



Propagation Models and Interference Protection Criteria for Sharing between the Fixed Service and Unlicensed Devices in the 6 GHz Band

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Propagation Models and Interference Protection Criteria for Sharing between the Fixed Service and Unlicensed Devices in the 6 GHz Band

1 Introduction

The 6 GHz Band Multi-stakeholder Committee (6MSC) is a committee of The Wireless Innovation Forum that will serve as an industry body to study and specify sharing arrangements in spectrum designated for unlicensed operation within all or part of the 6 GHz band (5925-7125 MHz). The Committee will provide technical input to inform the FCC's 6 GHz rulemaking and will facilitate the interpretation and implementation of the rulemaking that allows industry and regulators to collaborate on implementation of a common, efficient and well-functioning 6 GHz ecosystem.

The initial activities to be conducted by the Committee include:

- Defining:
 - Propagation Modeling
 - Interference Protection Criteria
 - Spectrum Occupancy Determination
- Developing a Security Threat Assessment
- Identifying Automated Frequency Coordination (AFC) Requirements for Incumbent Protection

The approach to the committee's work will emphasize the technical aspects of sharing while simplifying interfaces and requirements. This is done to advance innovative and competitive sharing approaches and to increase deployment speed of AFC systems.

The Committee is ultimately a standards and technical implementation forum for industry stakeholders and developers of the spectrum-sharing technologies. The Committee will not address policy-making or liability management but may occasionally make formal technical recommendations to the FCC or other regulatory bodies following the Forum's standard policies and procedures.

The participants of this Committee include, but are not be limited to, the following:

- Developers and operators of wireless equipment and devices
- Developers and operators of spectrum sharing systems
- Operators and service providers interested in deploying in the spectrum
- Suppliers of systems and components operating in this spectrum
- General users of spectrum outside of main providers
- Policy makers, academics, and researchers
- Liaisons from other standards groups with which joint work is desired or necessary

The FCC issued a Notice of Proposed Rule Making (NPRM) in Oct. 2018, proposing unlicensed use of the 5925-7125 MHz band in combination with protection for incumbent licensed services in the band [1]. The Commission has, within the NPRM, extended the Unlicensed National Information Infrastructure (U-NII) regime in the 5GHz band into four new parts, labeled U-NII-5 through U-NII-8. Specifically, the FCC introduces the NPRM with the suggestion that users in the 850 MHz comprised by U-NII-5 and U-NII-7 and corresponding to 5925-6425 MHz and 6525-6875 MHz respectively, be required to use an AFC “that would prevent the unlicensed devices from transmitting on frequencies where such transmissions could cause harmful interference to incumbent services.” The NPRM then asks respondents to offer answers to questions about the nature of the AFC, including whether the AFC database should have device registration requirements, the level of control on power and frequency allocation to devices under control by the AFC, periodic verification of continued frequency availability etc. The NPRM also raises questions about AFC security requirements, certification of the system, operator obligations and competition between operators. Many of these questions directly suggest that the FCC is not certain about the architecture of the system; clearly, industry guidance is sought and needed. Importantly, the NPRM also asks about preferences for interference protection of fixed services and other technical matters such as propagation models, adjacent channel protection, and fading margins.

In general, the NPRM is not uniformly accepted in its current form by all stakeholders in the band, and various petitions on suggested policy directions are still under review, including objections regarding the band plan as proposed. Some respondents to the NPRM have proposed that incumbents in U-NII-6 and U-NII-8 should also be protected using an AFC. Concerns have been raised regarding the architecture of the AFC and on which use cases and environments the AFC is applicable. Some organizations have raised questions around the aggregate accuracy of the information available, the integrity and conformance of devices, and the question of whether AFC mechanisms should be centralized, distributed within equipment, or could effectively be a hybrid between centralized resources and distributed control mechanisms (as has been suggested by the FCC or assumed by the WiFi industry).

This document interprets U-NII devices as being included within the classification of Radio Local Area Networks (RLAN) as defined by the ITU-R. Indeed, the FCC describes U-NII devices as unlicensed intentional radiators, which use wideband digital modulation techniques to provide a wide array of high-data-rate mobile and fixed communications used by individuals, businesses, and institutions, particularly for wireless local area networking – including Wi-Fi – and broadband access [2]. While RLANs are not restricted to unlicensed operation, they are

- a) widely used for fixed, semi fixed (transportable) and portable computer equipment for a variety of broadband applications;
- b) that broadband RLANs are used for fixed, nomadic and mobile wireless access applications;
- c) that broadband RLAN standards currently being developed are compatible with current wired LAN standards;

as detailed in Recommendation ITU-R M.1450 [3]. This document therefore freely references requirements for RLANs and applies them to U-NII devices.

It has been suggested by some members that the Citizens Broadband Radio Service (CBRS) approach of direct control by a centralized Spectrum Access System (SAS) has proven to be complex and prone to unnecessarily prolonged standardization and testing processes [4][5].¹ At the same time, the benefits of affirmative control and strong validation mechanisms (e.g. by an AFC) might prove to be beneficial to verifiable protection for some use cases in the band.² One advantage of an affirmative approach to frequency authorization is its compatibility with widespread outdoor deployment of unlicensed radios, that employ higher power levels for many important use cases. Another point of contention is whether low-power indoor devices need to be controlled by an AFC; indeed, it is possible to create several scenarios where indoor devices could significantly impact aggregate interference levels. This topic clearly requires further investigation to achieve a consensus among stakeholders.

This document does not concern itself with policy issues such as whether changes to the band plan or the organization of band into four sub-bands of the U-NII radio band will be adopted within any final Report and Order (R&O) that is issued.

The purpose of this report is to provide stakeholders, including the regulatory authorities, with relevant information regarding the operation of unlicensed mobile equipment within the 6 GHz band under terms to be detailed by the Federal Communications Commission under 47 CFR Part 15 rules. In addition, it provides a summary of viewpoints regarding some of the important criteria (e.g., propagation modelling approaches and interference protection criteria) that need to be considered when sharing that spectrum with one primary assignee to the band, namely the Fixed Service (FS), which is composed of point-to-point microwave links. The presented methodologies are meant to be extendable for AFC protection of other 6 GHz incumbents such as TV Pickup, Passive Sensor, and Broadcast Auxiliary services; specific attention to these will need to await further revisions. A secondary purpose of this report is to provide relevant information to regulators and stakeholders outside the United States, who may be interested in adopting similar sharing rules between the fixed service and unlicensed users in the band.

2 References

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- [2] FCC, “In the Matter of Revision of Part 15 of the Commission’s Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band,” FCC 14-30, ET Docket No. 13-49, April, 2014.
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¹ The CBRS is a novel authorized sharing regime between three tiers of users in the 3550-3700 MHz band that is introduced by the FCC rules in 47 CFR Part 96 and allows tier 1 incumbents such as military radar and commercial Fixed Satellite Service (FSS) users to share the band with secondary mobile broadband users constituted by Priority Access Licensees forming the second tier, and Generally Authorized Access (GAA) use of the spectrum for the third tier.

² Although the proposed regulations do not explicitly identify incumbent licensed use of the 6 GHz band as worthy of primary status or that unlicensed users would be secondary users, it is inconceivable that RLAN use of the band under unlicensed rules within 47 CFR Part 15 would be considered on an equal footing.

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3 Abbreviations

Abbreviation	Description
3DEP	3D Elevation Program (USGS)
6MSC	6 GHz Band Multi-stakeholder Committee
AFC	Automated Frequency Coordination
AP	Access Point
APO	Availability Performance Objective
ATPC	Automated Transmit Power Control
BAS	Broadcast Auxiliary Service
BEL	Building Entry Loss
CARS	Cable Television Relay Service

Abbreviation	Description
CBRS	Citizens Broadband Radio Service
CFR	Code of Federal Regulations
ECC	European Communications Committee
ECO	European Communications Office
eHata	Extended Hata
EPO	Error Performance Objective
FCC	Federal Communications Commission
FS	Fixed Service
FSS	Fixed Satellite Service
FWS	Fixed Wireless Systems (alternative name for FS)
IPC	Interference Protection Criteria
ISM	Industrial, Scientific, and Medical
ITM	Irregular Terrain Model
ITS	Institute of Telecommunications Studies
ITU-R	International Telecommunications Union, Radio Communications Bureau
LA	Link Adaptation (also known as Adaptive Modulation)
MCL	Minimum Coupling Loss
MIMO	Multiple-Input Multiple-Output
NLoS	Non-line of Sight
LoS	Lone of Sight
NLCD	National Land Cover Database
NPO	Network Performance Objective
NPRM	Notice of Public Rule-Making

Abbreviation	Description
NSMA	National Spectrum Management Association
NTIA	National Telecommunications and Information Administration
P2P	Point-to-Point
R&O	Report and Order
RLAN	Radio Local Area Network
SAS	Spectrum Access System
SDR	Software Defined Radio
UE	User Equipment
U-NII	Unlicensed National Information Infrastructure
USGS	United States Geological Survey
UWB	Ultra-Wide-Band
WAS	Wireless Access Systems
WiFi	Class of unlicensed RLAN devices conforming to IEEE 802.11
WinnForum	Wireless Innovation Forum

4 Characteristics of the Fixed Service in the 6 GHz band

A number of licensed users occupy this spectrum, prominent occupants being users of fixed point-to-point links[1]. The 5925-6425 MHz and 6525-6875 MHz bands are the most heavily used by the common carrier fixed point-to-point microwave service and private operational fixed point-to-point microwave service. The NPRM lists 17,580 common carrier fixed point-to-point microwave links, 15,011 microwave links in the industrial/business pool, and 13,664 microwave links in the public safety pool that are listed in FCC databases. A large fraction of these links serves critical functions that must maintain a high level of availability, very often designed for five- or six-nines of availability on an annual basis; designed outage targets may range from less than 1 minute to 5 minutes per year.

Many FS systems in the industrial/business pool are associated with process control of pipelines and serve critical control functions for railroad switches, synchronization of train movement, control of the electric grid including monitoring and control of distribution networks and utility circuit breakers, control of pumps and valves in petroleum and natural gas pipelines etc.

In addition, the band provides backhaul to dispatch public safety and emergency vehicles (first responders, emergency repair crews, etc.), Internet and telephone carriage, backhaul for cellular systems, including voice and 3G/4G/5G data, connecting commercial centers with real-time financial and market information, other business data etc.

Microwave links are designed for adequate margin, but the amount of available margin is dependent on path length and modulation. As modulation levels increase, receiver thresholds are higher and margins decrease. While some legacy links may have margins in the 40-50 dB range, state-of-the-art radios in use today typically implement higher-order modulations and typically have lower margins of the order of 30 dB at the primary modulation level. Modern radios have the option of Link Adaptation (LA) or Adaptive Modulation, but not every installation uses it. For long paths, the highest order modulations can rarely provide the required availability, so they are often unused. The allowable modulation levels are therefore limited to fewer states, or relegated to be a single static modulation order.

Automatic Transmit Power Control (ATPC) is used to avoid interference with incumbent links by keeping output power low until required during times of decreased received signal strength. All current radios have the feature, but as shown in the FCC database, its use is infrequent. Use of this feature on radios coordinated at the lower power levels cannot exceed time limits established by ANSI/TIA Standard 10 [6].

Some FS links have spatial diversity, used to increase availability during multipath conditions.

Multiple Input Multiple Output (MIMO) antenna systems are designed to increase the throughput of an FS link and the layers of a MIMO antenna system are equivalent in function to the use of higher-order modulations.

5 Propagation Overview

For fixed point-to-point microwave paths, the paths are designed to have approximately 0.6 first Fresnel zone clearance above the terrain or obstacles. For this condition, the received signal level is accurately predicted using the familiar free space attenuation formula in Section 2.2 of ITU-R P.525[7]. For the more general case corresponding to interfering signals, where the transmitter and receiver may be located anywhere, the received signal level is typically the resultant of a mix of direct, reflected, scattered and/or diffracted signals. Most frequency management procedures require a short term (0.01% probability) and long-term (greater than 80% probability) received signal estimate. In the analysis of compatibility between unlicensed stations in the 6 GHz band and the fixed microwave service, the long-term estimate may be especially consequential, although short-term variations must also be considered in relation to the assessment of bit-error rates to a victim receiver and the frequency of exercise of LA mechanisms designed to handle events like weather and wind shear as opposed to interference.

There is no consensus in the 6MSC whether the propagation models proposed within this document should be mandated by the FCC for inclusion as part of the rules. The material in the preceding section has been offered as a demonstration of good faith and diligence regarding the possible models that may be used by the AFC. Additional study is needed to resolve the actual

choice of model for a particular environment and further determine the parameters that will configure that chosen model.

5.1 Average Point to Point Signal Prediction

When an interfering transmitter and victim receiver are moved away from each other (distance between interference and receiver = d), initially the interfering radio signal propagation is line of sight (LoS) (essentially free space, path attenuation $\cong 20 \text{ Log } d$). Eventually as intervening clutter starts to obstruct the propagation path, propagation becomes non-line of sight (NLoS). The interfering signal is attenuated at a faster rate with distance [8].

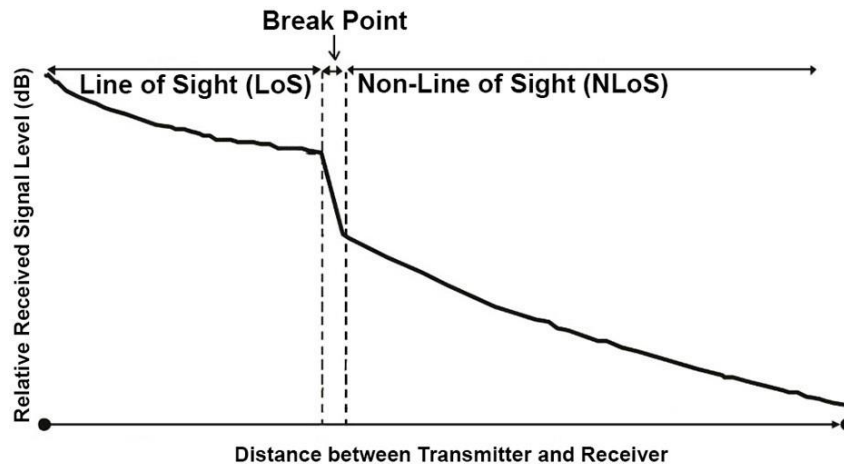


Figure 1 Measurements corroborate empirical models of median path loss that show a rapid transition at the break point between LoS and NLoS properties; e.g. the ITM and ITU-R P.452 models are designed to capture the effect of such real-world observations.

6 Propagation Models for Interference Analysis³

When modeling interference into FS stations from a deployment of a large number of RLANs across a large geographical area, any RF propagation must model the variations in interference path morphologies that exist. In particular, the model must allow the following requirements:

1. Applicability from low distances, e.g. at least 10 m to the order of 100-150 km.
2. Applicability in the band of interest, namely 5925-7125 MHz.
3. Modeling of terrain over long-distance propagation paths, with additional consideration of clutter beyond the break-point between LoS and NLoS propagation
4. Modeling of clutter and environmental effects over short distances

³ The treatment of propagation models specifically addresses the protection of 6 GHz incumbent receivers and does not pertain to the protection of earth-to-space links in the Fixed Satellite Service (FSS).

5. Consideration of the effect of propagation paths where one of the end-points (e.g. RLAN station) is within the clutter and the FS receiver is above the clutter.
6. Modeling of building entry loss where applicable to RLAN stations that are placed indoor
7. Applicability to typical FS antenna heights of up to 20m above ground level.

When applying a propagation model to statistical analysis of the impact of many RLAN stations to a single FS receiver, the effect of building entry loss may be accounted for in a probabilistic manner, i.e., the BEL can be applied to some fraction of the links in the process of estimating aggregate interference. When a propagation model is applied to the case of a single RLAN station desiring operation in the band, it is unclear whether BEL is directly applicable without clear validation of the conditions of deployment. Indeed, a declaration of indoor installation can only be taken at faith without the authority of enforcement of regulations.

Interference paths and their corresponding morphologies may be modeled using one of the following choices for propagation models of pathloss:

1. WINNER II [9] for near-in distances, out to 1 km for suburban and urban areas, followed by ITU-R P.452 [10] for propagation paths beyond 1 km in urban, suburban, and rural area. This approach has been used by ECC report 302 [11] for analyzing interference from RLANs into FS stations at 6 GHz.
2. CBRS Hybrid propagation (eHata/ITM) [12][13][14][15][16][17][18].
3. WINNER II [9] for near-in, out to 1 km for suburban/urban areas and P2P ITM for rural; then P2P ITM [15] for propagation pathloss beyond 1 km.

When using either ITU-R P.452 or ITM, we recommend the use of CBRS 3DEP DEM as the elevation profile [19] available from the Github repository hosted by the WinnForum [20]. The 6MSC favors Option 3 with further agreement needed on an appropriate clutter model for urban, suburban, and rural environments.

6.1 Clutter Loss

“Clutter” is described here in the context of ITU-R P-Series Recommendations.

Clutter refers to objects, such as buildings or vegetation, which are on the surface of the Earth but not actually terrain[21]. Clutter around a radio transmitter/receiver terminal can have a significant effect on the overall propagation. It is normally the clutter closest to the terminal that has most effect on the propagation, but the actual distance will depend on the nature of the clutter and the radio parameters.

The effects of clutter in the environment may be captured using the recommendations in ITU-R P.2108 [21] for urban and suburban environment,⁴ while the clutter model in section 4.5 of ITU-R P.452 [1] may continue to be used for the rural environment. It should be noted that the model

⁴ The model in Section 3.2 of ITU-R P.2108 [21] will replace the Section 4.5 of ITU-R P.452 [10].

in ITU-R P.452 is applicable from 50 m in coniferous and deciduous forests and from 100 m over open fields or sparse vegetation. The clutter model in ITU-R P.2108 is applicable from a distance of 250 m. ITU-R P.452 is itself valid beyond 1 km making the clutter loss model applicable without restriction. Moreover, the WINNER II and eHata model incorporate clutter loss in their design and Recommendation ITU-R P.2108 will not be applied when those models are used.

Recommendation ITU-R P.2108 (Equations 3-5 in [21]) provides a statistical distribution of clutter loss. The clutter loss is given as a cumulative distribution function where the loss is not exceeded for p% of locations.

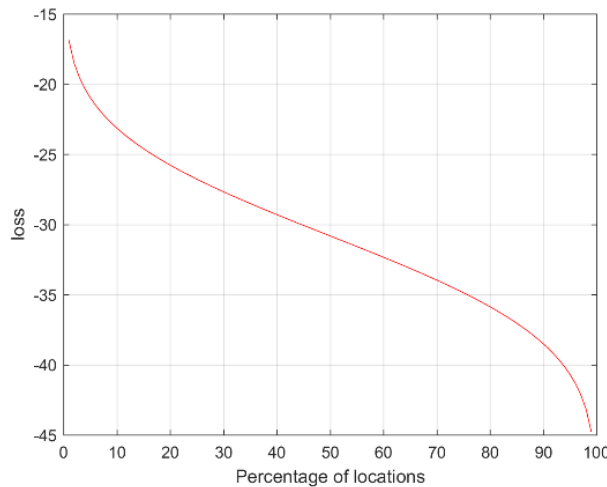


Figure 2 Inverse Cumulative Distribution of clutter loss.

It is important to understand the proper application of the above distribution in a way that is considerate of the need to be conservative when protecting microwave links. For example, the choice of the median clutter loss, suggested by some interested parties, is not conservative enough to account for worst case effects. While some would compromise at mean estimates of the loss function, arguments can be made for more conservative estimates such as the 20th percentile loss. The appropriate loss percentile to use to properly protect the incumbent users while permitting new unlicensed users into the band is an important issue that still needs to be resolved by this committee.

It is also important to understand that the loss in ITU-R P.2108 must be applied under the assumption of the interferer being within the clutter and the FS receiver being above it. Table 1 lists some default clutter heights with representative clutter height R (where local information is not available). NLCD is used to determine clutter type and appropriate $R(m)$.

Table 1 Clutter height R for various local clutter environments

Clutter Type	R (m)
Water/sea	10

Clutter Type	R (m)
Open/Rural	10
Suburban	10
Urban/trees/forest	15
Dense urban	20

The application of the recommended model is meant to be in a statistical manner. Clutter is already designed into the WINNER II and eHata models in a statistical manner. It is to be noted that, for short path lengths, the eHata model emulates free-space behavior.

6.2 Building Entry Loss (BEL)

ITU-R P.2109 [22] provides a well-documented model for BEL. This model is directly applicable to and is designed to be added to the effect of a long-distance propagation path represented by ITU-R P.452 and the ITM propagation pathloss models. BEL may be applied using ad hoc estimates (e.g 15 dB as is used in CBRS) for statistical considerations or by use of the ITU-R P.2109 model in the case of low distances where the WINNER II or eHata model are employed.

There are certain assumptions for the model that need to be noted:

- The statistical output of the model represents the generality of building orientations with respect to the outdoor terminal
- The model assumes that the indoor antenna is omnidirectional; the building entry loss will therefore take account of all energy arriving at the terminal location.
- The model makes the implicit assumption that terminals have an equal probability of location at any point within a building.

The implication of these assumptions indicates that the model is more suitable to the case where the receiving station in an outdoor-to-indoor path is within the building. In the case where the RLAN station has directional antennas, there may be a discrepancy in the ability of the model to account for the orientation of the antenna in relation to exterior walls or windows. It is still expected that the proposed model is a relevant statistical characterization of BEL.

Further study is recommended on the proper application of BEL.

6.3 Land-cover Data

The National Land Cover Database (NLCD) is an effort by the Multi-Resolution Land Characteristics (MRLC) consortium to coordinate and generate consistent and relevant land cover information at the national scale for a wide variety of environmental, land management,

and modeling applications. The NLCD2011 for land-cover data is hosted in the github repository in reference [23] by the WinnForum and is being used for CBRS, viz. NLCD Land Cover Class - 23 or 24 for urban and Class 22 for suburban.

6.4 Summary of available propagation models

Table 2 The various propagation models of interest to FS protection are listed.

Model	Purpose	Frequency Range	Distance	Constraints
ITU-R P.525	Propagation FS-to-FS	All EM waves	Straight-path distances	None
ITU-R P.452	Propagation RLAN-to-FS	0.1 to 50 GHz	Unspecified	Clutter losses are not applicable over short distances; rule of thumb is to use P.452 past 1 km
ITM	Propagation RLAN-to-FS	20 MHz to 20 GHz	1-2000 km	Elevation angle not to exceed 12 degrees
WINNER II	Propagation RLAN-to-FS	2 to 6 GHz	Metropolitan area or wide area short distances	Various models available. Weighted combinations of appropriate models as per [9]
eHata	Propagation RLAN-to-FS	100 MHz to 3 GHz	1 to 100 km	NTIA extension to 3.5 GHz in [24].
ITU-R P.2108	Clutter Loss	2 to 67 GHz	≥ 250 m	If clutter loss to be applied at both ends of the link, then minimum distance is 1 km
ITU-R P.2109	Building-entry loss	80 MHz to 100 GHz	N/A	model assumes that the indoor antenna is omnidirectional and applicability to an indoor transmitter with directional or sectorized antennas may be questionable.

7 Interference Protection Criteria

7.1 Sources of impairments to fixed links

It may be tempting to assume that advances in state-of-the-art microwave systems, such as those described in Section 4, e.g. adaptive modulation, spatial diversity, MIMO, can be harnessed to combat short-term interference effects and thereby mitigate such interference:

1. **Adaptive Modulation:** Interference from RLANs may cause a radio to switch to a lower modulation if it is capable of doing so, or it may just cause increased errors in critical systems. Members belonging to the microwave industry maintain that both conditions result in decreased availability.
2. **ATPC:** Use of this feature on radios coordinated at the lower power levels cannot exceed time limits established by ANSI Standard 10. It is felt by some that there is no ability to use this feature to combat interference from RLANs as it would increase interference from the FS link into all other FS links in range during the time of RLAN interference by increasing the output power of the FS link. This would then more quickly use up the allowable time above coordinated power level eventually rendering the feature unusable, and the FS link would be vulnerable to all future events.
3. **Spatial diversity:** Space diversity techniques can reduce the effects of multipath fading on line-of-sight systems to insignificance [25]. While spatial diversity is not used for interference mitigation in microwave deployments, its use for interference mitigation with RLAN devices requires further study. While space diversity does reduce the intensity and depth of fading events, the use of space diversity by microwave systems is usually limited to installations that are frequently subject to greater depletion of available margin due to the prevailing conditions.
4. **Antenna gain:** Antenna beamwidth generally decreases as antenna size increases, but the trend is to deploy smaller, lighter, and cheaper antennas. The side effect of their size is wider beamwidths meaning that the angle over which the RLAN handset can cause maximum interference is increasing. Although the gain of the smaller antenna is less, mobile stations or terminals in its larger half-power beamwidth area will likely contribute to the composite interference level at a much higher level than mobile stations or terminals outside of the smaller half-power beamwidth of a higher gain antenna.
5. **MIMO:** As detailed in Section 4, MIMO antenna systems are designed to increase the throughput of an FS link and not to increase the link's resistance to increased interference. Consequently, FS industry members of the 6MSC feel that RLANs cannot reasonably expect to use this feature to mitigate the interference they create.

Many of our members feel that the above features are already being used to maintain the availability of the existing systems and are not designed for use as a coexistence or interference

mitigation mechanism for sharing spectrum with RLANs. Especially in the case of ATPC, it is felt that increased RLAN interference could use up the time limits for increased power and cause the feature to be unusable, resulting in repeated outages throughout the year. While this is not a consensus view, the arguments above are made from a factual basis and are worthy of consideration.

7.2 ITU-R Recommendations on compatibility

The protection of FS is a well-studied problem in practice and the ITU-R has several recommendations on the performance characteristics of microwave links as well as considerations that must go into the protection of such services under various scenarios, among which are 1) intra-service (microwave) co-primary users, 2) interference from co-primary users that operate in other primary services (e.g. FSS earth-to-space), 3) unwanted and spurious emissions from other systems, 4) emissions from secondary radiators that are out-of-band or co-channel 5) emissions from secondary services authorized to operate in the band.

ITU-R recommendations are given for both long- and short-term interfering signal criteria. Excess long-term interference to FS receivers reduces the margin available to protect the FS system against fading, causing a reduction in the link availability. Short-term interference requires separate consideration because the interference power may be high enough to produce degradation even when the desired signal is unfaded, e.g., due to demodulator impairments such as synchronization and automatic gain control processing. Long-term interference is usually characterized as the interference power that is exceeded 20% of the time at the victim receiver input.

It is understood that some RLAN devices may not cause sustained long-term interference, e.g., some industry groups have sponsored studies that claim that the median duty cycle of Wi-Fi access points, operating across a wide range of environments and activities (e.g., file transfer, video streaming, audio, surfing on the internet), is on the order of 1% [26]. Further studies are needed on applicability of these models for RLAN device use cases to the 6 GHz band. For example, low individual duty cycles can still lead to significance in activity levels on an aggregate basis. The unlicensed spectrum is moreover not only limited to one class of devices, and new applications such as surveillance cameras can change the traffic characteristics significantly. Moreover, it must be recognized that the short-term peak activity by potential interferers can severely impact the performance of an FS receiver over periods spanning tens of minutes. Therefore, we cannot discount the impact of short-term interference effects, from individual radiators or populations of interferers during periods of high traffic, on the availability of a fixed microwave link. Furthermore, many other RLAN devices may operate at a much higher duty cycle, causing long-term interference. Specifically, the 6 GHz band is of importance to the commercial wireless industry and it is expected that the impending introduction of Licensed Assisted Access (LAA) or NR-U into the band will bring a host of new use cases into the band that do not conform to the prevailing wisdom regarding traffic characteristics. WiFi, LTE, and NR use of the band must reckon with the technology-neutral approach to RLAN use of the band on equal terms for access to spectrum and channel. Further study is needed to fully characterize the range of RLAN transmit duty cycles and, as a result,

whether FS receivers should be protected from RLAN interference using long- or short-term interference models or whether a combination of these models should be applied.

7.2.1 Protection Criteria Based on Long-Term Interference Models

While not directly pertinent to the introduction of RLAN devices, Recommendation ITU-R P.758 offers one potentially applicable treatment of the system parameters and considerations in the development of criteria for sharing or compatibility between fixed wireless systems and other services [27] given long-term interference. This recommendation could influence the sharing between RLANs and FS receivers. Additional considerations based on short term performance variations may also be applicable if the conditions for their application are met. There is significant disagreement on the relevance of short-term effects.

The document draws a distinction between two kinds of objectives that must enter into any such sharing or compatibility analysis: a) Availability Performance Objective (APO) and b) Error Performance Objective (EPO).

The difference between the two objectives is in the time basis of the evaluation. Availability evaluation occurs on an annual basis whereas error performance evaluation is typically done over the duration of a month. These objectives are independent of the measurement of the impact of short-term or long-term interference effects. In general, our concern is with long term interference effects that impact both the availability and error performance of a fixed service receiver (section 4.1 of [27]):

- a. Degradation in the error performance or the availability performance resulting from interference from the co-primary service, which is clearly specified as 10% in Recommendation ITU-R F.1094 (and also in Recommendation ITU-R F.1565).
- b. Degradation in fade margin due to the interference, which is directly calculated from (I/N) value, as $10 \log ((N + I)/N) = 10 \log ((1 + (I/N)))$ (dB).

ITU-R F.758 characterizes the objectives thus:

In particular, when the interference into FS victim is constantly present (e.g. from a GSO space station), it is generally assumed that the acceptable level of interference should be sufficiently low for not affecting the FS system availability threshold, on a yearly basis. In this case, ensuring the suitable FS availability degradation, it is generally assumed that any related “error performance” degradation would be within the acceptable limits (in any month) and no specific study is required.

On the contrary, when the interference into the FS victim is relatively fast varying (e.g. from a non GSO space station), it is generally assumed that, due to uncorrelated wanted and unwanted paths, the acceptable interference level may be higher, so that the “error performance” degradation would predominate over the possible “availability” degradation. In this case, the “error performance” degradation study should be carried out on the “worst month” basis (see example in Recommendations ITU-R F.1108 and ITU R F.1495).

For prediction purposes, conversion of annual statistics to worst-month statistics is addressed in ITU-R P.841[28].

The impact of RLAN interference into an FS receiver spans both these objectives, as the impact of interference from a single RLAN device may affect the expected availability of a FS receiver adversely, whereas the aggregate interference emitted by hundreds or thousands of RLAN devices with varying traffic characteristics that operate in the vicinity of an FS receiver may affect its EPO adversely. Thus, we submit that the introduction of unlicensed devices into the 6 GHz band may need to be evaluated from an availability as well as an error performance perspective.

The understanding of the difference is further illustrated by the following:

1. Automated Frequency Coordination from the perspective of a single RLAN transmitter seeking to operate in the 6 GHz band should consider the impact of that transmitter on the availability of FS receivers that would be impacted by the presence of the RLAN transmitter as a cochannel or in-band interferer. This impact may be assessed by means of a minimum coupling loss analysis of the link.
2. The criteria used to establish exclusion or coordination regions around an FS receiver must consider the impact of aggregate interference. This can be done using a number of ways:
 - i. Estimate the number of interferers and perform a Monte-Carlo analysis of the error performance impact
 - ii. Assess the number of interferers present and either simulate or sense the impact at the FS receiver
 - iii. Use the Minimum Coupling Loss (MCL) analysis corresponding to the availability evaluation of a median interferer and add a margin corresponding to the expected impact of aggregate effects.

Of the above methods, (iii) is practical, while (i) deserves further study allowing that there is precedent from CBRS, while (ii) is dependent on a significant amount of diligence and system knowledge to make it suitable for unlicensed devices in the band.

7.2.1.1 Network Performance Objective (NPO)

The performance requirements that pertain to assessing the ability to meet the APO or EPO are defined in Recommendation ITU-R F.1094 in the form of maximum allowable degradations to error performance and availability [29]. The assessment of the NPO which in turn comprises the EPO and the APO is conducted in five parts based on:

- a) Emissions from FS links operating in the same band
- b) Emissions from other radio services which share frequency allocations on a primary basis

- c) Emissions from radio services which use frequency allocations on a non-primary basis;
- d) Unwanted emissions (i.e. out-of-band and spurious emission domains such as energy spread from radio systems, etc.) in non-shared bands ;
- e) Unwanted radiations (e.g. among others, UWB applications)

Clearly, unlicensed communication devices such as RLAN/WAS should be classified as in category (c) above.

Of the above categories of emissions that may cause degradation to a Fixed Service or microwave receiver, the maximum allowable value of error performance and availability degradation defined by the NPO should be divided into:

- I. an element X% for the fixed service portion, including equipment imperfections and degradations due to propagation effects (intraservice sharing as in (a) above),
- II. Y% for frequency sharing on a primary basis (interservice sharing as in (b) above), and
- III. Z% for all other sources of interference (encompassing the sum of contributions from (c), (d), and (e) in the preceding list).

The sum of X% + Y% + Z% is not to exceed the EPO or the unavailability objectives from ITU-R F.1668 and ITU-R F.1703 respectively [30][31]. Both documents provide identical values of X=89, Y=10, and Z=1.

7.2.1.2 Interference Protection Criteria for FS

Table 3 Relevant interference protection criteria for FS links assuming Long-Term Interference Objective

Impairment category from Section 7.2.1.1	I/N⁵	Frequency range	Sharing/compatibility conditions	Comments and relevant ITU-R Recommendations
(a)	-6 dB	30 MHz to 3 GHz	Co-primary intra-service sharing	Generally applicable value for the aggregate interference corresponds to
	-10 dB	Above 3 GHz		
(b)	≤ -6 dB	30 MHz to 3 GHz	Sharing with more than one co-primary service e.g. FSS earth to space	-6 dB or -10 dB, as appropriate, may be applicable where the risk of simultaneous interference from the stations of the other co-primary allocations is negligible. In other cases, a more stringent criterion may be required to account for aggregate interference from all interfering co-primary services (i.e. -6 dB or -10 dB should be intended as maximum aggregate I/N from all other co-primary services).
	≤ -10 dB	Above 3 GHz		
(e)	-20 dB	3-8.5 GHz	Compatibility with UWB	SM.1757
(c)	-20 dB	All	Compatibility studies	F.1094

ITU-R recommendations for 6 GHz microwave protection from long-term interference are summarized:

1. Aggregate interference protection levels corresponding to an I/N level better than -10 dB for intra-service co-primary protection for a FS receiver; this corresponds to 89% of the allowable error performance or availability degradations;
2. Aggregate interference protection levels corresponding to an I/N level better than -10 dB for intra-service co-primary protection for a FS receiver, corresponding to 10% of allowable error performance or availability degradations;
3. All other services and extraneous sources of interference are accorded an interference protection threshold equivalent to an I/N level of -20 dB, corresponding to the remaining 1% of the allowable error performance or unavailability levels.

⁵ All values in the table pertain to aggregate interference.

7.2.2 Protection Criteria Based on Short-Term Interference Models

ITU-R Recommendations SF.1650 and F.1108 provide examples of studies of short-term interference objectives [32][33]. Recommendation ITU-R SF.1650 is based on a treatment of Earth Stations in Motion (E-SIM) that are based on vessels off-shore; acceptability criteria result in distances 293-404 km from the coast and a scaling down of coupling loss will allow casual understanding of expectations for RLANs. While the equivalence of the study to the sharing between FS and RLANs must be drawn with care, the methodologies used to derive the results bear examination and are relevant for future consideration. Table 4 is a reproduction of interference objectives suggested by ITU-R SF.1650.

Table 4 Relevant interference protection criteria for FS links Assuming Short-Term Interference Objective

Short-term interference objective		
Interference criteria, I/N_{th} (dB)	<ul style="list-style-type: none"> – $I/N = 23$ dB, not to be exceeded for more than $1.2 \times 10^{-5}\%$ of the time for the severely errored second (SES) level. – $I/N = 19$ dB, not to be exceeded for more than $4.5 \times 10^{-4}\%$ of the time for the errored second (ES) level 	<p>These figures are based on a net fade margin of 24 dB referenced to the 1×10^{-3} BER level.</p> <p>Note that the interference criterion associated with the ES level is the more stringent criterion and hence this is used to determine the required distance</p>

Recommendation ITU-R F.1108 addresses the short-term interference criteria for protection of FS receivers from space stations in non-geostationary orbits. The document offers two methods for characterization of performance: (1) a translation of the estimate of fractional degradation in performance, due to short-term interference, into a fade margin loss, and (2) a relation between the fractional degradation in performance and I/N. Clearly, the propagation models used to analyze space stations are not directly applicable here and the methodology is alone of importance.

RLAN duty cycles may potentially exceed those in Table 4 [11]. However, the table shows that there exist certain situations with duty cycle less than 20%, where higher levels of I/N could be tolerated for brief periods of time. The open question is whether these levels are considerate of the APO and EPO objectives in Table 7.2. As mentioned before, low duty cycles do not automatically translate to a change of protection regime to that in Table 4. Interference can still be of such duration as to impact the availability of a critical service. Under these circumstances, the typical FS user would justifiably resist alteration of long-term requirements to short-term interference protection objectives.

7.3 US Considerations

Lastly, the question of over what area must frequency management be imposed must be addressed. ITU-R addresses this with their recommendation F.1095 [34]. In the United States a different area definition is used as defined by the NSMA [35].

In both cases, there is a distinction between coordination distances in the proximity of the receiver antenna boresight as opposed to an off-axis location of the interfering station.

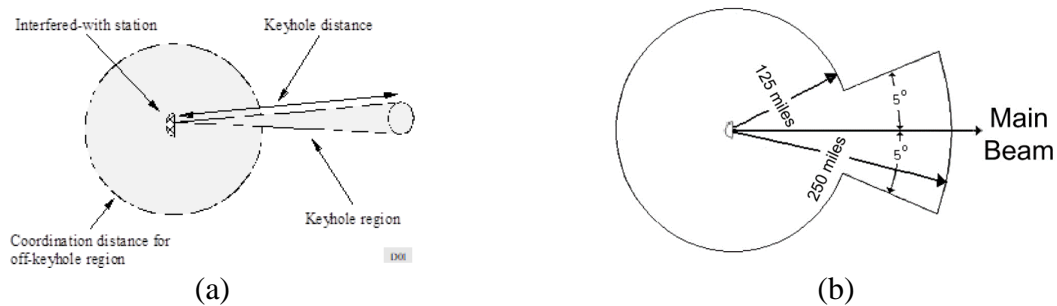
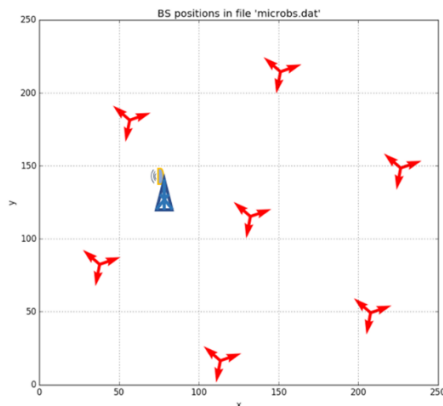


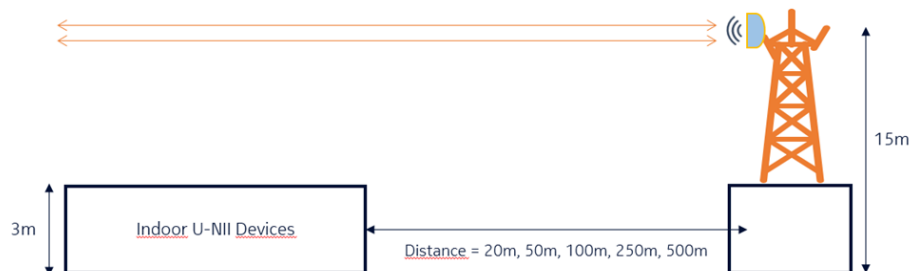
Figure 3 Coordination of fixed service operation in (a) ITU-R F.1095, (b) NSMA recommendation for 6 GHz from WG3.90.026.



(A) Outdoor Deployment of RLAN devices in proximity of an FS receiver



(B) Indoor RLAN devices in the same building as the rooftop FS receiver



(C) Indoor RLAN devices in an adjacent building to the rooftop FS receiver

Figure 4 Scenarios simulated in [36]; as a reminder, U-NII devices are identical to RLAN devices.

7.4 Protection Considerations

7.4.1 Aggregate Interference Effects

Some studies of compatibility between RLANs and the Fixed Service (FS) are described in reference [36]. The referenced annex to Nokia’s *ex parte* filing to the FCC reports on Monte Carlo simulations of three scenarios:

- A. Outdoor macro/micro deployments of RLAN/WAS in the same area as an FS receiver;
- B. Indoor RLAN deployments in a building with the FS receiver installation on its rooftop; and
- C. Indoor RLAN deployments buildings that neighbor a building with an FS receiver.

Adjacent Carrier Interference (ACI) and Co-channel Carrier Interference effects were considered. The traffic model used was full-buffer. Under the assumptions and deployment scenarios considered, the study’s results demonstrated that co-channel aggregate interference can be an issue in all the cases simulated. Figure 5 provides some details for context with results in Figure 6 and the reader is referred to the submission [36] for further details.

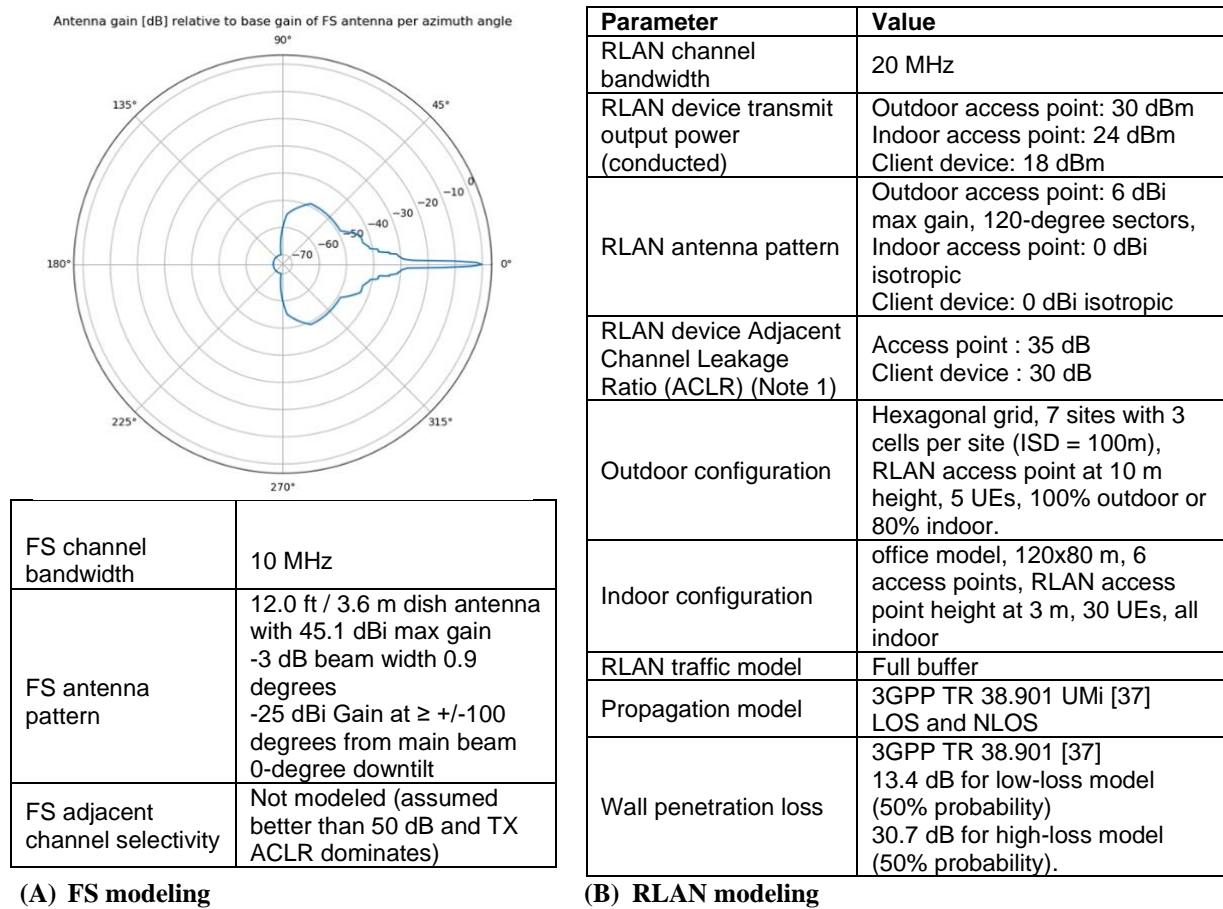
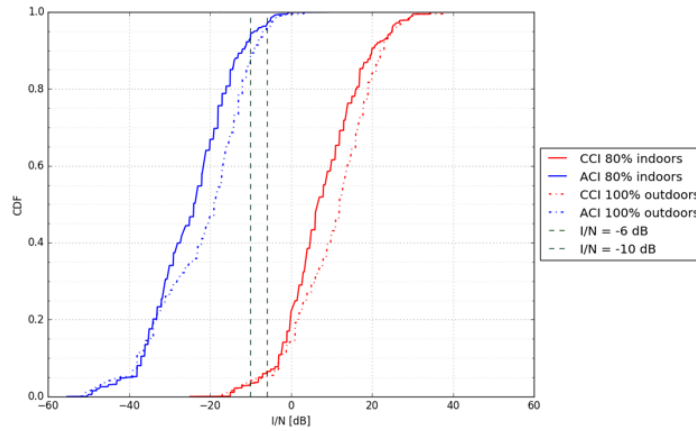
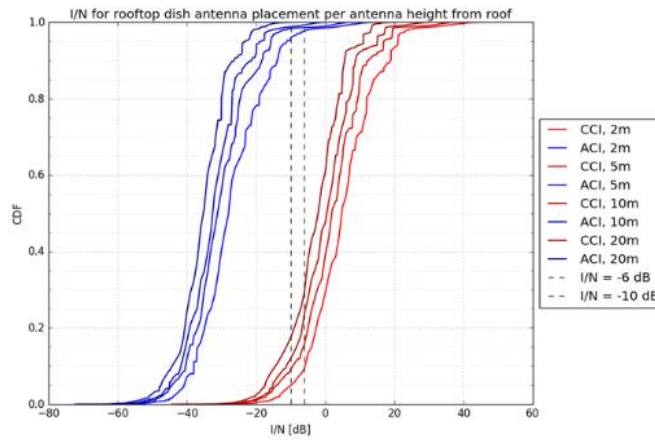


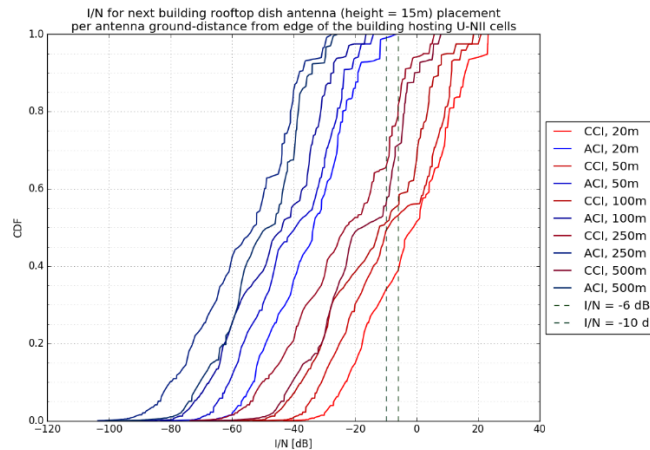
Figure 5 Simulation conditions for a sample aggregate interference study.



(A) CDF of aggregate I/N for FS with Outdoor Deployment of RLAN devices



(B) Indoor RLAN devices in the same building as the rooftop FS receiver



(C) Indoor RLAN devices in an adjacent building to the rooftop FS receiver

Figure 6 Results on I/N under ACI and CCI conditions for scenarios in Figure 4; here, RLAN is identical to U-NII.

7.4.2 Interference characterization

There is a temptation among some proponents to treat microwave links on terms equivalent to the way mobile wireless systems coordinate between themselves, namely by using geometry measures based on C/I. This is not advisable. Apart from requiring a dependency of the AFC on very detailed knowledge of the equipment characteristics, it will place an additional burden on the AFC function to be aware of the environmental conditions under which the FS receiver is deployed. In the case of microwave applications that span hundreds of kilometers, where the end-to-end system is composed of several Path Elements (PE), this is particularly problematic.

There is a very clear recommendation in ITU-R F.758 to relate error performance and availability objectives to an I/N threshold for the FS receiver. The choice of I/N allows the characterization of error performance and objective in a device-independent manner. Thus, evaluations of equipment need not be tied into a minimum performance objective dependent on the transmission characteristics of the microwave links. In other words, higher complexity equipment can be used to improve the performance of a link with some degree of flexibility in being able to retain high availability constraints.

Based on the above considerations, the WinnForum 6 GHz Multi-stakeholder Committee strongly recommends that FS protection be based on an I/N requirement.

7.5 Important considerations regarding fixed service protection

We raise the following questions and proffer answers as noted below:

1. To what extent should fixed microwave services be protected?

The stakeholders represented in the WinnForum 6MSC currently analyzing a sharing regime for the band that primarily protects fixed service incumbents, keeps the band viable for new entrants, and makes the band available for RLAN use, in a manner where the primary status of incumbents is not violated.

2. Does microwave deserve to be in the 6 GHz band?

The lower segment of the 6 GHz band corresponding to the U-NII-5 designation for RLAN users as well as the upper segment U-NII-7 is heavily used by microwave links as detailed in Section 4, many of which are for critical purposes; the U-NII-7 segment is relatively less utilized [1]. Furthermore, the band is assigned to the fixed service throughout much of the world and is an important resource for long-haul carrier-grade links and many critical services. A sharing regime that is not considerate to the performance requirements of critical use of the band for high availability applications will cause users to exit the band. The US benefits from the economies of scale of the supply chain. It must be noted that other segments have BAS and CARS systems that deserve their own assessment in addition to the treatment of FS protection in this report.

3. What is the interference objective (I/N) for co-primary protection of fixed services on an intra-service manner?

The 6MSC accepts that there is reasonable consensus around an I/N threshold of -6 dB for a single exposure of interference between one FS interferer and a victim FS receiver. This is based on an assumption of a 1 dB threshold on noise rise. The FS industry does not formally consider requirements on Multiple Exposure Allowance (MEA) for FS-to-FS coordination because "simultaneous [approximately equal] interfering signals from multiple FS transmitters [are] considered rare" (see TIA-10 [6]).

4. What is the level for I/N for completely uncoordinated unlicensed services relative to the above?

There does not exist consensus among stakeholders regarding whether the ITU-R recommendations are or are not appropriate or applicable for the purpose of U.S. rules. Indeed, there are strong indications that the relevant protection level for FS protection from intra-service sharing may be raised to as high as a nominal level of I/N = -6 dB on aggregate interference allowance assumptions. This would be 4 dB higher than the ratio I/N recommended by the ITU-R at 6 GHz for long-term interference. If such a relaxation is warranted, and the long-term interference model is deemed most appropriate, the logical conclusion may well be to raise the other levels in Table 2 by an equivalent amount of 4 dB.

5. It may also be argued that the interference levels in Table 3 corresponding to non co-primary services are based on an assumption of no interference coordination capabilities in relation to compatibility between co-primary use of the band. Under those circumstances, would the availability of an AFC to protect a victim FS receiver with more relevant information accord a further relaxation of the I/N thresholds?

The 6MSC will need to study this further. It is a majority opinion that the ITU-R recommendation of -20 dB is untenable. The rationale in this document would tend to place the fixed service industry at some level of I/N that accounts for the relaxation of the co-primary number somewhere in the range of -10 dB to -6 dB and additionally adds a suitable relaxation for RLAN devices based on the characteristics of the AFC mechanism that is chosen..

6. What are the further relaxations that may be possible to the above level given that an automated frequency coordination is envisaged for the band?

Although no consensus exists in the 6MSC, some incumbent stakeholders have suggested that an I/N level of -12 dB may be considered as a nominal threshold for the portion of interference contributed by RLAN users. Further study of the overall effectiveness of the AFC mechanisms that are adopted must be conducted before this level is validated.

This level may be amenable to further relaxation given the following two considerations:

- *Interference from 6 GHz RLAN devices may have radio characteristics and use cases (e.g. a duty cycle well less than 20%) under which circumstances the long-term protection criteria may be substantially conservative and short-term interference protection criteria involving much higher I/N levels than those*

provided for long-term interference. As discussed before, there are doubts about whether characterizations of low duty cycle for some kinds of RLAN use cases do not cause any impact to FS receiver performance.

- *Long-term interference recommendations do not take into account FS link features such as spatial diversity and link improvements due to adaptive modulation, forward error correction, and more directive transmit and receive antennas. Such features are commonly available in FS and RLAN products. As mentioned earlier, spatial diversity is usually employed in specific situations where availability or error performance is compromised by prevailing environmental conditions for the link. It must further be recognized that the use of such margins to compensate for short-term interference from RLAN devices will impact the error performance objectives and the overall throughput objectives of an FS link beyond what was dimensioned at initial planning prior to deployment.*

The answers to the preceding questions depend on a number of interdependent factors:

1. Trust in the AFC: The architecture, design, and certification of an decentralized AFC must assure that it works, sufficiently protects incumbents, is secure and not prone to faults or tampering etc.
2. Trust in the devices and their ability to declare their location: Whereas CBRS has an elaborate operational diligence around installation and registration of the devices (based largely on the need to protect extremely sensitive Tier 1 DoD incumbents, which may not be applicable in 6 GHz), the proposed applications in the 6 GHz unlicensed band cannot reasonably be expected to conform to the same level of operational control. Indoor U-NII devices that originate from diverse, global supply chains will not have any way of validating their declared location. Such processes can be subverted by malicious or uninformed users (e.g., as is the case for some existing regulations concerning WiFi APs).
3. Validation of AFC operation and certification of devices: A centralized AFC can be validated and certified. Distributed implementation of the AFC function in U-NII devices should likewise be subject to certification and the level of trust in industry compliance needs to be assured.
4. Effect of aggregate interference: Further study is needed to characterize the level of isolation needed between U-NII devices and the FS receiver, accounting e.g. the relative duty cycle of individual U-NII devices, using a standard set of models acceptable to all industry members etc. Previous studies have shown that under certain conditions, allowing outdoor or indoor RLAN use in the same channel used by an FS link can cause unacceptable noise rise in an incumbent receiver [36]. This revelation, although interesting, must still be reconciled with the recommendations of this report leading towards a common understanding of modeling and analysis principles. The ability of the AFC to retain state of U-NII use of the band will significantly improve the coordination of interference towards fixed service receivers.

5. Vulnerabilities to critical infrastructure from U-NII devices: The fact that many critical services in the utility industry and public safety users depend on the 6 GHz band should be assessed and taken into account when devising the AFC architecture.

8 Recommendations and Conclusions

Propagation models chosen must protect incumbents. Several suggestions have been provided, specifically WINNER II [4] for near-in distances, out to 1 km for suburban and urban areas, followed by ITM [15] for propagation paths beyond 1 km, and ITM alone for rural areas for all distances. Further study is needed regarding the application of clutter models, which are potentially favored to be consistent with ITU-R P.2108 and Section 6.1 for urban and suburban cases and with ITU-R P.452, Section 4.5, for the rural case. Clutter loss will be applied consistent with ITU-R P.2108 and Section 6.1. Further study is needed on BEL, but ITU-R P.2109 is promising. Use of the elevation profile 3DEP DEM is recommended [19]. Land cover modeling should be according to NLCD2011 [23].

Currently, incumbents have offered technical arguments in favor of an interference protection level of $I/N = -12$ dB. It has also been pointed out that FSS receivers are accorded protection of $I/N = -12$ dB for e.g. AWS-3 in the 1695-1710 MHz band. Given the nature of use of the 6 GHz band by many critical services, it is therefore reasonable to expect some sort of a support for I/N less than or equal to -6 dB, pending further studies to establish a better assessment of the right I/N value based on analysis such as an MCL calculation.

9 Future work

The following studies bear future consideration:

1. Aggregate interference effects have to be analyzed either with Monte Carlo simulations or an MCL analysis followed by a reasonable accounting of user density. This is an analysis that could be carried out by the 6MSC.
2. Effective duty cycle values for different classes of indoor and outdoor users are worth studying in order to get a better idea of the impact of multiple exposure situations.
3. More work needs to be done on sharing studies with the other incumbents in the band.
4. Contributions have been received in the area of BEL values and measurement approaches. These include using either fixed values or building loss measurements with systems such as GPS/GNSS.
5. Additional Studies are required on clutter loss considering the preference for the ITM model.
6. The impact of advanced antenna technologies on incumbents and U-NII operation may also be studied further.

One final objective of the 6MSC is a more detailed analysis of the requirements of the AFC and study of AFC architecture given the FS industry's desire for affirmative control of spectrum authorization.