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	)	
Implementation and Administration of a Coupon Program for Digital-to-Analog Converter Boxes	)	Docket No. 06051 21 29-61 29-01

COMMENTS OF
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The proposed coupon program is to be applauded to the extent that it accelerates the DTV transition. A primary goal of the transition is to free up spectrum for other uses. As noted in the FCC proceedings to allow unlicensed access to this spectrum,[1] both low-power devices and high-power devices are possible. High-power devices are more significant since they will allow a new and significant channel for broadband access that will be especially important in closing the digital divide in rural areas. As described in the attached analysis, the ability of high-power secondary devices to effectively use this spectrum without causing interference is limited by the TV receiver characteristics; in particular their ability to reject adjacent channel interference. Therefore, the NTIA is encouraged to apply strong receiver standards to the set top boxes, at least the ATSC A-74 *DTV Receiver Performance Guidelines.*

[1] FCC Proceeding: Notice of Proposed Rulemaking, In the Matter of Unlicensed Operation in the TV Broadcast Bands, ET Docket No. 04-186, Federal Communications Commission, adopted May 13, 2004.

A Model for Analyzing Unlicensed Device Operation in Licensed Broadcast Service Bands

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Abstract – **Unlicensed devices operating in licensed broadcast service bands can cause interference to the licensed receivers. It would assist unlicensed rules analysis, proposed rulemaking, and unlicensed device design to have analytic models for quantifying the impact of the unlicensed interference to the licensed receivers. This paper presents such a model that not only provides quantitative analysis, but, also provides insight into how factors such as directional antennas, power control, and licensed channel avoidance strategies affect the aggregate interference. Further, it suggests that complex factors such as unlicensed device modulation schemes can be captured in a simple measurement.**

I. Introduction

The FCC 04-186 proceedings discussing the notice of proposed rulemaking, Unlicensed Operation in the TV Broadcast Bands[2], the recent Ultra Wideband rules, and existing Part 15 rules open the possibility for unlicensed devices to coexist with licensed devices in licensed broadcast bands. The traditional approach (UWB and Part 15) limits the unlicensed devices to very low powers in order to minimize the potential for harmful interference. Today's technology enables more sophisticated radios that can use means other than simply limiting power to avoid harmful interference.

In a widespread deployment of unlicensed devices: How many licensed devices would be affected? How could this quantity be changed with different rules? What factors in an unlicensed device design are significant? How might regulators assess a particular unlicensed device for compliance or non-compliance? These questions require a detailed analytic model.

An interference model is developed in this paper. The model computes the fraction of licensed devices made unavailable because of unlicensed operation. It considers factors such as the type of unlicensed signal modulation, antennas, ability to detect active licensed channels, power control, and activity levels of the licensed and unlicensed devices. Examples using the model suggest that allowing a small increase in interference allows unlicensed device densities over 1,000 unlicensed devices per square kilometer. A high density apartment building example is also analyzed. It is found that there are mitigating factors in this case that supports over 20,000 unlicensed devices per square kilometer.

[2] Notice of Proposed Rule Making, Unlicensed Operation in the TV Broadcast Bands, FCC 04-186 Released May 25, 2004.

II. General Setting

To better understand the model we provide an interference context. The model considers a large area that is covered by some licensed broadcast service. There are many licensed receivers within the area. In this area is a deployment of unlicensed devices. The concern is the interaction of the transmitted unlicensed signals with the licensed broadcast signal at the licensed receivers. The combination of multiple unlicensed signals is not considered. Given that propagation tends to spread signal powers over many orders of magnitude, it is likely that one of the interfering signals is much stronger than the others and any service outage is a result of this one strongest signal. Conversely, a single unlicensed device, if it is well designed, is unlikely to interfere with many licensed receivers, if any. The interference is in the context of a widespread and dense deployment of the unlicensed devices and we examine the expected total number of licensed devices that will experience an interference outage.

The unlicensed devices can have mechanisms to avoid interference. They might have mechanisms for avoiding the broadcast channels; use directional antennas; control their power to only what is needed; transmit only part of the time; and use sophisticated modulation schemes. Further some licensed devices may obtain their signal from cable or a recording device and thus be immune to interference. The model in this paper is designed to capture these factors.

III. A Model for Estimating Interference

This section contributes a model of the impact of unlicensed devices that enables uniform comparison and evaluation of the unlicensed devices. It does not promote any particular approach but does provide a framework for discussing and comparing each approach's performance.

The model predicts the expected fraction of licensed receivers disrupted over a broadcast coverage area. A single unlicensed device, if properly designed, will not have wide impact on licensed usage across a coverage area. It is when the number of devices grows that the impact becomes significant. The model is a tool to show what is required for a high-density unlicensed device deployment (e.g., 1000 devices per square kilometer) to avoid harmful interference.

A. Model Summary

Mathematically, the model consists of a series of factors that account for the different elements that influence the number of disrupted licensed devices:

$$F = r_{\min}^2 PCEG_{UL}G_L MN_{UL} / A$$

where

- F is the expected fraction of licensed devices with service disrupted.
- $r_{\min}$ is the minimum separation between the unlicensed and licensed device in order to prevent the unlicensed device from interfering with the licensed device under typical operating conditions near the boundary of the broadcast coverage area. This is done under worst case conditions of the licensed device transmitting at maximum power on the same channel as the licensed device with both devices antennas pointing at each other.
- P accounts for the use of power control by the unlicensed device. $P \leq 1$.
- C accounts for the ability of the device to avoid communicating on the same and adjacent channels as the licensed device. $C \leq 1$.
- E is the fraction of devices on and eligible to interfere with each other $E \leq 1$.
- G_{UL} accounts for the antenna gain pattern of the unlicensed device. $G_{UL} \leq 1$.
- G_L accounts for the antenna gain pattern of the licensed device. $G_L \leq 1$.
- M captures all the model constants. A typical value is $M = 2.9$.
- N_{UL} is the number of unlicensed devices in the area.
- A is the size of the area.

Most of the factors are less than or equal to one. In some cases they are very small and are the key to achieving a small F. Worst case analysis of viewing only $r_{\min}$ would be overly pessimistic. The last four factors are outside the influence of the unlicensed device designer. But the first five factors can be affected by the unlicensed device design. Different modulation techniques, maximum transmit power, etc. can all affect $r_{\min}$. The sophistication of power control algorithms affects P. The fidelity of channel detection techniques strongly affects C. The level of device activity affects E. The unlicensed device's antenna affects G_{UL}. Technical readers are encouraged to read the model details in the appendix as important assumptions and derivations are presented there. Less technical readers may safely go to the next section.

B. Examples

To help interpret the model we give several examples. We emphasize that the examples and the numbers used are purely illustrative. For all the examples we will use a broadcast coverage area of 10,000km^2 which corresponds to a 56km (34mile) circle of broadcast coverage. We also use N_{UL} = 10,000,000 devices. This yields a N_{UL}/A of 1000 devices/km^2. This represents a large number of unlicensed devices deployed over a metropolitan area. The broadcast pathloss exponent is $a = 2$ and joint shadow fading is $\sigma = 7$dB.

Consider a low power device operating under the following conditions: r_{min} = 100m; the unlicensed devices have an omnidirectional antenna; the licensed antennas are approximated by 60 degree ideal sectorized antennas; the pathloss exponent for low-power devices is $b = 4$; and power is controlled uniformly over a log scale between max power and 20dB below max power. The fraction of: unlicensed devices turned on is 25%; licensed devices turned on. is 25%; and licensed devices listening to broadcast channels is 25%. As a reference, we consider the worst case that the licensed device is using a random channel. In this case, $P = 0.39$; $C = 0.02$; $E = 0.016$; $G_{UL} = 1$; $G_L = 0.17$; and $M = 2.9$. Combining these factors yields an expected fraction of disrupted licensed devices of about 6/10,000. This suggests that even limited additional work to avoid using known TV channels would reduce the expected number of disrupted devices to an insignificant level. For instance if the unlicensed device could determine the presence of and avoid licensed broadcast channels (and adjacent channels) 90% of the time and the remaining 10% of the time the channel choice is random, then $C = 0.0022$, and the fraction of disrupted licensed devices is less than 1/10,000. We emphasize that these number are across a major metropolitan area with ten million unlicensed devices. A suburban or rural area which we might expect to have factors of 10 to 1000 lower device density would have similarly reduced fraction of disrupted devices. For example a rural area with 100 devices per square kilometer would have a fraction of disrupted devices less than 1/10,000 even if the unlicensed devices chose channels randomly.

Consider next a high-power device operating under the same conditions as for the low power device except that: r_{min} = 10km; the unlicensed antennas are high-gain 30 degree sectors; $b = 2$; the fraction of unlicensed devices turned on is 50%; and again random channel selection. In this case, P = 0.21; $C = 0.02$; $E = 0.031$; $G_{UL} = 0.083$; $G_L = 0.17$; and M = 5.8. Combining these factors yields an expected fraction of disrupted devices of close to 1. This implies the unlicensed devices must be much more reliable in detecting and avoiding broadcast channels. For instance, if the licensed channel could be detected and avoided 99.99% of the time (all but 50 minutes per year) then, $C = 2.\text{x}10^{-6}$ and the expected fraction of disrupted licensed devices is less than 1/10,000. The same level could be achieved in a rural area if licensed channels could be detected 99.9% of the time (all but 8 hours per year).

The greatest potential for interference exists in dense settings, for instance in apartment buildings where the effective density could be above 1000 devices per square kilometer. There are several mitigating factors in this case. Such buildings are more likely to have wired Internet access (i.e., less likely to be high-power unlicensed devices). Similarly, they are more likely to have cable TV. Such buildings are often in urban areas where broadcast signals are stronger and easier to detect. For low-power devices used within these apartments, the communication distances are likely much smaller and thus require less transmit power. Social factors should not be ignored either. If some neighbor is too loud, you can ask them to be quieter. Similarly, if a neighbor places a wireless device too close to your TV, you can ask them to move it.[3]

We can incorporate these factors into the model by assuming half as many licensed devices listening to broadcast channels, channel detection can be twice as accurate, the power is controlled uniformly over a log scale between 10dB below max power and 20dB below max power, and half of all potential disruptions can be solved by social means (i.e., P = 0.19; C = 0.0012; and E = 0.0039) would support in our illustrative examples more than 20,000 unlicensed devices per square kilometer without exceeding the harmful interference threshold.

IV. Conclusion

This paper develops a model which shows that high-power and low-power unlicensed devices can successfully coexist with licensed devices. The model estimates the fraction of licensed devices disrupted by the presence of the unlicensed devices. It incorporates a range of factors that can influence the final result. All of the factors can be easily estimated or directly measured. In particular, one of the most influential factors, r_{min}, could be measured through direct measurement. This suggests that a device compliance model can be developed based on factors inherent to the device. In other words, the definition of compliance could be defined in terms of a bound on r_{min} as measured in a lab.

Illustrative examples indicate high-power devices will need to pay special attention to how they choose transmit channels since they have a strong potential to interfere over a large area if they choose an active licensed channel. The model here provides concrete guidelines on how reliably the procedure for avoiding licensed channels must be.

The examples show that low-power devices can be much less reliable in this procedure and yet have minimal impact on licensed devices. They are helped by being lower power. Because they are envisioned as being used indoors or at ground level, the walls and clutter (as expressed by the larger path-loss exponent) provide more isolation. But, since the licensed channel avoidance procedure is likely to be more ad hoc its reliability may be more difficult to assess.

The model suggests that licensed and unlicensed devices can coexist at densities exceeding 1000 unlicensed devices per square kilometer. When applied to a worst-case scenario of a high-density apartment building, it is found that densities over 20,000 devices per square kilometer can be supported. Further work is needed to fix the parameters of the model and to provide more accurate estimates.

The examples in this paper assumed a harmful interference standard defined as no more than 1 in 10,000 licensed devices will suffer outages because of the unlicensed devices. Such a standard exercise an abundance of caution considering that other sources of interference may cause more than 10 times as many outages. It should be clear from the model that such extreme caution imposes direct and substantial penalties on the deployment of unlicensed devices. For instance, if the harmful interference standard admitted 10 times more outages, the model would immediately support a 10 times higher unlicensed device density.[4] Therefore, the harmful interference standard in this paper should be considered a model and the specific interference level should be set with careful consideration.

V. Appendix: Model Details

A. Model Assumptions

The basic idea of the model is that licensed receivers and unlicensed devices will be spread over a large area such as a metropolitan or rural area. A conceptual notion is that this area consists of the area covered out to some maximum distance (such as to the Grade B contour of a typical broadcast station). The shape of this contour is not particularly important as long as it is reasonably compact. A key concept is $r_{\min}$, the minimum non-interfering distance separation between unlicensed transmitter and licensed receiver when the licensed device is transmitting at full power on the same channel as the receiver is listening and both devices antennas are pointed toward each other. This, of course, is the worst case situation and other factors come into play to mitigate this situation. It is precisely the point of this model to make these factors explicit so that the mitigating role of smart unlicensed devices can be expressed concretely.

[3] General guidelines used in Part 15 rules development are (a) self-interference between two devices operated by the same household is not considered; and (b) between households a working assumption is 10m separation and wall attenuation of at least 10dB. The original NPRM, supra 2, footnote 50 reiterates this assumption. This suggests that some disrupting interference in such high density settings may not be considered harmful interference.

[4] Or, it would ease the design challenge for the same density by a factor of 10. For instance, using a 1 in 1000 standard in the illustrative example of a high-power device, the unlicensed devices would have to detect and avoid licensed devices 99.9% of the time (i.e., incorrect no more than 8 hours per year) instead of 99.99% of the time (i.e. incorrect no more than 50 minutes per year).

The basic model makes the following assumptions:

1. Only two-dimensional scenarios are considered.
2. Received power at a licensed device from an unlicensed transmitter is $P_{int} = K_{int}\, g_{UL}\, g_L\, P_{UL} S_{int}/r^b$, where K_{int} is a constant related to antenna heights, cable losses, and other constants; g_{UL} and g_L are the unlicensed and licensed device antenna gains along the path connecting them; P_{UL} is the transmit power; r is the separation between the unlicensed transmitter and licensed receiver; b is the pathloss exponent for signals between the unlicensed and licensed device; and S_{int} is the shadow fading factor representing the variation in received power due to terrain, clutter, and other environmental factors.[5]
3. Received power at a licensed device from a broadcast tower is $P_{sig} = K_{sig} S_{sig}/R^a$, where K_{sig} is a constant related to broadcast power, antenna heights, cable losses, etc.; R is the separation between the transmitter and receiver; a is the pathloss exponent between the transmitter and receiver; and S_{sig} is a shadow fading factor representing the variation in received power due to terrain, clutter, and other environmental factors. Note the specific effects for the broadcast power and antenna gains are not broken out as separate factors since they will likely be constants and not vary over time.
4. The licensed device is disrupted if $P_{sig}/P_{int} < T$ for some defined threshold T. Note that this threshold depends on the nature of the interference signal, and whether it is in the same channel as the licensed receiver or another nearby channel. Combining the previous assumptions, the signal to interference ratio is $P_{sig}/P_{int} = K\ S\ r^b/(g_{UL}\ g_L\ P_{UL}\ R^a)$, where $K = K_{sig}/K_{int}$, and $S = S_{sig}/S_{int}$.
5. The shadow fading S is well modeled by a log-normal distribution (i.e. log S is normal) with log normal standard deviation σ. If S_{sig} and S_{int} are both log normal with log-normal standard deviation σ_{sig} and σ_{int}, then their ratio is also log normal. In practice, S_{sig} and S_{int} are correlated. A TV in the basement will receive weaker signals from both the broadcaster and the unlicensed device. Thus, $\sigma^2 < \sigma_{sig}^2 + \sigma_{\text{int}}^2$.
6. The licensed devices are uniformly distributed over the broadcast coverage area. The coverage area is a circle of radius R_B. The probability a device is within R of the center is $\frac{R^2}{R_B^2}$. Let A be the coverage area, N_L the number of unlicensed devices in this area, and N_L/A the average density of licensed devices. For simplicity, all broadcast channels have the same coverage area.
7. The unlicensed devices are uniformly distributed over the broadcast coverage area and the number of these devices is N_{UL}. The licensed and unlicensed device separation, r, is small relative to the radius of the broadcast coverage so that r is independent of R.
8. A device which is turned off can not disrupt or be disrupted. A licensed device not using the broadcast channel (e.g. using cable) can not be disrupted.
9. Unless otherwise stated, antennas have a uniform random azimuth orientation.

Some notes on these assumptions are in order. The limitation to two-dimensional does not apply well to built-up metropolitan areas such as New York City. It does apply to urban environments with few high-rise buildings and typical suburban and rural environments. Later work will expand this model to three-dimensional environments.

The pathloss exponent is allowed to differ for the unlicensed and broadcast transmitters. It is expected that the broadcast transmitter will be close to a free-space pathloss model ($a = 2$). The unlicensed device will differ depending on the device. For low-power devices without special antenna mounting, the pathloss will be closer to the two-ray ground model ($b = 4$). For higher power transmitters mounted on outdoor poles, it will be between 2 and 4 depending on antenna height and location.

Shadow fading can have log-normal standard deviations as large as 10dB for both S_{sig} and S_{int} suggesting a total of 14dB for the log normal standard deviation for their ratio. Because of correlations between them we might expect a total variation equal to half of this value or 7dB.

With the uniform distribution of unlicensed devices the expected number of licensed devices in a ring of thickness dr and radius r from the unlicensed device is $2\pi r\, N_L/A\, dr$.

B. Model Derivation

There are three main random variables in this model. The distance of the licensed device to the broadcast transmitter, R; the distance from the licensed device to the unlicensed transmitter, r; and the shadow fading value S. Once these are accounted for, secondary random variables can be easily admitted.

We are interested in computing expected number of licensed devices disrupted by an unlicensed device. First we compute the expected number disrupted by a single unlicensed device and then scale to more than one unlicensed device. Consider a single unlicensed device. Given r and S, a licensed device is disrupted if $\frac{P_{sig}}{P_{\text{int}}} = \frac{SKr^b}{g_{UL} g_L P_{UL} R^a} < T$, i.e.

[5] The model for assumptions 1-5 is derived from standard texts such as Rappaport, T.S., *Wireless Communications Principles and Practice*, 2nd Ed. Prentice Hall, 2002. Ch. 3-5

$R > \left(\frac{SKr^b}{g_{UL} g_L P_{UL} T}\right)^{1/a}$. T is the threshold given the current channels of the licensed and unlicensed devices; and the modulation scheme used by the unlicensed device. It follows from assumption 6:

$$\Pr\left\{R > \left(\frac{SKr^b}{g_{UL} g_L P_{UL} T}\right)^{1/a}\right\} = \begin{cases} 1 - \frac{1}{R_B^2}\left(\frac{SKr^b}{g_{UL} g_L P_{UL} T}\right)^{2/a} & \text{if } \left(\frac{SKr^b}{g_{UL} g_L P_{UL} T}\right)^{1/a} \le R_B \\ 0 & \text{otherwise} \end{cases}$$

The expected number of licensed radios at a distance r to $r + dr$ is $N_L/A\ 2\pi r\ dr$. To get the total expected users disrupted by the unlicensed device we integrate over all distances r, and for each r, over all possible S.

$$D = \int_0^\infty \int_0^\infty \frac{N_L}{A} 2\pi r \Pr\left\{R > \left(\frac{sKr^b}{g_{UL} g_L P_{UL} T}\right)^{1/a}\right\} p_S(s)\, dr ds$$

where p_S is the distribution of S. Switching the order of the integration and integrating yields:

$$D = \pi \frac{N_L}{A}\left(\frac{R_B^a g_{UL} g_L P_{UL} T}{K}\right)^{2/b} \frac{b}{b+a} e^{\frac{2\sigma^2}{b^2}}.$$

This is the expected number of licensed devices disrupted by a single unlicensed device. For N_{UL} unlicensed devices, we conservatively overestimate[6] the number of disrupted devices as simply N_{UL} times larger.

An alternative form of this equation is derived as follows. Consider the worst case when a licensed device is at the edge of the broadcast area, the unlicensed device is at maximum power on the same channel as the licensed device with both antennas pointing at their maximum gain towards each other. Let $S = 1$ and consider the distance r_{min} that would just meet the signal to interference criteria for an interferer on the same channel. In this case (with obvious notation):

$$\frac{P_{sig}}{P_{\text{int}}} = \frac{K r_{\min}^b}{g_{UL}^{\max} g_L^{\max} P_{UL}^{\max} R_B^a} = T_S$$

$$r_{\min} = \left(\frac{g_{UL}^{\max} g_L^{\max} P_{UL}^{\max} R_B^a T_S}{K}\right)^{1/b}$$

Combining these results we get

$$D = \pi \frac{N_L N_{UL}}{A} r_{\min}^2 \left(\frac{g_{UL}}{g_{UL}^{\max}} \frac{g_L}{g_L^{\max}} \frac{P_{UL}}{P_{UL}^{\max}} \frac{T}{T_S}\right)^{2/b} \frac{b}{b+a} e^{\frac{2\sigma^2}{b^2}}$$

The role of the broadcast path loss exponent, a, is somewhat subdued in this equation. This is because it is implicitly subsumed in the definition of the coverage area. A bigger a would lead to a smaller coverage area and vice versa. Here it reflects how quickly the licensed signal power increases above the threshold as the center of the coverage area is approached. Since most licensed devices are closer to the edge than the center this effect has only a small impact on the final result.

There are four final random variables that need to be considered: the distribution of the unlicensed and licensed antenna gains; the distribution of unlicensed power levels; and the distribution of device thresholds. These are assumed to be independent of each other and the other random variables.

The unlicensed antenna has an antenna pattern, $g_{UL}(\theta)$. The expected contribution to the number of disrupted receivers is:

$$\int_0^{2\pi} (g_{UL}(\theta))^{2/b} p_{g_{UL}}(\theta) d\theta = \frac{1}{2\pi} \int_0^{2\pi} (g_{UL}(\theta))^{2/b} d\theta$$

where the distribution $p_{g_{UL}}$ is assumed to be uniform.[7] Define

$$G_{UL} = \frac{1}{2\pi} \int_0^{2\pi} \left(\frac{g_{UL}(\theta)}{g_{UL}^{\max}}\right)^{2/b} d\theta$$

Typical values are

$G_{UL} = 1$ if the antenna is omnidirectional

$G_{UL} = w/360$ if the antenna is an ideal sectorized antenna of width w in degrees.

Similarly we define the licensed antenna gain factor:

$$G_L = \frac{1}{2\pi} \int_0^{2\pi} \left(\frac{g_L(\theta)}{g_L^{\max}}\right)^{2/b} d\theta$$

Power control would result in a distribution of power levels. Similar to the antenna gains we define the power control gain factor:

$$P = \int_0^{P_{UL}^{\max}} \left(\frac{P_{UL}(x)}{P_{UL}^{\max}}\right)^{2/b} p_{P_{UL}}(x) dx.$$

[6] If two different unlicensed devices disrupt the same licensed device it counts as two licensed devices disrupted.

[7] A receiver detection technique might lead to null steering or other techniques so that the antenna angle distribution would not be uniform.

where $p_{P_{UL}}$ is the distribution of power levels. Example values are

P = 1 when the unlicensed device always transmits at maximum power

$P = b/(b+2)$ if power is uniform between 0 and $P_{UL}^{\max}$.

$P = \frac{b}{2}\frac{1-\left(P_{UL}^{\min}/P_{UL}^{\max}\right)^{2/b}}{\ln P_{UL}^{\max}/P_{UL}^{\min}}$ if $\ln P_{UL}$ is uniform between $\ln P_{UL}^{\min}$ and $\ln P_{UL}^{\max}$ (i.e. it is uniform in dB between the min power in dB and the max power in dB).

The distribution of required thresholds depends on the likelihood of choosing the same channel, or one of the neighboring channels, or more separated channels. Even if the unlicensed device is working on a channel far removed from the channel used by the licensed device, a sufficiently strong signal can overwhelm the receiver. So, all channels must be considered. Therefore we define:

$$C = \sum_i p_i \left(T_i/T_S\right)^{2/b}$$

where if N is the channel used at a licensed receiver, p_i is the probability of the unlicensed device being on channel $N + i$, and T_i is the threshold required in this case. For instance, for DTV[8]

I	T_i/T_s(dB)
0	0.0
+/–1	48.5
+/–2	74.2
+/–3	78.2
+/–4	84.2
+/–5	86.2
+/–6	80.2
+/–7	87.2
|i|>7	90.2

As a worst case example, let the channels be chosen randomly and we ignore effects at the edge of the licensed band. Then

$C = 0.020$ if $b = 2$

$C = 0.020$ if $b = 4$

If the unlicensed radio avoids the same and adjacent channels of the licensed receiver (i.e. is at worst at N +/– 2) then at worst:

$C = 3.8\text{x}10^{-8}$ if $b = 2$

$C = 2.0\text{x}10^{-4}$ if $b = 4$

If the unlicensed radio can always avoid any channel within +/– 7 of a receiver channel, then

$C = 9.6\text{x}10^{-10}$ if $b = 2$

$C = 3.1\text{x}10^{-5}$ if $b = 4$

We let all the model factors be denoted by M

$$M = \pi \frac{b}{b+a} e^{\frac{2\sigma^2}{b^2}}$$

Then

M = 5.8 if $a = 2$, $b = 2$, and σ = 7dB

M = 2.9 if $a = 2$, $b = 4$, and σ = 7dB

Licensed receivers or unlicensed transmitters may simply be turned off and not part of creating or suffering interference. A licensed receiver may be receiving its signal via cable and not through over-the-air broadcasts. The last factor captures the fraction of devices eligible to participate in the device interaction:

$E = F_{ONUL} F_{ONL} F_{BC}$

Where F_{ONUL} is the fraction of the unlicensed devices that are turned on at any time, F_{ONL} is the fraction of licensed receivers that are on, and F_{BC} is the fraction of receivers that listen to over-the-air broadcasts as opposed to cable TV.

Putting all these factors together and noting $F = D/N_L$ yields the main result:

$$F = r_{\min}^2 PCEG_{UL}G_L MN_{UL} / A$$

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[8] ATSC A-74 *DTV Receiver Performance Guidelines*