] As is evident to many households whose residents' Wi-Fi clients can receive strong signals from multiple Wi-Fi access points in their neighbours' premises, even across the road.

[4] GSMA, "Vision 2030: Insights for mid-band spectrum needs," July 2021 (here and here). GSMA Intelligence, "The socioeconomic benefits of the 6 GHz band considering licensed and unlicensed options," June 2022 (here).

Accordingly, we expect MFCN deployments to be **predominantly focussed in urban areas, including cities and large towns**.

As explained in our response to Question (1), we consider that MFCNs in the upper 6 GHz will play a role for the provision of services **both outdoor and indoors**.

Priorities for Wi-Fi

We consider that the priority for Wi-Fi deployments are primarily indoors, both for consumer premises and enterprises. That said, we **do not consider** the **upper 6 GHz** band to be a **priority for Wi-Fi**.

Our simulations and modelling indicate that **Gbit/s connectivity** can be delivered in each apartment in **dense urban** scenarios by leveraging the availability of the 2.4 GHz, 5 GHz, and **lower 6 GHz** bands for Wi-Fi, even with only one Wi-Fi access point (AP) deployed per apartment and with less advanced MIMO technologies.

Significantly **higher throughputs** can be achieved in less dense scenarios due to reduced inter-AP interference. Similar results can be expected in **isolated single-tenant buildings** (e.g., schools) including through the use of Wi-Fi **network controllers** to optimize frequency planning in such larger buildings.

In short, we consider that household and enterprise connectivity targets can be met by Wi-Fi supported by the lower 6 GHz band for the foreseeable future. Beyond this, we consider than any additional demand could be met through the use of Wi-Fi at mmWaves (e.g., 60 GHz) in combination with the emerging market for easy-to-install fibre-to-the-room (FTTR) technologies.

Question 3: What are your views on a modified AFC or SAS-type approach to enable hybrid sharing? What additional work do you think would be required?

These approaches fall under the broad category of database-assisted access to spectrum, sometimes also referred to as *geolocation databases*.

In the context of this consultation, database-assisted access refers to mechanisms whereby MFCN base stations and RLAN equipment would be required to regularly query an online database in order to provide their respective up-to-date locations and to subsequently receive confirmation that they are authorised to access the upper 6 GHz band, and to be informed of any regulatory technical conditions which might apply[5]. This is illustrated in Figure (1).

Examples of such database mechanisms exist today, including for TV white spaces, CBRS, and more recently AFC for Wi-Fi[6].

Database-assisted access can – at least in principle – allow MFCNs and RLANs to avoid mutual co-channel interference in the upper 6 GHz band by operating

a) in the same geographic area (or subject to low radio isolation) at different times, or
b) at the same time but in different geographic areas (or subject to high radio isolation).

[5] Based on experience from past implementations of geolocation databases, MFCN user equipment and RLAN stations (clients) might not be required to query databases directly, and would be informed by MFCN base stations and RLAN access points, respectively. Moreover, for MFCN base stations, the requirement could be placed on the licensed operator of the licensed equipment, rather than the equipment itself.

[6] Automatic Frequency Coordination (AFC) is a framework which has been developed by the FCC to protect fixed incumbent services (such as fixed links) in the US from harmful interference by Wi-Fi in parts of the 6 GHz band. Under this AFC framework, a Wi-Fi access point would query a cloud server daily informing it of its geolocation in three dimensions and whether it is located indoors or outdoors. In return, the server would provide a list of channels and maximum permitted transmit power spectral densities which the Wi-Fi access point is authorised to use.

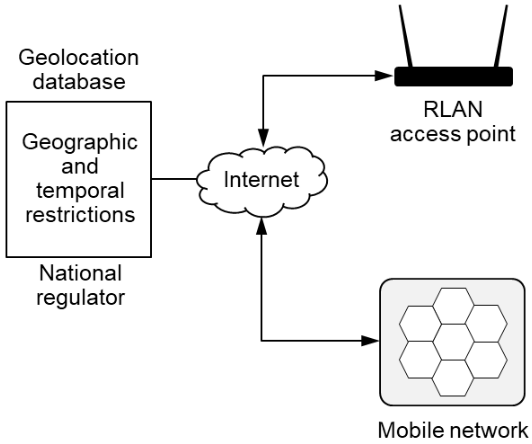


Figure 1: Illustration of database-assisted access to potentially enable co-channel operation of MFCNs and RLANs.

With reference to MFCNs and RLANs operating co-channel at the same time (see (b) above), the possibility of extreme proximity between MFCN user equipment and RLAN equipment would demand a geographic separation between the coverage areas of an MFCN and any RLAN access point for their simultaneous operation. This is illustrated in Figure (2). An exception might be where there is substantial radio isolation between the two networks, even though they might be in close proximity; e.g., where the RLAN is deep indoors (see also our response to Question 7).

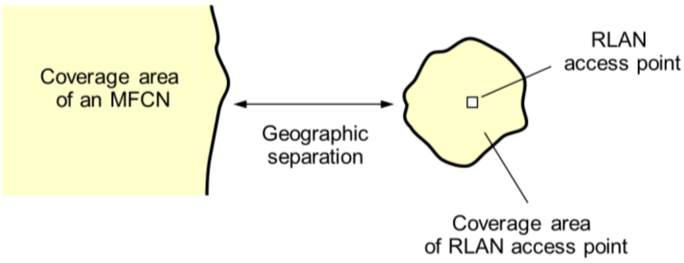


Figure 2: Co-channel operation via geographic separation between the coverage area of an MFCN and the coverage area of an RLAN access point.

Challenges

While database-assisted access is generally considered to be more reliable than *sensing* as a mechanism for spectrum sharing between different systems, it has its own unique challenges. We discuss some of these below:

- Efficient use of spectrum via database-assisted access would rely on the availability of accurate and reliable information on the geographic locations of radio equipment. While such information might be readily available for licensed MFCN base stations, this is less likely to be the case for MFCN user equipment, RLAN access points and RLAN stations (clients), especially when these are located indoors and may not have access to satellite navigation services.

- Efficient use of spectrum via database-assisted access would also rely on availability of accurate information on radio propagation among radio equipment. Radio propagation can vary substantially, not only as a function of the geographic separation between the radio equipment, but also as a function of what surrounds the equipment. For example, whether the equipment is located deep indoors or near a window, whether or not the window is specially coated, whether any intervening walls between transmitter and receiver are made of wood or reinforced concrete, etc. Access to such detailed information at high geographic granularity can be challenging.

- Whereas it is conceivable for MFCN base stations (via their core networks) and RLAN access points (via their broadband connections) to regularly query a database directly, this is less likely to be feasible for MFCN user equipment and RLAN stations (clients). These would have to query a database indirectly via their serving MFCN base stations and RLAN access points, respectively. Some RLAN stations (clients) may communicate directly with each other without the intervention or control of an RLAN access point, in which case the stations would have no means of querying a database at all. The database would have no information on these stations, and would not be able to efficiently account for their potential to cause interference.

Summary

The above factors mean that – in light of various uncertainties – databases will need to build in extra protection margins in their calculations of *aggregate* interference which would inevitably result in inefficient use of spectrum and technical conditions that are not least-restrictive.

Beyond the above technical matters, there are also policy, standardisation, commercial, and legal questions which would need to be addressed. For example, questions such as the extent to which harmonisation and standardisation are necessary, and whether all administrations would be in a position to introduce database-assisted access? Whether there would be one database operated by (or on behalf of) the national regulator, or one or more commercial databases? And in the latter case, whether there would be any legal barriers for commercial database providers to benefit financially from effectively granting access rights to spectrum for which they themselves have no legal rights of access? Or what would happen if commercial database providers decide to leave the market for whatever reason?

Question 4: How could existing access protocols and sensing mechanisms be leveraged (i.e., those in Wi-Fi or 5G NR-U) to enable hybrid sharing?

Sensing refers to the process whereby radio equipment would detect the over-the-air presence of signals from other radio equipment of the same type or of a different type, and would take specific actions in response.

Sensing can – at least in principle – allow MFCNs and RLANs to operate co-channel at the same locations but in mutually exclusive slices of time. This is illustrated in Figure (3) below. The choice for the duration of the time slices will have different impacts on performance (in terms of latency for example) and the level of disruption to the operation of the PHY/MAC layers of the technologies used in MFCNs and RLANs, and is for further study.

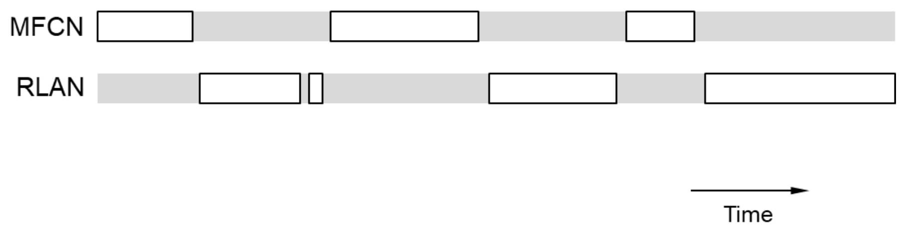


Figure 3: Illustration of separation in time between MFCN and RLAN operation enabled through sensing.

Such sensing is already implemented in the medium access control (MAC)[7] protocols and the dynamic frequency selection (DFS)[8] protocols of RLANs and rely on the ability of RLAN radios to assess the occupancy of the channel by sensing the presence of received signals over the air. If the received signal powers are assessed to be above specific thresholds, the RLAN radios must defer their transmissions in the said channel until such time as the channel is assessed to be free and available.

In what follows, we discuss some of the challenges which exist in the use of sensing as a means for facilitating co-channel sharing of the upper 6 GHz band by MFCNs and RLANs.

Challenges for RLANs

Our analysis (see our response to Question 8) indicates that, if RLAN radios were to operate co-channel with MFCNs in the upper 6 GHz band, they would be unable to detect the presence of MFCN downlink signals over significant proportions of an MFCN cell area indoors and outdoors, and would accordingly consider the channel to be available for RLAN transmissions despite the presence of MFCN downlink transmissions in the channel.

In principle, this issue could be mitigated by tightening (reducing) the detection thresholds by at least around 25 to 30 dB, so that Wi-Fi radios could detect the presence of MFCN downlink signals and take mitigating action. However, this can have important implications:

- The energy detection threshold (EDT) of RLANs is specified to optimise the performance of RLAN radios in accessing the channel fairly, while minimising the risk of harmful interference to other RLAN radios. A reduction of this energy detection threshold would mean that each RLAN radio must compete for access to the channel with a much larger number of other RLAN radios and at greater distances. This would a) proportionally reduce the radio resource (and hence maximum achievable throughput) available to each RLAN radio, as each RLAN radio may need to defer transmissions many more times, and b) result is a non-graceful degradation in RLAN spectral efficiency (of the type observed when RLAN encounters highly congested channels whereby each RLAN radio needs to defer transmissions by exponentially greater amounts of time as a result of increased packet collisions).

- The issue of false positives is a problem which is frequently cited in relation to DFS in the 5 GHz band. A false positive means that an RLAN radio mistakenly assesses that a radar signal is present, whereas this might not be the case. As a result, a false positive would trigger a channel change, when one is not actually needed, leading to unnecessary disruptions to RLAN. The causes of false positives include transient conditions due to high densities of RLAN clients, co-channel interference from distant RLAN radios, and intentional and non-intentional co-channel transmissions from non-RLAN radios. These issues would be significantly exacerbated if DFS is applied in the upper 6 GHz band with substantially reduced thresholds for the detection – and avoidance – of MFCNs.

- Importantly, RLANs' detection thresholds may need to be reduced far below the minimum power (sensitivity) at which MFCN signals can be decoded by MFCN user equipment. This is because to avoid harmful interference to MFCNs, any transmitting RLAN radio would need to be located beyond a minimum protection distance outside the edge of MFCN coverage (see Figure (2)), where the MFCN signals would be received at extremely low powers (perhaps even below the thermal noise floor of the RLAN equipment). Further work is needed to assess whether detection of such low MFCN power levels can be technically feasible for Wi-Fi equipment.

[7] Separation in time via sensing is precisely how different Wi-Fi radios are able to coexist in a decentralised manner in licence-exempt spectrum through carrier-sense multiple access (CSMA/CA) medium access control (MAC) protocols, often referred to as "listen-before-talk" (LBT). Each Wi-Fi radio waits a random amount of time, then senses the channel, and if it detects no other transmissions, it proceeds to transmit. In the case of over-the-air collisions (absence of acknowledgement packets), the Wi-Fi radio waits (backs off) for greater amounts of time before repeating the sensing process.

[8] Wi-Fi radios in the 5 GHz band are required to perform dynamic frequency selection (DFS) by sensing the presence of – and thereby avoiding co-channel operation with – nearby weather radar systems which also operate in the band.

Challenges for MFCNs

Sensing and listen-before-talk (LBT) protocols work well for RLANs and allow radios to access spectrum in a decentralised manner. However, these protocols are entirely different from the MAC protocols used by MFCN technologies where channel access is coordinated by the MFCN base stations (BSs) in order to deliver a managed QoS (not achievable with LBT-based protocols). Introduction of sensing and LBT protocols to MFCN technologies would require a fundamental re-design of the MAC protocols of MFCNs in a manner which is not consistent with the target KPIs of MFCNs[9].

In addition, technologies designed for macro-cellular MFCNs cannot operate based on the type of LBT-based MAC protocols used by RLAN technologies for two key reasons:

1) **The hidden-node problem**. The LBT protocols used in RLANs rely on the ability of radios to sense transmissions from other RLAN radios. This can work well in cases where there is a good link among the radios; e.g., across a few rooms, or in open-plan settings. However, with cell sizes typical of MFCNs, signals can be subject to high propagation losses (fading caused by reflections and shadowing due to obstructions), whereby large numbers of user equipment would not be able to hear each other and so would transmit simultaneously, resulting in over-the-air packet collisions.

2) **Congestion.** The LBT protocols used in RLANs allow radios to share access to spectrum in a decentralised manner based on what is effectively a waiting time overhead to avoid over-the-air packet collisions (assuming correct sensing in the absence of hidden-node issues). As the number of users in an RLAN cell increases, the absolute and relative cost of this overhead grows, to the extent that QoS degrades disproportionately to the number of users. While this might be tolerable where a few tens of users are involved, this would not be the case for the many tens to hundreds of users which are typically served in MFCN cells.

Summary

The viability of sensing as a reliable means of enabling co-channel use of the upper 6 GHz by MFCNs and RLANs is as yet unproven, and the feasibility of the required low levels of RLAN sensing thresholds that could enable coexistence with MFCNs requires further assessment. Furthermore, the introduction of sensing mechanism to the MAC protocols of MFCN technologies would not be consistent with their wide area cellular coverage, and would substantially degrade the performance of the MFCNs.

It is also worth noting that to date, detection and sensing mechanisms have not proven to be particularly successful or robust in enabling spectrum sharing between different radio systems[10]. Such mechanisms tend to be challenging or unreliable and at the mercy of highly variable radio propagation conditions.

For the above reasons, we consider that where the geographic location of the radio systems can be known, spectrum sharing mechanisms based on the use of database-assisted access are more appropriate.

Question 5: What mechanisms could potentially enable device-to-device connectivity?

Direct client-to-client (or device-to-device) communication has been a feature in Wi-Fi for many years, enabled by mechanisms such as Tunnelled Direct Link Setup (TDLS) whereby clients coordinate with an access point before commencing direct communications.

However, in our view, the authorisation of the upper 6 GHz band (essential for wider-area mobile communications) for such very short-range communications would be a questionable policy. Short-

[9] One example is the case of 4G LTE-U and 5G NR-U. With the requirement to operate in licence-exempt bands and to coexist with existing Wi-Fi equipment, LTE-U and NR-U were designed to operate with LBT-based protocols. As a result, LTE-U and NR-U are both RLAN technologies, and like Wi-Fi, cannot deliver managed QoS as delivered by MFCNs.

[10] See here and here for reports of issues with sensing in CBRS.

range client-to-client communications can already be accommodated in the 2.4 GHz, 5 GHz and lower 6 GHz bands, where the short-range nature of the link can provide data rates which can readily exceed a few Gbit/s. This ought to be sufficient for most foreseen applications. Should greater bandwidths be required for such short-range communications, the use of mmWave bands would be a better option than the upper 6 GHz.

Ofcom suggests that one potential approach to enable indoor client-to-client communications might be for the clients to be enabled via an "enabling signal" from a Wi-Fi router. We understand that such a mechanism has been proposed at ETSI BRAN. However, there are a number of issues with such approaches:

- The approach is predicated upon the notion that the regulator can establish with reasonable certainty that the clients are located indoors. It is not readily possible for radio equipment, be they Wi-Fi routers or clients, to automatically ascertain whether or not they are located indoors. Such information could be input into the equipment by the user, but this raises the risks of mis-use. For this reason, it is difficult to ensure that any client-to-client communications would be indoors-only.

- It can be argued that if the clients are enabled by an indoor router, and assuming that the "enabling signal" is transmitted by the router with sufficiently low power, then there is a high likelihood that the said clients are also indoors. However, factors such as radio propagation through windows mean that there is always a likelihood that the relevant clients may not be located indoors.

  Furthermore, this approach is again predicated upon the notion that the regulator can establish with reasonable certainty that the router is itself located indoors. As noted earlier, this is not readily achievable. To date, the only solution to such issues has been to rely on the manufacturer declaring that the router is for indoor operation only (i.e., that it is not suitable for outdoor installation – e.g., is not weather proofed). Accordingly, any "enabling signal" capability would need to be restricted to routers that are declared by the manufacturer to be intended for indoor use only. But this in itself would not prevent such routers from being installed outdoors.

- Another issue is the risk of interference to MFCNs that would also be operating in the upper 6 GHz band within a possible sharing framework between MFCNs and RLANs. Even if the Wi-Fi clients radiate with very low powers, their likely proximity to indoor MFCN user equipment (UE) can cause harmful co-channel interference. We emphasise that MFCNs are expected to provide not only outdoor-to-outdoor, but also outdoor-to-indoor coverage in the upper 6 GHz band.

Question 6: If hybrid sharing is eventually adopted, and requires licensed mobile to operate at medium power, in what way would mobile networks use the upper 6 GHz band?

As indicated by GSMA[11], the upper 6 GHz band is required (in addition to the mid-bands that are available to mobile networks today and which will eventually be re-farmed for use by 5G) in order to achieve the IMT-2020 5G data rates specified by the ITU-R for the delivery of high-capacity coverage across cities and along major transport routes in the 2025-2030 timeframe in support of mobile broadband, smart city, automotive and industrial use cases.

The importance of the upper 6 GHz band in this respect is that it would allow mobile operators to re-use the existing citywide grids of macro-cellular MFCN base stations. Absent the possibility of macro-cellular deployments, the mobile radio networks would need to be substantially densified (numbers of base station sites increased) in order to deliver the IMT-2020 data rate targets, and this would lead to a significant increase in energy consumption and radio network cost, and may also be technically unfeasible (due to interference between closely spaced sites). Specifically, GSMA indicates that for a

[11] GSMA, "Vision 2030: Insights for mid-band spectrum needs," July 2021 (here and here).

typical large European city, the implication would be a doubling of power consumption, and a four-fold increase in total network costs. This is in addition to the carbon footprint involved in the manufacture of the greater number of MFCN equipment[12].

Accordingly, if high-power macro-cellular MFCN deployments are not permitted in the upper 6 GHz band, then the provision of high-capacity citywide mobile coverage would become economically and environmentally prohibitive due to the required densification. As such, any MFCN deployments in the upper 6 GHz would be limited to small cells for provision of non-contiguous capacity at specific hot spots, which would be far better served in the 26 GHz band instead.

In short, restrictions on the power of MFCN base stations to the extent that macro-cellular base station deployments are prohibited, would very substantially reduce (perhaps even to near zero) the value of the upper 6 GHz for MFCNs.

Question 7: How would you suggest that the mechanisms presented here can be used, enhanced, or combined to enable hybrid sharing or are there any other mechanisms that would be suitable that we have not addressed?

Importance of prioritisation

Any potential frameworks aiming at co-channel shared use of the upper 6 GHz band by MFCNs and RLANs will need to make decisions to establish which among the two network types should be able to access the band at any given location and time.

It is well understood that services delivered by MFCNs and RLANs greatly overlap both geographically and in time. Mobile operators have clearly and consistently stated[13] their expectation to deploy macro-cellular 5G networks in the upper 6 GHz by reusing existing 3.5 GHz sites, starting from more densely populated urban areas. These are also precisely the geographic areas where Wi-Fi demand is most concentrated today.

Accordingly, the priority placed by the regulator on the two network types will have a profound impact on the regulatory frameworks implemented.

Prioritisation of MFCNs in urban/suburban areas

We consider that access by licensed MFCNs to the upper 6 GHz band must be prioritised over access by licence-exempt RLAN to the band at **all locations where the signal power from the MFCNs in the band is sufficiently high to provide services to users.**

This is because any other prioritisation approach would discourage investments in MFCNs in this band and would effectively make the band exclusively available for RLANs only. After all, why would a mobile operator invest in acquiring spectrum licences and in deploying costly mobile network infrastructure where they would not have priority over licence-exempt use, and where the mobile network's operation can be interrupted and/or its performance substantially degraded at any given time and place?

Prioritisation in rural areas

There is an argument that RLANs could be given priority over MFCNs outside urban/suburban areas where MFCNs are less likely to provide services in the upper 6 GHz band.

However, the need by RLANs for spectrum in the upper 6 GHz band in rural areas is not at all justified. In fact, our own analysis based on extensive modelling and simulations indicates that – using spectrum

[12] Analysys Mason: "Impact of additional mid-band spectrum on the carbon footprint of 5G mobile networks: the case of the upper 6GHz band," June 2023 (here).

[13] GSMA, "Vision 2030: Insights for mid-band spectrum needs," July 2021 (here and here).

available today in the 2.4 GHz, 5 GHz and the lower 6 GHz bands – Wi-Fi6 can readily deliver aggregate throughputs of 3 to 20 Gbit/s depending on deployment scenarios within rural premises[14].

Furthermore, the identification of areas outside urban/suburban locations where RLANs could be prioritised over licensed MFCNs is itself not trivial. Think of potential MFCN use cases such as FWA, or emerging V2X or train communications along major transport routes, whose footprints may extend beyond densely populated urban/suburban areas, and whose opportunity for use of the upper 6 GHz band could be impacted – if not eliminated – due to unpredictable co-channel interference from licence-exempt RLANs.

Accordingly, any regulatory framework for co-channel sharing in the upper 6 GHz would need to be sufficiently **future-proof** and **reversible** in order to account for the evolving market and technological landscape.

Prioritisation deep indoors

As we noted earlier, we consider that licensed MFCNs in the upper 6 GHz band should be prioritised over licence-exempt RLAN at all locations where the signal power from the MFCNs in the band is sufficiently high to provide services to users. And this is likely to include cities and their suburbs.

However, there will likely be locations deep indoors in cities and their suburbs where MFCN downlink signal powers at upper 6 GHz will be *insufficient* to provide services to the users. At such deep indoor locations, there could be scope to investigate the possibility to prioritize RLANs over MFCNs, noting that MFCN outdoor-to-deep-indoor coverage will be primarily addressed in the lower bands, the availability of which is expected to increase significantly at the beginning of the next decade.

Such prioritisation could be implemented via database-assisted access, although this would be accompanied with the challenges which geolocation databases face when dealing with indoor equipment.

Alternatively, prioritisation for RLANs deep indoors and in the absence of any indoor MFCN deployments could be implemented through sensing. Specifically, the RLAN energy detection threshold can be reduced and set such that it sits slightly above the level of MFCN downlink signal powers received deep indoors. Accordingly, RLANs would not detect the presence of MFCNs deep indoors, and can therefore operate normally and without any constraints imposed by their listen-before-talk protocols. There would be no risk of interference to MFCN services deep indoors, given that – by definition – no MFCN service exists at such locations.

The reduction in the RLAN energy detection threshold is necessary to ensure that if the RLAN radios move outside deep indoor locations and into non-deep indoor locations (the vast majority of which would benefit from MFCN services in the upper 6 GHz, according to our modelling), the RLAN radios can appropriately detect the presence of MFCN signals, and cease their transmissions. In effect, the value of the reduced RLAN energy detection threshold itself acts as a definition of "deep indoor" – i.e., where MFCN services are not delivered. This is illustrated in Figure (4).
That said, and despite the reduced RLAN energy detection thresholds, there will still be some risk of interference from indoor RLANs to MFCN services both indoors and outdoors, and this will need to be investigated to assess the viability of this sharing approach.

Furthermore, the energy detection threshold of RLANs cannot be reduced arbitrarily, and will be limited by the noise figure of the RLAN receivers. As such, it is possible that the required reliable detection of the low levels of MFCN signal power deep indoors may be technically infeasible. And even if the necessary levels of reduction were technically feasible, the potential impact on the performance of RLANs themselves would need to be closely examined. These factors all need careful consideration.

[14] The high throughputs are due to the reduced interference between Wi-Fi access points in different premises in rural areas.

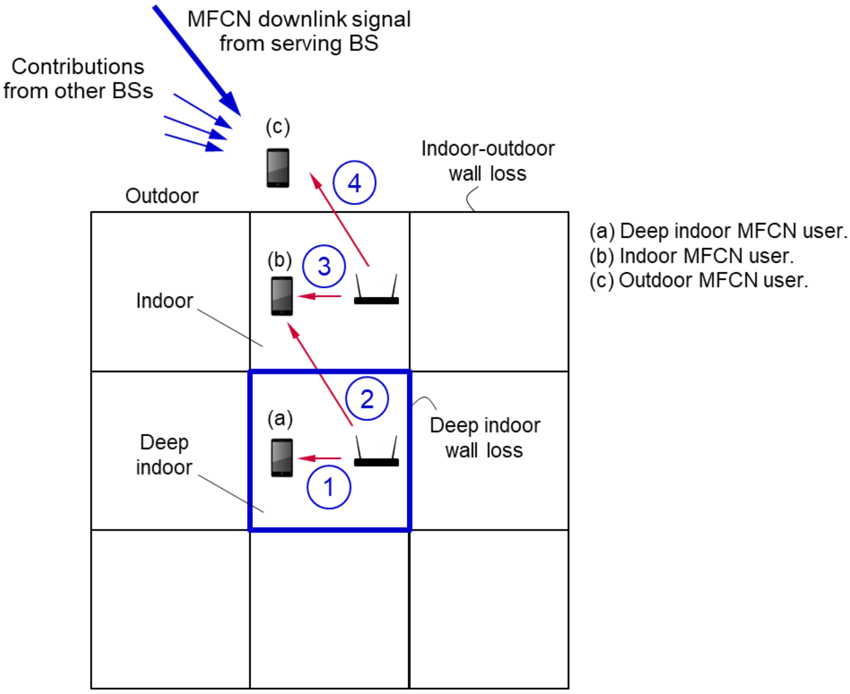


Figure 4: Potential for RLANs to operate deep indoors without constraints where MFCN signals cannot reach. This would require an appropriate reduction in the RLAN energy detection threshold. Harmful interference from RLANs to indoor and outdoor MFCNs may still occur. This is for further investigation.

Question 8: Assuming the future of the band includes indoor use for Wi-Fi and outdoors use for mobile: *a) how could this be achieved without creating or suffering interference?* *b) could there be a combination of technical adjustments such as power limits and other mechanisms (including databases or sensing mechanisms)?*

Here we first present the preliminary results of our modelling of the potential for harmful mutual interference between RLANs and MFCN downlink, when these two network types operate co-channel at the same location and at the same time. The details of our modelling can be found in Annex 1 and Annex 2 of this document.

The case of mutual interference between RLANs and MFCN uplink is for further study.

Interference from RLAN to MFCN downlink

RLAN's polite protocols allow RLAN radios to operate in licence-exempt spectrum in a decentralised manner and in competition with an indeterminate number of other co-channel RLAN radios. RLANs in the 5 GHz band are also required to perform dynamic frequency selection (DFS) to avoid co-channel operation with meteorological radar systems in the band.

In both cases, RLAN radios assess the occupancy of the channel by sensing the presence of received signals over the air. If the received signal powers are above specific thresholds, the RLAN radios must defer their transmissions until such time as the channel is assessed to be free and available (this is also referred to as "listen-before-talk" or LBT for short).

However, RLAN detection thresholds are around 25-30 dB greater than the minimum power (sensitivity) at which MFCN signals can be decoded by an MFCN UE. As a result, RLAN radios would be unable to detect the presence of MFCN downlink signals over significant proportions of an MFCN cell area indoors and outdoors, and would accordingly consider the channel to be available for RLAN transmissions, thereby causing potential harmful interference to MFCNs.

Indeed, our modelling indicates that there is a substantial likelihood that the MFCN downlink signal powers would not exceed the RLAN energy detection threshold, and that RLAN radios would not be able to detect the existence of MFCN downlink in around 65% of locations indoors and 15% of locations outdoors within the coverage area of MFCNs.

Our modelling also indicates the following:

- Where an RLAN radio and an MFCN UE are **both** located **indoors**, the MFCN downlink throughput would be substantially degraded as a result of emissions from the RLAN radio and would be reduced to zero in around 65% of locations (up from 26%) within the coverage area of the MFCN.

- Where an RLAN radio and an MFCN UE are **both** located **outdoors**, the MFCN downlink throughput would be reduced to zero in 18% of locations (up from 3%) within the coverage area of the MFCN.

- Where an RLAN radio is **indoors**, but the MFCN UE is **outdoors**, the building penetration loss would mitigate the impact of interference, and – assuming an indoor-to-outdoor loss that is consistent with a brick wall – the MFCN downlink throughput would be reduced to zero in 10% to 20% of cases (up from 3%) for interferer-victim separations of 10 metres and 5 metres, respectively.

In summary, co-channel operation of RLANs with MFCNs at the same time and place can result in substantial interference to the MFCN downlink both indoors and outdoors.

Interference from MFCN downlink to RLAN

MFCN downlink signals would impact the operation of co-channel RLANs in two important ways:

- Firstly, if the level of the received MFCN downlink signals is greater than the RLAN energy detection threshold, RLAN radios assess the channel to be occupied and therefore cease transmissions, thereby resulting in zero RLAN throughput.

- Secondly, where the RLAN energy detection threshold is not exceeded, and the RLAN radios do transmit, the MFCN downlink signals reduce the RLAN throughput; or for the same throughput, they reduce the RLAN communication range.

Indeed, our modelling indicates the following:

- **RLAN communications indoors –** The presence of MFCN downlink signals prevent RLAN radios from transmitting in around 35% of indoor locations within the coverage area of an MFCN, thereby reducing RLAN throughput and range to zero at such locations. Furthermore, RLAN range is reduced to less than 13% of what it would be in the absence of MFCN downlink signals in around 50% of indoor locations within the coverage area of an MFCN.

- **RLAN communications outdoors –** The presence of MFCN downlink signals prevent RLAN radios from transmitting in around 85% of outdoor locations within the coverage area of an MFCN, thereby reducing RLAN throughput and range to zero at such locations. Furthermore, RLAN range is reduced to less than 25% of what it would be in the absence of MFCN downlink signals in 100% of outdoor locations within the coverage area of an MFCN.

Summary

The results of our modelling indicate that in the absence of any additional measures, there is a substantial risk of mutual harmful interference between RLANs and MFCN downlink, and significant degradation in the performance of both network type if they are to operate co-channel in the same geographic area and at the same time in the upper 6 GHz band. Consequently, mitigation measures would be necessary to enable co-channel sharing between MFCNs and RLANs.

Mitigation measures and their implications

The risk of harmful interference can be potentially reduced as follows:

a) **Applying restrictions on the power of IMT base stations**. It is evident that the co-channel operation of any two networks at the same time and in the same geographic area can be facilitated if they use similar radiated powers.

   An obvious example is the coexistence of different RLANs in licence exempt spectrum. Although, even then, the use of polite protocols is still essential for efficient coexistence. However, as we indicated in our response to Question (4), the introduction of polite protocols to MFCNs is fundamentally incompatible with MFCN radio technologies designed to deliver managed quality of service.

   But **more importantly**, as we indicated in our response to Question (6), any restrictions on the transmit power of MFCN base stations would **prohibit** the deployment of **citywide macro-cellular** mobile networks in practice (due to economic and environmental constraints), and would only allow small cell deployments at specific hotspots. This would effectively **reduce to near zero the value of the upper 6 GHz band for MFCNs**, on the basis that the 26 GHz band would be far more suitable for such non-contiguous hot-spot coverage.

   For the above reasons, we consider that the placing of **restrictions on the power** of MFCN base stations is **not appropriate** in a hybrid sharing framework and cannot generate **net benefits** compared to the case where the upper 6 GHz is used by either MFCNs or RLANs alone.

b) **Reducing the energy detection threshold of Wi-Fi**. At least in principle, by setting the energy detection threshold of RLANs to sufficiently low values, it could be possible to ensure that RLANs can appropriately detect the presence of MFCNs, and act to avoid mutual harmful interference.

   However, in practice, this can also destabilise the operation of RLANs, by making the equipment over-sensitive to low levels of electromagnetic radiation, and thereby forcing them to compete with increasing numbers of distant RLAN equipment for access to the spectrum.

   Moreover, the appropriate level of energy detection threshold necessary for the effective detection of MFCN signals may be so low as to make its implementation highly costly, if not technically unfeasible. This is for further study.

c) **Database-assisted access.** Databases are generally considered to be more robust and reliable than the use of sensing in facilitating spectrum sharing between networks whose geographic locations are known.

   MFCNs can be considered to be effectively subject to database-assisted access **by default**, on the basis that MFCN base stations are licensed and under the control of core networks operated by the licensees.

   The same cannot be said of licence exempt RLAN equipment. These would have to be equipped with the ability to query specially designed databases in order to receive information on any geographic or temporal regulatory restrictions which might apply. Importantly, the **ability to query databases** must be embedded in RLAN equipment **right from the very start** in order to avoid the proliferation of uncontrolled licence exempt equipment in the upper 6 GHz band.

In summary, we consider that the implementation of frameworks for the co-channel operation of MFCNs and RLANs in the upper 6 GHz band can be quite challenging in practice, and may ultimately not result in a net benefit compared to the scenario where the band is used by either MFCNs or RLANs alone.

Question 9: We are interested in input about the importance of the upper 6 GHz band for its incumbent users, and on the potential impact of hybrid sharing of the band.

a) What evidence do you have on whether incumbents are likely to coexist with hybrid sharing of the band with mobile and Wi-Fi? Are there unique advantages of the upper 6 GHz band for these uses?

b) What are your views on the initial analysis we have conducted around hybrid sharing and coexistence with incumbents?

c) For any incumbent uses that you view as unlikely to be able to coexist, what alternatives are there? What are the barriers that might prevent those alternatives?

In relation to the coexistence of MFCNs and FSS uplink in the upper 6 GHz band, we consider that Ofcom's so-called "**D2**" approach[15] of using UK mobile network deployments in the **2100 MHz** band as a proxy for deployments at 6 GHz and then extrapolating these across the entire Region-1, is **highly questionable**.

This is because UK deployments at **2100 MHz** were originally intended for **national 3G coverage**, and continue to be used today for national LTE coverage. Accordingly, we consider that the above approach is **not appropriate** for modelling MFCN deployments at **upper 6 GHz** which are primarily intended as **citywide capacity layers** (see also our response to Question (2)).

By using 2100 MHz deployments as a proxy, the UK assumes ~48,000 IMT base stations (sectors) per operator in the UK, extrapolated to **~1,800,000 base stations (sectors) per 100 MHz channel** in Region-1. We consider this to be a **gross over-estimation** of the likely number of MFCN base stations in the upper 6 GHz band, and our own analysis indicates that the correct number is closer to somewhere between 400,000 and 500,000 base stations.

Interestingly, Ofcom also considered a so-called "**D1**" approach based on **2600/3500 MHz** deployments in the UK, which we consider to be **more representative** of capacity layer MFCN deployments in upper 6 GHz. This approach indicated a more plausible ~10,000 base stations (sectors) per operator in the UK, extrapolated to ~300,000 base stations (sectors) per 100 MHz channel in Region-1. However, we note that the Ofcom **did not adopt** this **more realistic** model in deriving the limits on expected EIRP which it – jointly with ANFR – proposed to CEPT, and which are now captured in the European Common Position on WRC-23 Agenda Item 1.2 in relation to the 6425-7125 MHz band.

[15] See ECC PT1(23)031 for a description of UK's "D1" and "D2" modelling approaches.

Question 10: Do you have any other thoughts that you would like to share about hybrid sharing in the upper 6 GHz band, or about hybrid sharing more generally and its potential for applications in other bands?

Question 11: Do you have any other comments to make on these proposals or on the future use of the upper 6 GHz band?

The need for an impact assessment

Technical analysis must go hand-in-hand with economic and market impact assessments in order to avoid regulatory frameworks that – while interesting in theory – have little or no market relevance.

We consider that it is still very **far from obvious** that **shared co-channel use** of the upper 6 GHz band by MFCNs and RLANs would **deliver greater benefits** than the use of the band by either MFCNs or RLANs alone.

Impact assessments must be performed to understand if the additional complexity and performance degradation introduced through co-channel sharing of MFCNs and RLANs in the upper 6 GHz are justified. In other words, to establish

- whether such sharing would deliver a net value that is greater than the value of each network type operating alone in the upper 6 GHz, or
- whether the resulting economic cost, performance degradations, and commercial uncertainties (due to an uncertain radio interference environment) would diminish the utility of the networks and imply a lower value than in the absence of sharing.

Impact assessments must also account for the broader landscape and options, as well as relevant policy targets with the intention of benefiting citizens and consumers. **Spectrum sharing should not be a policy target in itself.**

We recommend that Ofcom undertakes impact assessments to address the following:

- Start by identifying the relevant connectivity targets for outdoor and indoor communications.
- Investigate how outdoor connectivity targets would be met if the upper 6 GHz band was made available to RLANs. Relevant factors here might be the required extreme densification of MFCN base stations in cities and larger towns by having to rely on higher frequencies (e.g., 26 GHz).
- Investigate how indoor connectivity targets would be met if the upper 6 GHz band was made available to MFCNs. Relevant factors here might be the possible need for densification of Wi-Fi access points in premises and having to rely on higher frequencies (e.g., 60 GHz), in conjunction with the growing availability of fibre-to-the-room (FTTR).
- Account for the fact that – in any realistic sharing framework – access to the upper 6 GHz band by licensed MFCNs would have to be prioritised over access by licence-exempt RLANs as an essential pre-condition to incentivise costly investment in MFCNs by mobile operators, and that this would have a substantial impact on the performance and utility of RLANs in areas served by MFCNs.

Annex 1: Potential for interference from RLAN to MFCN downlink in the upper 6 GHz band

Summary

In this contribution we analyse the potential for harmful co-channel interference from RLANs to MFCN downlink in the upper 6 GHz band.

In order to calculate the probability of an RLAN radio transmitting co-channel with MFCNs and within the coverage area of MFCNs in the upper 6 GHz band – and thereby potentially causing harmful interference to nearby MFCN user equipment (UE) – we calculate the statistics of the *total* (both wanted and unwanted) MFCN downlink signal power received at different locations within an MFCN cell, and compare this with the energy detection threshold of RLAN.

Our modelling indicates that there is a substantial likelihood that the MFCN downlink signal powers would not exceed the RLAN energy detection threshold, and that RLAN radios would not be able to detect the existence of MFCN downlink in around 65% of locations indoors and 15% of locations outdoors within the coverage area of MFCNs.

We then calculate the impact of the emissions from a single RLAN radio on the downlink signal-to-interference (SINR) and downlink throughput of a nearby MFCN UE. We model separations of 0.5 metre to 10 metres between the RLAN radio and MFCN UE.

Our modelling also indicates the following:

- Where an RLAN radio and an MFCN UE are **both** located **indoors**, the MFCN downlink throughput would be substantially degraded as a result of emissions from the RLAN radio and would be reduced to zero in around 65% of locations (up from 26%) within the coverage area of the MFCN.
- Where an RLAN radio and an MFCN UE are **both** located **outdoors**, the MFCN downlink throughput would be reduced to zero in 18% of locations (up from 3%) within the coverage area of the MFCN.
- Where an RLAN radio is **indoors**, but the MFCN UE is **outdoors**, the building penetration loss would mitigate the impact of interference, and – assuming an indoor-to-outdoor loss that is consistent with a brick wall – the MFCN downlink throughput would be reduced to zero in 10% to 20% of cases (up from 3%) for interferer-victim separations of 10 metres and 5 metres, respectively.

In summary, co-channel operation of RLANs with MFCNs at the same time and place can result in substantial interference to the MFCN downlink both indoors and outdoors.

1. Introduction

In March 2023 a new work item was set up at CEPT PT1 on “Feasibility of shared use of the 6425-7125 MHz frequency band by MFCN and WAS/RLAN”. The output of this work item will be an ECC Report with a target completion date of March 2025. In the April 2023 meeting of PT1 a working document for the draft ECC Report was created, with initial text including a list of interference scenarios as shown in Table (1) below.

In this contribution, we examine the case of harmful interference from RLAN radios to MFCN user equipment (UE). We use the term RLAN as short-hand for WAS/RLAN. And, unless otherwise stated, we use IMT parameter values specified in Annex 4.4 to 5D/716 to model MFCNs.

In Sections (2) and (3) we present our approach for modelling the statistics of the MFCN downlink received signal powers, as well as the MFCN downlink SINR and throughput. In Section (4) we present our approach for modelling the degradation in MFCN downlink SINR and throughput as a result of emissions from an RLAN radio in the proximity of an MFCN UE. The results of our modelling are presented in Section (5).

Table 1: Non-exhaustive initial list of possible interference scenarios/paths.
Source: ECC PT1 working document for the draft ECC Report.

Aggressors	Victims
• Outdoor macro terrestrial MFCN BS • Outdoor medium power terrestrial MFCN BS • Indoor small cell terrestrial MFCN BS • Outdoor terrestrial MFCN UE • Indoor terrestrial MFCN UE	WAS incl. VLP and LPI RLAN AP and STA
WAS incl. VLP and LPI RLAN AP and STA	• Outdoor macro terrestrial MFCN BS • Outdoor medium power terrestrial MFCN BS • Indoor small cell terrestrial MFCN BS • Outdoor terrestrial MFCN UE • Indoor terrestrial MFCN UE

2. Total received MFCN downlink signal power

The total received MFCN downlink signal power plays an important role in determining the potential for co-channel interference from RLANs to MFCNs. This is because RLAN radios would only transmit co-channel within the coverage area of an MFCN if

$$\breve{P}_{Rx} \leq P_{DET} \ , \tag{2.1}$$

where $\breve{P}_{Rx}$ is the *total* received (over-the-air)[16] MFCN downlink signal power in mW/(B MHz) at the location of interest, and P_{DET} is the energy detection threshold of RLAN radios. This is illustrated in Figure (1). Note that bandwidth B represents the RLAN channel bandwidth. To address co-channel interference, we assume the same channel bandwidth for MFCN.

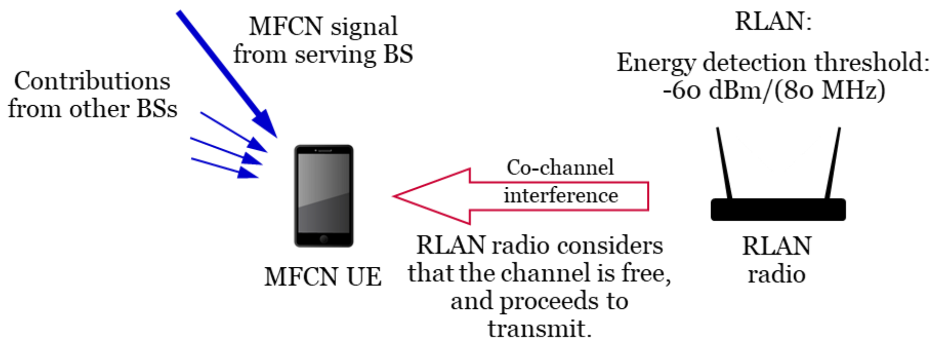


Figure 1: Interference scenario.

Our objective here is to model the statistics of $\breve{P}_{Rx}$ across the coverage area of a macro-cellular MFCN base station (BS) in a dense urban area such as a city. In this way, we can identify the likelihood that RLAN radios would transmit co-channel with MFCN signals and cause harmful interference.

[16] Hence the symbol '˘'. Note that $\breve{P}_{Rx}$ is the signal power "over-the-air" because the RLAN energy detection threshold P_{DET} is specified for a receiver antenna gain of 0 dBi, and so is itself an over-the-air value.

To this end, we model the downlink emissions from a total of 19 sites, and the corresponding $N = 19 \times 3 = 57$ MFCN BSs (three BSs or cells per site), where each BS *simultaneously* forms K beams to serve K UEs located in its cell (one beam per UE). This is illustrated in Figure (2). We then calculate the total received power $\check{P}_{Rx}$ at a point within the hexagonal area of the central cell (marked in grey) by adding $57K$ terms, reflecting the power receive from *all* MFCN BS beams.

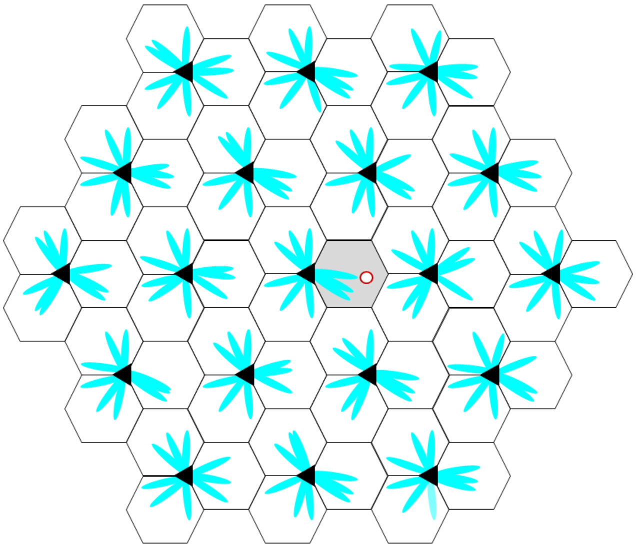


Figure 2: A total of 57 beamforming MFCN BSs (19 sites) contributing to the total MFCN signal power received at a location (red circle) in the central cell (marked in grey).

According to Annex 4.4 to 5D/716, each MFCN BS can be modelled as simultaneously serving $K = 3$ UEs through *frequency division*. That is to say, for a channel bandwidth of B Hz, each UE would be served via a beamformed signal of bandwidth B/K Hz.

Accordingly, we account for the $K = 3$ non-co-channel beams in calculating the total received MFCN downlink signal power $\check{P}_{Rx}$. This is illustrated in Figure (3). Therefore, with $N = 57$ BSs in total, then we must calculate and add $NK = 171$ terms to derive the value of $\check{P}_{Rx}$ in the central cell.

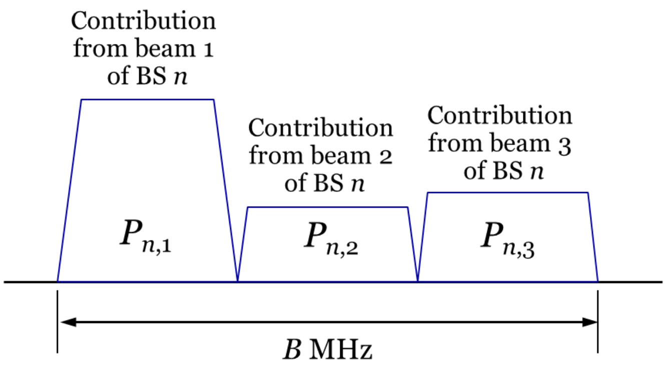


Figure 3: Contributions to total received MFCN downlink signal power $\check{P}_{Rx}$ from $K = 3$ beams radiated from the nth BS.

Specifically, assuming N BSs each forming K simultaneous non-co-channel beams of bandwidth B/K Hz, the total MFCN downlink signal power $\check{P}_{Rx}$ in mW/(B MHz) received at any point within the central cell can be written as

$$\check{P}_{Rx} = \sum_{n=1}^{N} P_n = \sum_{n=1}^{N}\sum_{k=1}^{K} P_{n,k}$$
$$= \sum_{n=1}^{N}\sum_{k=1}^{K} \frac{1}{K} P_{Tx}\, G_{n,k} = \frac{1}{K} P_{Tx} \sum_{n=1}^{N}\sum_{k=1}^{K} \frac{G_{AAS,n,k}}{L_{P,n}\,.\,L_{SH,n}\,.\,L_{BP}\,.\,L_{POL}} \tag{2.2}$$

where index 'n' represents the nth BS, index 'k' represents the kth beam, $P_{n,k}$ is the received power in mW/(B/K MHz) from the kth beam of the nth BS (in $(1/K)$th of the channel bandwidth B), P_{Tx} is the conducted transmit power (less any losses) of each BS in mW/(B MHz), $G_{n,k}$ and $G_{AAS,n,k}$, are the coupling gain and active antenna system (AAS) gain from the kth beam of the nth BS to the location of interest, $L_{P,n}$ and $L_{SH,n}$ are the path loss and shadowing loss from the nth BS to the location of interest, and L_{BP} and L_{POL} are the building penetration loss (where applicable) and polarisation loss, respectively.

Note that the factor $1/K$ in Equation (2.2) represents the fact that a fraction $1/K$ of each BS's conducted power P_{Tx} is applied to each of the K beams.

By repeating the calculations in Equation (2.2) at a large number of locations within the central cell, we can establish the statistics of $\check{P}_{Rx}$ in the form of a cumulative distribution function. Further details of this process are presented in Annex-4 of this document.

3. MFCN downlink SINR and throughput

The downlink signal-to-interference-plus-noise ratio (SINR) across the central cell can be written as

$$SINR = \frac{P_S}{P_I + P_N}, \tag{3.1}$$

where P_S is the received wanted MFCN downlink signal power, P_I is the received MFCN inter-cell interference power, and P_N is the receiver noise power, all in units of mW/(B/K MHz). Assuming an omnidirectional MFCN UE antenna with gain G_A, and body loss L_B, the wanted signal power P_S – due to emissions from beam '1' of the 1st (central) cell – is given as

$$P_S = \frac{1}{K} P_{Tx} \frac{G_{AAS,n,k}\,.\,G_A}{L_{P,n}\,.\,L_{SH,n}\,.\,L_{BP}\,.\,L_{POL}.\,L_B} \qquad n = 1,\; k = 1, \tag{3.2}$$

and the interference P_I is the sum of powers from the co-channel beam '1' of all BSs excluding the serving BS, and is given as

$$P_I = \frac{1}{K} P_{Tx} \sum_{n=2}^{N} \frac{G_{AAS,n,k}\,.\,G_A}{L_{P,n}\,.\,L_{SH,n}\,.\,L_{BP}\,.\,L_{POL}.\,L_B} \qquad k = 1. \tag{3.3}$$

The thermal noise power P_N is given as

$$P_N = k.T.(B/K)\,.NF, \tag{3.4}$$

where $k = 1.38 \times 10^{-23}$ W/Kelvin/Hz is Boltzmann's constant, $T = 290°$ is the temperature in Kelvins, $B = 80$ MHz, and NF is the noise figure of the UE receiver.

The downlink SINR can then be mapped to the achievable downlink throughput via Shannon's channel capacity bound. We specifically use the mapping described in Annex 4.4 to 5D/716-E where the throughput r in bit/s/Hz over a channel with a given SINR when using link adaptation can be approximated as

$$r = \begin{cases} 0 & \text{for } SINR < SINR_{MIN} \\ \alpha . f(SINR) & \text{for } SINR_{MIN} \leq SINR < SINR_{MAX} \\ \alpha . f(SINR_{MAX}) & \text{for } SINR \geq SINR_{MAX} \end{cases} \quad (3.5)$$

$$f(SINR) = log_2(1 + SINR), \quad (3.6)$$

where for downlink we have $\alpha = 0.6$, $SINR_{MIN}(\text{dB}) = -10$, and $SINR_{MAX}(\text{dB}) = +30$, assuming a 1:1 antenna configuration, an AWGN channel, link adaptation and no HARQ. Note that the AAS characteristics of the MFCN BSs are already captured in the MFCN BS antenna gains $G_{AAS,n,k}$ used in the calculation of SINR.

4. Degradation in MFCN downlink SINR and throughput due to co-channel interference from an RLAN radio

Consider that an RLAN radio in the proximity of an MFCN UE assesses that the channel is free (i.e., that $\check{P}_{Rx} < P_{DET}$) and therefore proceeds to transmit. The SINR at the MFCN UE is then reduced as follows

$$SINR = \frac{P_S}{P_I + P_X + P_N} , \quad (4.1)$$

where P_X in mW/(B/K MHz) is the received co-channel interference from the RLAN radio, and equals

$$P_X = P_{RLAN} \frac{G_A}{L_P . L_{BP} . L_B} , \quad (4.2)$$

where P_{RLAN} is the RLAN radio's EIRP in mW/(B/K MHz) over the relevant channel bandwidth, G_A is the antenna gain of the MFCN UE, L_P is the propagation loss between the RLAN radio and the MFCN UE, L_{BP} is building penetration loss (where applicable), and L_B is body loss at the UE.

For the short distances of interest (several metres) between the MFCN UE and the RLAN radio, we can model propagation loss L_P simply as free-space path loss, i.e. in dB we have,

$$L_{FSPL}\,(dB) = -147.55 + 20log_{10}(f) + 20log_{10}(d) \quad (4.3)$$

where f is frequency is Hz, and d is separation in metres. More sophisticated propagation models would be required for greater distances between interferer and victim. The reduced SINR at the MFCN UE translates to a reduced MFCN downlink throughput as specified per Equation (3.6).

5. Modelling results

5.1 Parameter values

We have used MFCN parameter values that are recommended in Annex 4.4 to 5D/716-E for urban macro-cellular IMT deployments.

MFCN network characteristics and topology

Frequency	7 GHz
Channel bandwidth, B	80 MHz
Number of MFCN sites	19 (hexagonal)
Number of MFCN BSs per site	3
Inter-site distance	450 metres (cell range of 300 metres)
BS antenna height	18 metres

5D/716 recommends a bandwidth of 100 MHz. We assume 80 MHz here for consistency with an RLAN channel bandwidth of 80 MHz and the study of co-channel interference. We do not expect this to have a material impact on the conclusions.

MFCN BS active antenna system characteristics

Antenna array gain, $G_{AAS,n,k}$	As per ITU-R M.2101
Element gain	5.5 dBi
Horizontal/vertical 3 dB beamwidth of single element (degree)	90º for both H and V
Horizontal/vertical front-to-back ratio	30 dB for both H and V
Antenna polarization	Linear ±45º
Antenna array configuration (Row × Column)	16 × 8 (16 V and 8 H)
Horizontal/vertical radiating element spacing	0.5 of wavelength for both H and V
Array Ohmic loss	2 dB (already included in element gain)
Total conducted power [1]	45 (dBm/80 MHz)
Base station maximum coverage angle range in the vertical plane [2]	90º – 120º
Base station maximum coverage angle range in the horizontal plane	±60º
Mechanical downtilt	10°

1 WP 5D specifies a conducted power per *single polarised* antenna element of 22 dBm/(100 MHz). With 16 × 8 = 128 dual polarised elements, we have 256 single polarised antenna elements, so that the total conducted power is 22 + $10log_{10}$(256) = 22 + 24 = 46 dBm/(100 MHz) or 45 dBm/(80 MHz).

2 Additionally, subject to a minimum BS-UE horizontal separation of 35 metres.

MFCN UE characteristics

UEs served simultaneously per BS, K	3 (channel bandwidth B/K)
UE antenna height	1.5 metres
UE antenna gain, G_A	-4 dBi
UE noise figure, NF	9 dB

RLAN characteristics

EIRP, P_{RLAN}	23 dBm (80 MHz carrier)
Energy detection threshold, P_{DET}	-65 dBm/(80 MHz)[1]

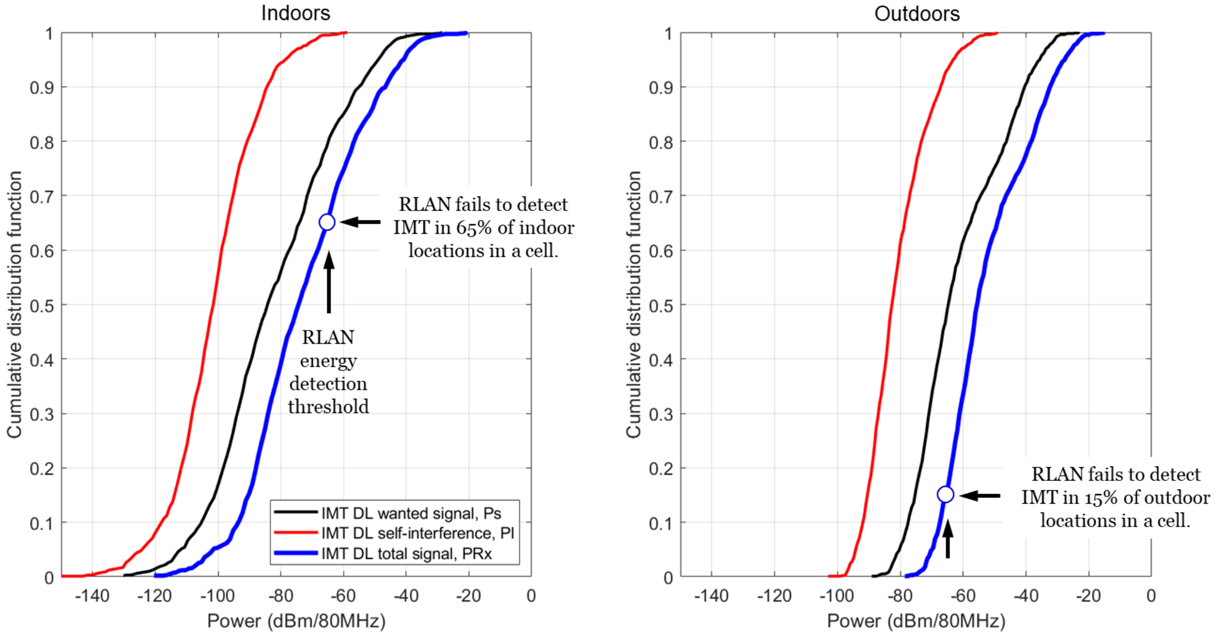
1 See Annex 3.

Propagation loss

Path loss from BSs to UEs, $L_{P,n}$	3GPP TR 38.901
Shadowing loss from BSs to UEs, $L_{SH,n}$	3GPP TR 36.873
Building penetration loss, L_{BP}	3GPP TR 38.901
Polarisation loss, L_{POL}	2 dB
Body loss, L_B	4 dB
Path loss from RLAN to UE, L_{FSPL}	Free space path loss
Wall loss from RLAN to UE, L_{BP}	15 dB (see a reference here.)

5.2 Statistics of MFCN downlink signal powers

Figure (4) shows the statistics of the received MFCN downlink wanted signal power P_S, the received MFCN downlink inter-cell interference power P_I, and the *total* received (over-the-air) MFCN downlink signal power $\check{P}_{Rx}$, all in dBm/(80 MHz). Note that P_S and P_I include UE antenna gain and body loss, whereas $\check{P}_{Rx}$ does not.



a) Indoor b) outdoor

Figure 4: Statistics of MFCN downlink signals.

The total received (over-the-air) MFCN downlink signal power should be compared with the -65 dBm/(80 MHz) energy detection threshold of RLAN. See Annex 3 of this document.

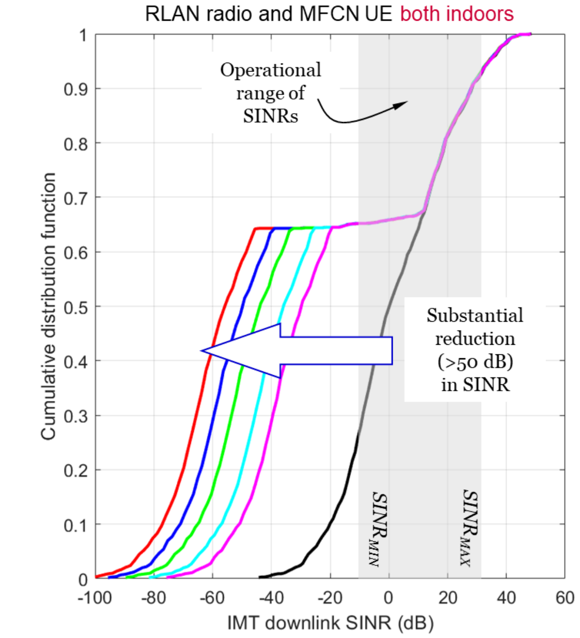
As can be seen from Figure (4a), in the scenario where RLAN radios are indoors, they would fail to detect the presence of MFCN downlink in around 65% of locations within the MFCN coverage area, and would therefore consider the channel to be available. Figure (4b) shows that the same occurs in around 15% of locations in scenarios where the RLAN radios are outdoors.

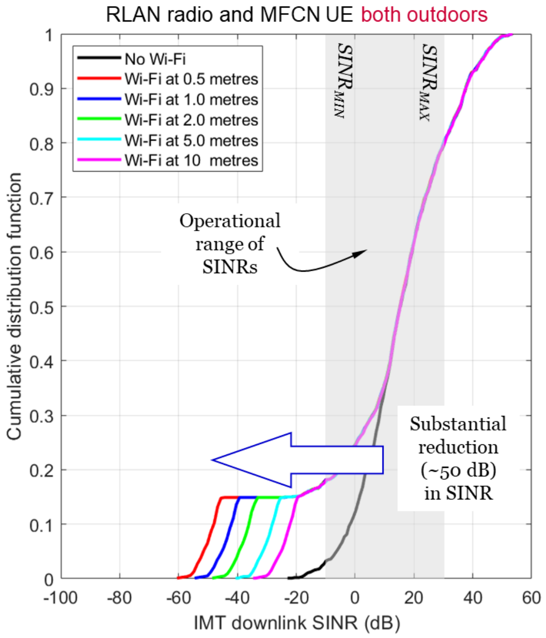
5.3 Degradation in MFCN downlink SINR and throughput

5.3.1. Interference: outdoor to outdoor and indoor to indoor

Figure (5) shows the statistics of the MFCN downlink SINR and throughput in the absence of RLAN and also where a single RLAN radio transmits (as a consequence of failing to detect MFCN downlink signals) within 0.5, 1, 2, 5, and 10 metres of an MFCN UE. Here, the RLAN radio and MFCN UE are assumed to be either both indoors, or both outdoors.

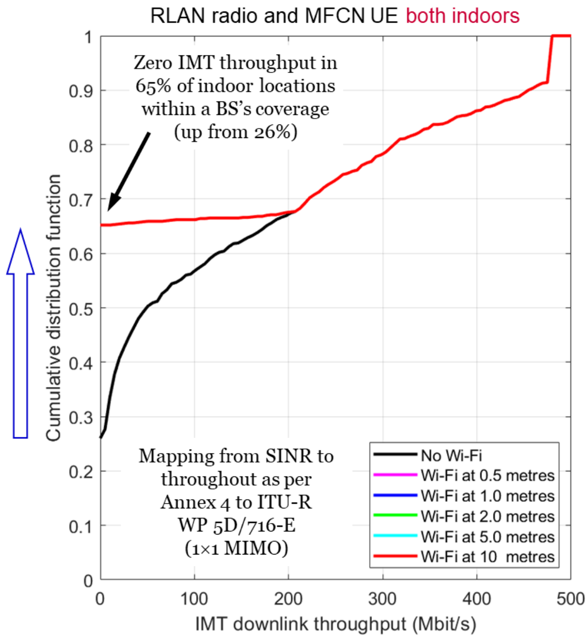
The impact of emissions from the RLAN radio on MFCN downlink SINR is especially significant indoors (SINR loss of up to 50 dB or more) as compared to outdoors (SINR loss of up to 50 dB). This is expected, because the MFCN wanted signal strength is weaker indoors. According to the WP 5D mapping of SINR to throughput, the minimum MFCN operating SINR is -10 dB. This means that the emissions from the RLAN radio would reduce the MFCN downlink throughput to zero in around 65% of cases indoors and around 18% of cases outdoors within the MFCN coverage area.

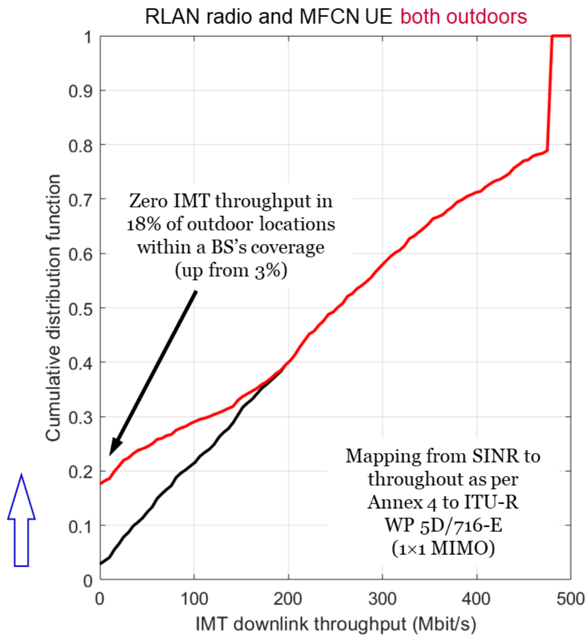




a) Indoor

b) outdoor





a) Indoor

b) outdoor

Figure 5: Statistics of MFCN downlink SINR and throughput with and without emissions from a nearby RLAN radio, where MFCN UE and RLAN radio are a) both indoors and b) both outdoors.

5.3.2. Interference: indoor to outdoor

Figure (6) shows the same statistics of the MFCN downlink SINR and throughput where the MFCN UE is located outdoors but the RLAN radio is indoors. A wall loss of 15 dB is assumed which corresponds to a brick wall (see a reference here). Concrete can result in much greater loss, whereas normal glass can result in very little loss.

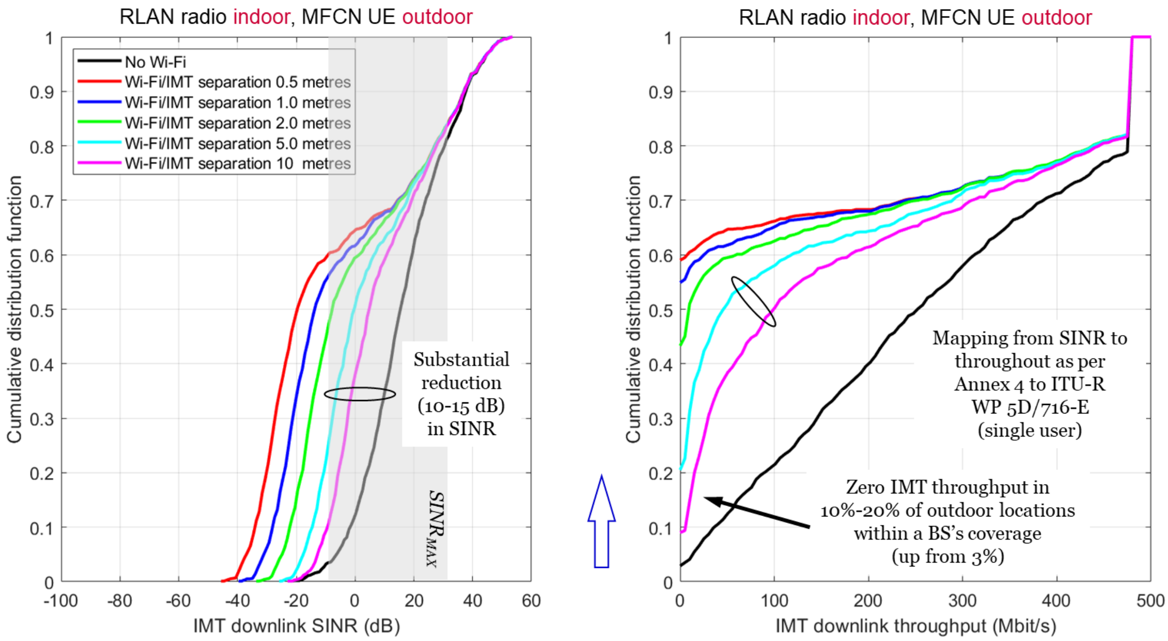


Figure 6: Statistics of MFCN downlink SINR and throughput with and without with and without emissions from a nearby RLAN radio, where the MFCN UE is outdoors and the RLAN radio is indoors. Separations of 5 and 10 metres are more relevant in such scenarios.

As can be seen, the wall loss mitigates the impact of interference from the emissions of the indoor RLAN radio, such that the emissions from the RLAN radio would reduce the MFCN downlink throughput to zero in around 10% to 20% of cases outdoors within the MFCN coverage area.

Annex 2: Potential interference from IMT downlink to RLAN in the upper 6 GHz band

Summary

In this contribution we analyse the potential for harmful co-channel interference from MFCN downlink to RLANs in the upper 6 GHz band.

We calculate the statistics of the *total* (both wanted and unwanted) IMT downlink signal power received at different locations within an IMT cell, in order to quantify the probability of IMT downlink signals causing harmful co-channel interference to RLAN radios located within the coverage area of IMT in the upper 6 GHz band.

MFCN downlink signals would impact the operation of co-channel RLANs in two important ways:

- Firstly, if the level of the received MFCN downlink signals is greater than the RLAN energy detection threshold, RLAN radios assess the channel to be occupied and therefore cease transmissions, thereby resulting in zero RLAN throughput.

- Secondly, where the RLAN energy detection threshold is not exceeded, and the RLAN radios do transmit, the MFCN downlink signals reduce the RLAN throughput; or for the same throughput, they reduce the RLAN communication range.

Indeed, our modelling indicates the following:

- **RLAN communications indoors –** The presence of MFCN downlink signals prevent RLAN radios from transmitting in around 35% of indoor locations within the coverage area of an MFCN, thereby reducing RLAN throughput and range to zero at such locations. Furthermore, RLAN range is reduced to less than 13% of what it would be in the absence of MFCN downlink signals in around 50% of indoor locations within the coverage area of an MFCN.

- **RLAN communications outdoors –** The presence of MFCN downlink signals prevent RLAN radios from transmitting in around 85% of outdoor locations within the coverage area of an MFCN, thereby reducing RLAN throughput and range to zero at such locations. Furthermore, RLAN range is reduced to less than 25% of what it would be in the absence of MFCN downlink signals in 100% of outdoor locations within the coverage area of an MFCN.

In summary, co-channel operation of RLANs with MFCNs at the same time and place can result in substantial interference to RLANs both indoors and outdoors.

1. Introduction

In March 2023 a new work item was set up at CEPT PT1 on “Feasibility of shared use of the 6425-7125 MHz frequency band by MFCN and WAS/RLAN”. The output of this work item will be an ECC Report with a target completion date of March 2025. In the April 2023 meeting of PT1 a working document for the draft ECC Report was created, with initial text including a list of interference scenarios as shown in Table (1) below.

In this contribution, we examine the case of harmful interference from IMT base stations (BSs) to RLAN radios. We use the term RLAN as short-hand for WAS/RLAN. And, unless otherwise stated, we use IMT parameter values specified in Annex 4.4 to 5D/716 to model MFCNs.

In Section (2) we present our approach for modelling the statistics of the *total* IMT downlink received signal power. In Sections (3) and (4) we present our approach for modelling the degradation in RLAN

SINR and communication range as a result of the received co-channel IMT downlink signals. The results of our modelling are presented in Section (5).

Table 1: Non-exhaustive initial list of possible interference scenarios/paths.
Source: ECC PT1 working document for the draft ECC Report.

Aggressors	Victims
• Outdoor macro terrestrial MFCN BS • Outdoor medium power terrestrial MFCN BS • Indoor small cell terrestrial MFCN BS • Outdoor terrestrial MFCN UE • Indoor terrestrial MFCN UE	WAS incl. VLP and LPI RLAN AP and STA
WAS incl. VLP and LPI RLAN AP and STA	• Outdoor macro terrestrial MFCN BS • Outdoor medium power terrestrial MFCN BS • Indoor small cell terrestrial MFCN BS • Outdoor terrestrial MFCN UE • Indoor terrestrial MFCN UE

2. Total received IMT downlink signal power

The total received IMT downlink signal power plays an important role in determining the potential for co-channel interference from IMT networks to RLANs. This is because RLAN radios would only transmit co-channel within the coverage area of an IMT network if

$$\breve{P}_{Rx} \leq P_{DET} \ , \qquad (2.1)$$

where $\breve{P}_{Rx}$ is the *total* received (over-the-air)[17] IMT downlink signal power in mW/(B MHz) at the location of interest, and P_{DET} is the energy detection threshold of RLAN radios. This is illustrated in Figure (1). Note that bandwidth B represents the RLAN channel bandwidth. To address co-channel interference, we assume the same channel bandwidth for IMT.

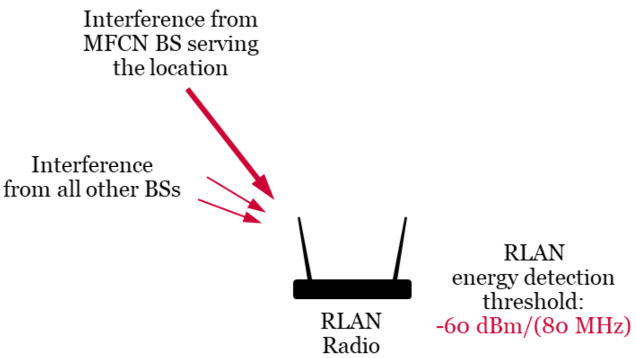


Figure 1: RLAN clear channel assessment in the presence of IMT downlink signals.

Our objective here is to model the statistics of $\breve{P}_{Rx}$ across the coverage area of a macro-cellular IMT base station (BS) in a dense urban area such as a city. In this way, we can identify the likelihood that IMT downlink signals would cause harmful co-channel interference to RLANs.

To this end, we model the downlink emissions from a total of 19 sites, and the corresponding $N = 19 \times 3 = 57$ IMT BSs (three BSs or cells per site), where each BS *simultaneously* forms K beams to

[17] Hence the symbol '˘'. Note that $\breve{P}_{Rx}$ is the signal power "over-the-air" because the RLAN energy detection threshold P_{DET} is specified for a receiver antenna gain of 0 dBi, and so is itself an over-the-air value.

serve K UEs located in its cell (one beam per UE). This is illustrated in Figure (2). We then calculate the total received power $\check{P}_{Rx}$ at a point within the hexagonal area of the central cell (marked in grey) by adding $57K$ terms, reflecting the power receive from *all* IMT BS beams.

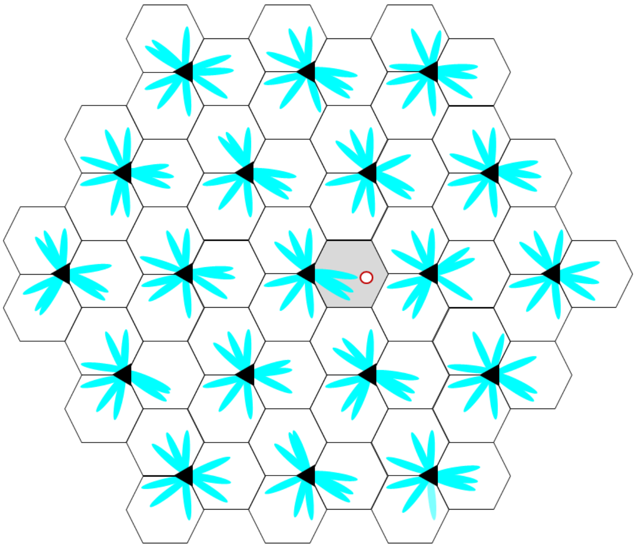


Figure 2: A total of 57 beamforming IMT BSs (19 sites) contributing to the total IMT signal power received at a location (red circle) in the central cell (marked in grey).

According to Annex 4.4 to 5D/716, each IMT BS can be modelled as simultaneously serving $K = 3$ UEs through *frequency division*. That is to say, for a channel bandwidth of B Hz, each UE would be served via a beamformed signal of bandwidth B/K Hz.

Accordingly, we account for the $K = 3$ non-co-channel beams in calculating the total received IMT downlink signal power $\check{P}_{Rx}$. This is illustrated in Figure (3). Therefore, if we model $N = 57$ BSs in total, then we must calculate and add $NK = 171$ terms to derive the value of $\check{P}_{Rx}$ in the central cell.

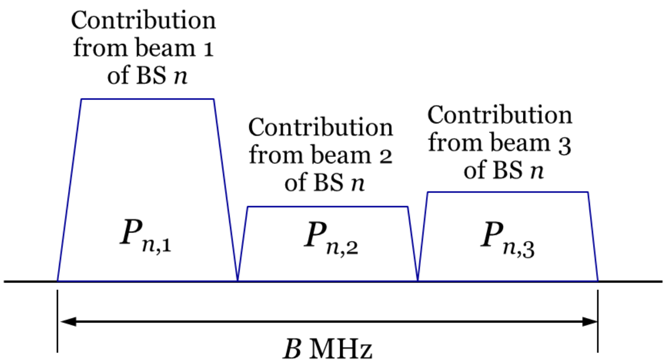


Figure 3: Contributions to total received MFCN downlink signal power $\check{P}_{Rx}$ from $K = 3$ beams radiated from the nth BS.

Specifically, assuming N BSs each forming K simultaneous non-co-channel beams of bandwidth B/K Hz, the total IMT downlink signal power $\check{P}_{Rx}$ in mW/(B MHz) received at any point within the central cell can be written as

$$\check{P}_{Rx} = \sum_{n=1}^{N} P_n = \sum_{n=1}^{N}\sum_{k=1}^{K} P_{n,k}$$
$$= \sum_{n=1}^{N}\sum_{k=1}^{K} \frac{1}{K} P_{Tx}\, G_{n,k} = \frac{1}{K} P_{Tx} \sum_{n=1}^{N}\sum_{k=1}^{K} \frac{G_{AAS,n,k}}{L_{P,n}\,.\,L_{SH,n}\,.\,L_{BP}\,.\,L_{POL}} \tag{2.2}$$

where index 'n' represents the nth BS, index 'k' represents the kth beam, $P_{n,k}$ is the received power in mW/(B/K MHz) from the kth beam of the nth BS (in $(1/K)$th of the channel bandwidth B), P_{Tx} is the conducted transmit power (less any losses) of each BS in mW/(B MHz), $G_{n,k}$ and $G_{AAS,n,k}$, are the coupling gain and active antenna system (AAS) gain from the kth beam of the nth BS to the location of interest, $L_{P,n}$ and $L_{SH,n}$ are the path loss and shadowing loss from the nth BS to the location of interest, and L_{BP} and L_{POL} are the building penetration loss (where applicable) and polarisation loss, respectively.

Note that the factor $1/K$ in Equation (2.2) represents the fact that a fraction $1/K$ of each BS's conducted power P_{Tx} is applied to each of the K beams.

By repeating the calculations in Equation (2.2) at a large number of locations within the central cell, we can establish the statistics of $\check{P}_{Rx}$ in the form of a cumulative distribution function. Further details of this process are presented in Annex-4 of this document.

3. RLAN SINR

An RLAN receiver's signal-to-interference-plus-noise ratio (SINR) can be written as

$$SINR_0 = \frac{P_S}{P_I + P_N}, \tag{3.1}$$

where P_S is the received wanted RLAN signal power, P_I is the received interference from other RLAN equipment, and P_N is the receiver noise power, all in units of mW/(B MHz).

Assuming that the listen-before-talk (LBT) MAC protocol of RLAN (e.g., the CSMA/CA protocol in Wi-Fi) is functioning adequately, it is reasonable to assume that $P_I = 0$. Any interference from distant RLAN equipment which may not be engaged with the LBT process at the location of interest can also be assumed to be insignificant due to the implied high propagation loss.

Assuming an omnidirectional RLAN receiver antenna with gain G_A, body loss L_B, and propagation loss $L_{P,a}$ between the RLAN transmitter and receiver, the RLAN SINR is then given as

$$SINR_a = \frac{P_S}{P_N} = \frac{1}{P_N}\,\frac{P_{RLAN}\,.\,G_A}{L_{P,a}\,.\,L_B}, \tag{3.2}$$

where P_{RLAN} is the Wi-Fi radio's EIRP in mW/(B MHz), and the thermal noise power P_N is given as

$$P_N = k.T.B\,.NF, \tag{3.3}$$

where $k = 1.38 \times 10^{-23}$ W/Kelvin/Hz is Boltzmann's constant, $T = 290°$ is the temperature in Kelvins, $B = 80$ MHz, and NF is the noise figure of the RLAN receiver.

4. Degradation in RLAN SINR and range due to co-channel interference from IMT downlink

As shown in Figure (4), consider an RLAN receiver of interest located within an IMT cell and operating co-channel with IMT. Also assume that the RLAN equipment at that location assesses that the channel is free (i.e., that $\check{P}_{Rx} < P_{DET}$) and therefore proceed to communicate normally with the RLAN receiver of interest. Then the reduced SINR at the RLAN receiver can be written as

$$SINR_b = \frac{P_S}{P_X + P_N}\ , \tag{4.1}$$

where P_X is the received co-channel interference from the IMT BSs, and equals $G_A\check{P}_{Rx}$ in mW/(B MHz). Re-writing, we have

$$SINR_b = \frac{1}{G_A\check{P}_{Rx} + P_N}\frac{P_{RLAN}\,.\,G_A}{L_{P,b}\,.\,L_B}. \tag{4.2}$$

where $L_{P,b}$ is the corresponding propagation loss.

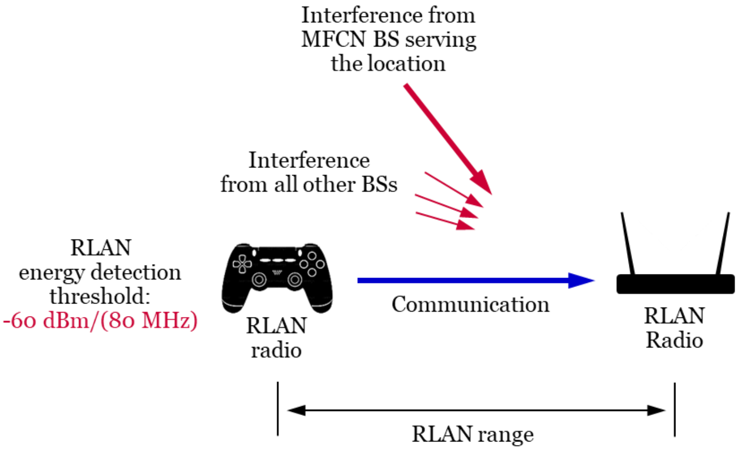


Figure 4: RLAN communication in the presence of interference from IMT downlink.

We are now able to assess the impact of interference from IMT downlink on the operating range of RLAN communications. For the same quality of RLAN communications with and without co-channel interference from IMT downlink, we must have $SINR_0 = SINR_1$. So, from (3.2) and (4.2) we have

$$\frac{1}{P_N}\frac{P_{RLAN}\,.\,G_A}{L_{P,a}\,.\,L_B} = \frac{1}{G_A\check{P}_{Rx} + P_N}\frac{P_{RLAN}\,.\,G_A}{L_{P,b}\,.\,L_B}. \tag{4.3}$$

Noting that given a radio propagation exponent ϑ the propagation loss L_P is proportional to the ϑth power of distance between transmitter and receiver ($L_P \propto d^{\vartheta}$), and ignoring any shadowing loss effects for short propagation distances, we have

$$\frac{L_{P,b}}{L_{P,a}} = \left(\frac{d_b}{d_a}\right)^{\vartheta} = \frac{P_N}{G_A\check{P}_{Rx} + P_N}. \tag{4.4}$$

In other words, the ratio of RLAN communication range with interference from IMT downlink over the RLAN communication range without interference from IMT downlink is

$$\frac{d_b}{d_a} = \left(\frac{P_N}{G_A \check{P}_{Rx} + P_N}\right)^{1/\vartheta}. \tag{4.5}$$

For the short distances of interest (several metres) between the RLAN transmitter and receiver, we can model propagation loss L_P simply as free-space path loss, in which case, ϑ = 2.

5. Modelling results

5.1 Parameter values

We have used MFCN parameter values that are recommended in Annex 4.4 to 5D/716-E for urban macro-cellular IMT deployments.

IMT network characteristics and topology

Frequency	7 GHz
Channel bandwidth, B	80 MHz
Number of IMT sites	19 (hexagonal)
Number of IMT BSs per site	3
Inter-site distance	450 metres (cell range of 300 metres)
BS antenna height	18 metres

5D/716 recommends a bandwidth of 100 MHz. We assume 80 MHz here for consistency with a Wi-Fi channel bandwidth of 80 MHz and the study of co-channel interference. We do not expect this to have a material impact on the conclusions.

IMT BS active antenna system characteristics

Antenna array gain, $G_{AAS,n,k}$	As per ITU-R M.2101
Element gain	5.5 dBi
Horizontal/vertical 3 dB beamwidth of single element (degree)	90º for both H and V
Horizontal/vertical front-to-back ratio	30 dB for both H and V
Antenna polarization	Linear ±45º
Antenna array configuration (Row × Column)	16 × 8 (16 V and 8 H)
Horizontal/vertical radiating element spacing	0.5 of wavelength for both H and V
Array Ohmic loss	2 dB (already included in element gain)
Total conducted power [1]	45 (dBm/80 MHz)
Base station maximum coverage angle range in the vertical plane [2]	90º – 120º
Base station maximum coverage angle range in the horizontal plane	±60º
Mechanical downtilt	10°
UEs served simultaneously per BS, K	1 (channel bandwidth B MHz)

1 WP 5D specifies a conducted power per *single polarised* antenna element of 22 dBm/(100 MHz).
With 16 × 8 = 128 dual polarised elements, we have 256 single polarised antenna elements,
so that the total conducted power is 22 + 10 log_{10}(256) = 22 + 24 = 46 dBm/(100 MHz) or 45 dBm/(80 MHz).

2 Additionally, subject to a minimum BS-UE horizontal separation of 35 metres.

RLAN characteristics

EIRP, P_{RLAN}	23 dBm (80 MHz carrier)
Energy detection threshold, P_{DET}	-65 dBm/(80 MHz)[1]
Antenna gain, G_A	2.15 dBi (0 dBd)[2]
UE noise figure, NF	6 dB[2]

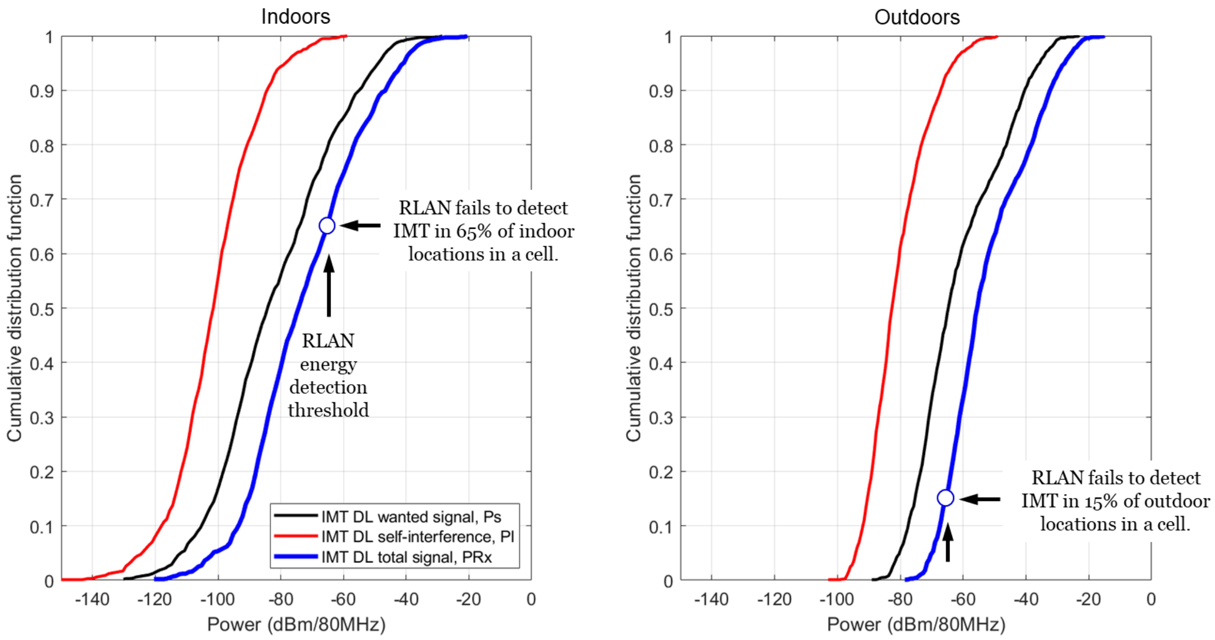
1 See Annex 3.
2 ECC PT1(23)122, Meta.

Propagation loss

Path loss from BSs to UEs, $L_{P,n}$	3GPP TR 38.901
Shadowing loss from BSs to UEs, $L_{SH,n}$	3GPP TR 36.873
Building penetration loss, L_{BP}	3GPP TR 38.901
Polarisation loss, L_{POL}	2 dB
Body loss, L_B	4 dB
Path loss from RLAN STA to AP, L_P	Exponent ϑ = 2

5.2 Statistics of IMT downlink signal powers

Figure (5) shows the statistics of the *total* received (over-the-air) IMT downlink signal power $\check{P}_{Rx}$ in dBm/(80 MHz). Also shown are the statistics of the received IMT downlink wanted signal power P_S, and the received IMT downlink inter-cell interference power P_I. But these are not relevant for our analysis here. Note that P_S and P_I include UE antenna gain and body loss, whereas $\check{P}_{Rx}$ does not.



a) Indoor b) outdoor

Figure 5: Statistics of IMT downlink signal powers.

The total received (over-the-air) IMT downlink signal power should be compared with the -65 dBm/(80 MHz) energy detection threshold of RLAN. See Annex 3.

As can be seen from Figure (5a), in the scenario where RLAN radios are indoors, they would fail to detect the presence of IMT downlink in around 65% of locations within the IMT coverage area, and would therefore consider the channel to be available. Figure (5b) shows that the same occurs in around 15% of locations in scenarios where the RLAN radios are outdoors.

5.3 Degradation in RLAN range

Figure (6) shows the statistics of the the ratio of RLAN communication range with interference from IMT downlink over the RLAN communication range without interference from IMT downlink.

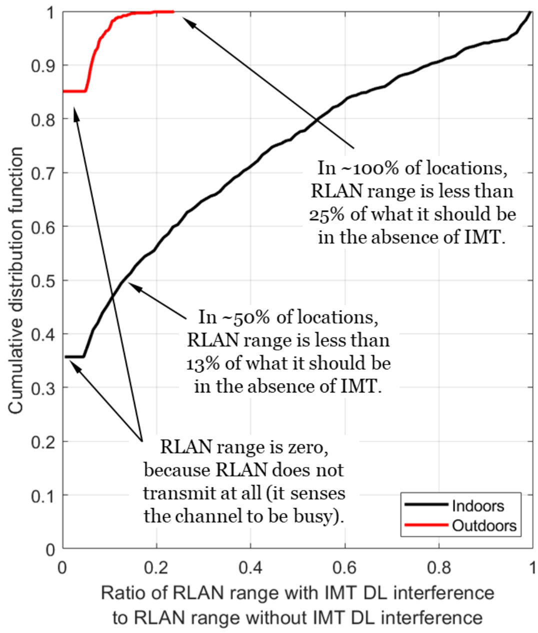


Figure 6: Statistics of the ratio of RLAN range with MFCN downlink interference to RLAN range without MFCN downlink interference for indoor and outdoor RLAN communications.

Annex 3: RLAN energy detection thresholds

Minimum IMT signal power

Considering an IMT UE noise figure of NF = 9 dB, and a bandwidth of B = 80 MHz, the thermal noise floor of an IMT UE is $10.log_{10}(k.T.B.NF)$ = –95 + 9 = –86 dBm/(80 MHz) for T = 290K. IMT signals can be decoded with a minimum SINR of -10 dB, in which case the minimum decodable received signal power at which an IMT signal can be decoded is around –86 – 10 = –96 dBm/(80 MHz). Assuming an ITM UE antenna gain of -4 dBi, the over-the-air value is –92 dBm/(80 MHz).

RLAN energy detection threshold

RLAN's polite protocols allow RLAN equipment to access spectrum in a decentralised manner by detecting the status of the channel prior to transmission, and deferring any transmissions if the channel is assessed to be occupied by other RLAN equipment. According to EN 303 687, the energy detection threshold of RLAN equipment (assuming a 0 dBi antenna gain) in the lower 6 GHz is given as EDT = −85 dBm/MHz + $(24 \text{ dBm} - P_{max})$, where P_{max} is equipment's maximum configured transmit power.

For P_{max} = 23 dBm, the over-the-air detection threshold is −85 + (24 – 23) = −84 dBm/MHz. For the purposes of our modelling, this translates to **−65 dBm/(80 MHz)**. As can be seen, this threshold is some 27 dB greater than the minimum signal power (sensitivity) of **−92 dBm/(80 MHz)** at which IMT signals can be decoded by an IMT UE. This means that RLAN radios' MAC protocol would be unable to detect the presence of co-channel IMT downlink signals over large proportions of an IMT cell area indoors and outdoors. Accordingly, RLAN radios would consider the channel clear for transmission despite the presence of IMT downlink transmissions in the channel.

Annex 4: Monte Carlo process for calculating received IMT downlink signal powers

The Monte Carlo modelling involves the following steps:

1) Drop UEs – In each of N = 57 hexagonal cells, drop $K = 3$ UEs with a uniform random distribution of the UEs' x and y coordinates within the cell. The nearest BS to each UE is considered to be its serving BS.

2) Beamforming – Form a beam from each N BS to each of its K served UEs.

3) Calculate propagation gains – For one of the UEs in the central cell, calculate the path loss $L_{P,n}$ and shadowing loss $L_{SH,n}$ $n = 1, \ldots N$ to each of the surrounding N BSs.

4) Calculate received signal powers – For the same UE in the central cell, calculate the coupling gain $G_{n,k}$ $1, \ldots N$ $k = 1 \ldots K$ from each of the N BSs and for each of the K beams per BS. Multiply the coupling gains by the relevant transmit powers to calculate the various received signal powers for this trial.

5) Go back to Step (1) and repeat, say, $L = 1000$ times to build up statistics.

■