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Before
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

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OFFICE OF THE SECRETARY
01-145

In the Matter of	)
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Request for Declaratory Ruling	)
Removing the Commission's Minimum	)
Sub-carrier Requirement for OFDM Modulation	)
In MDS and ITFS Services	)

PETITON FOR DECLARATORY RULING

Cisco Systems, Inc. ("Cisco") hereby requests the Commission to declare that a minimum of 256 QAM-modulated carriers (or tones) is not necessary in order to use OFDM modulation in the MDS and ITFS services. The grant of Cisco's request will remove an unnecessary and harmful restriction on permitted OFDM modulation types.

Introduction

On 31 August 1998, Clarity Wireless, Inc. ("Clarity")[1] filed a Petition for Declaratory Ruling ("Petition") requesting the Commission to authorize the use of Orthogonal Frequency Division Multiplexing ("OFDM") digital modulation to provide MDS and ITFS networking. At that time, Clarity noted the public interest in using the MDS and ITFS bands for high-speed interactive data services, but pointed out that existing digital communications equipment was not optimal for achieving high data rates in multipath environments. Consequently, MDS/ITFS services were then limited to using high-power, line-of-sight equipment.

[1] Subsequently, on November 2, 1998, Cisco Systems, Inc. acquired Clarity.

By contrast, Cisco's OFDM technology could be implemented at higher data rates and, by virtue of its ability to mitigate multipath effects, would not be limited to line-of-sight usage. Further, Cisco's solution could be implemented in lower-power, lower cost cellular and microcellular architectures.[2] Based on a study commissioned by Clarity[3] that analyzed 256-carrier OFDM and 4096-carrier OFDM as examples, the Commission declared that OFDM could be used in the MDS and ITFS services, but required that a minimum of 256 QAM-modulated carriers (or "tones") be used. *See* Declaratory Ruling and Order ("OFDM Order"), DA 98-2129, ¶ 7 (1999).[4] This requirement is not necessary or wise, and the Commission should now declare that OFDM can be used in these services without a minimum of 256 tones.

Background

In its *Request for Declaratory Ruling on the Use of Digital Modulation by Multipoint Distribution Service and Instructional Television Fixed Service Stations, Declaratory Ruling and Order*[5] the Commission established policies to authorize MDS and ITFS operators to use digital transmission technologies. The Commission said it would routinely authorize QAM and VSB modulations, and would consider authorizing other digital modulation techniques based upon test data demonstrating that interference

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[2] Of course a benefit of these architectures is frequency reuse of limited spectrum.

[3] Engineering Statement and Support of a Petition for Declaratory Ruling on the Use of OFDM Modulation in MDS and ITFS Services, Hardin and Associates, Inc. ("Hardin Study"), 1998.

[4] In the OFDM Order, the Commission also required that permitted OFDM modulated transmissions comply with the spectral mask and power limitations in the Commissions rules (*see* 47 C.F.R. §21.908).

[5] *Request for Declaratory Ruling on the Use of Digital Modulation by Multipoint Distribution and Instructional Television Fixed Service Stations, Declaratory Ruling and Order ("Digital Declaratory Ruling"),* 11 FCC Rcd 18839 (1996).

would not be caused to other MDS/ITFS operations. In subsequent rulemaking proceedings, the Commission suggested it would approve new digital modulation types without test data provided there was a reasonable basis for concluding that a particular modulation would not cause interference to other MDS/ITFS operations.[6] Since establishing that policy, the Commission has permitted other digital modulation types,[7] including certain subsets of the OFDM modulation authorization requested by Clarity in its 1998 Petition.[8]

Discussion

A. 256 Tones Are Not Needed to Protect Other MDS/ITFS Services

In its Digital Declaratory Ruling, the Commission expressly declined to limit the types of digital technologies it would approve for MDS/ITFS by adopting inflexible technical regulations.[9] Instead, the Commission wisely ***encouraged*** the use of new digital modulation techniques, and established a flexible technology policy whereby advanced digital technologies would be authorized on a case-by-case basis.[10] Moreover, it indicated that it would approve without test data certain digital modulation types that were determined to be a subset of an already approved modulation type.[11]

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6 *See, Amendment of Parts 1, 21 and 74 to Enable Multipoint Distribution Service and Instructional Television Fixed Service Licenses to Engage in Fixed Two-Way Transmissions, Notice of Proposed Rulemaking,* at ¶ 30, 12 FCC Rcd 22174 (1997).

7 *See, Amendment of Parts 21 and 74 to Enable Multipoint Distribution Service and Instructional Fixed Television Service Licenses to Engage in Fixed Two-Way Transmissions, Report and Order,* cite at ¶ 23, 13 FCC Rcd 19112 (1998).

8 *OFDM Order* at ¶ 7.

9 Digital Declaratory Ruling cite at ¶

10 *Notice of Proposed Rulemaking* at ¶¶ 30, 31.

11 *See, Report and Order* at ¶¶ 23-25.

Clarity's 1998 Hardin Study included comprehensive laboratory test data, and a thorough analysis, demonstrating that OFDM modulations would not cause interference to other types of MDS/ITFS transmissions. That analysis used 256-tone and 4096-tone OFDM signals as examples. Since the Commission uses desired-to-undesired (D/U) signal ratios, and performance objectives related to spectral emission masks and spectral occupancy, to achieve interference protection, the Hardin Study used spectral shaping to generate "worst case" OFDM signals whose power spectral density completely filled the spectral mask in the Commission's rules.[12] The Hardin Study results show that even these "worst case" signals easily met the Commission's interference requirements. Practical OFDM signals, regardless of the number of tones used, would not fill the Commission's spectral emission mask and would be even more interference-benign.

On 19 March 1999, the Commission issued the OFDM Order granting Clarity's request for a declaratory ruling.[13] The Commission pointed out that many new services envisioned in its MDS & ITFS Two-Way Order, such as broadband Internet access, would depend on sophisticated digital transmission technologies. The Commission reasoned correctly that authorizing different modulations to serve different service requirements would be in the public interest. However, because the study and test data associated with Clarity's petition used 256-tone OFDM as the lower limit example, the Commission set 256 as the minimum number of QAM carriers that can be used for OFDM modulated signals.

Clarity, though, had failed to make clear that the 256-tone example was essentially arbitrary and selected only for the sake of convenience. It was not intended to

[12] 47 C.F.R. §21.908

reflect any impact on interference potential – and, in fact, it has none. An unintended consequence of Clarity's lack of clarity was that the Commission adopted a requirement that was likewise arbitrary and without effect on interference potential. Thus, the 256-tone limit needlessly constrains OFDM modulations that could yield greater efficiencies in MDS/ITFS operations.

B. Eliminating Tone Minimums Will Not Increase Interference Potential

As explained in the attached Technical Appendix, the number of tones chosen in the Hardin study was intended to be representative of a general range of OFDM signals that might be used in deployed MDS/ITFS systems. OFDM signals using other tone numbers could have been tested as well. However, this was thought to be unnecessary as varying the number of tones will have no effect on the OFDM signal's potential to interfere with other MDS/ITFS operations.

As noted, the spectral shaping was employed to generate "worst case" OFDM signals to prove that ***any*** OFDM test signal would comply with the Commission's interference requirements. This "worst case" spectral shaping could be applied to an OFDM signal with any number of tones and the co-channel test results would not change. That is because the signals would have equivalent power spectral densities. Therefore, the relationship of the number of tones and the potential to exceed the Commission's spectral mask and spectral occupancy requirements is not an issue. Consequently, other characteristics of the OFDM signal should be examined to determine the relationship between the number of tones used and the signal's interference potential.

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[13] *OFDM Order, supra.*

In the Technical Appendix, Cisco examines the peak-to-mean envelope power ratio (PMEPR) as a predictor of interference to co-channel operations.[14] In particular, the probability that the PMEPR for a given OFDM data burst exceeds a certain value in dBs is compared for OFDM signals with tones ranging from 128-2048 tones. This exercise reveals that the probability that the PMEPR exceeds a certain value decreases as the number of tones decreases. For example, the Commission already allows 256-tone OFDM. The Technical Appendix shows that at the 10^{-2} probability point the PMEPR value of a 128-tone OFDM signal is approximately 0.3 dB lower than that of the 256-tone signal.[15] Thus, the 128-tone signal would have <u>less</u> interference potential than higher-tone OFDM signals. However, it is interesting to note that in the OFDM signal range analyzed in the attached Technical Appendix, the spread of PMEPR values is only 1.2 dB.[16] Therefore, while the PMEPR is an important consideration in judging interference potential, the number of tones used in an OFDM signal has little effect on its value.[17]

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[14] The peak-to-mean envelope power ratio can be defined as the ratio of the instantaneous peak power value to the time-averaged power value of a signal. Consistent with the Hardin study, Cisco has examined the PMEPR of the modulating signal and has examined worse case OFDM signals spectrally shape to fill the Commission's spectral masks.

[15] Essentially, one could consider that this means the 128-tone signal would have less "power spikes" when compared to a higher-tone signal. However, we emphasize that even a 4096-tone OFDM signal will not cause interference.

[16] The range analyzed in the Technical Appendix spans from 128 to 2048 tones. However, it is important to note that the general relationship between number of tones and PMEPR established in the Technical Appendix is not limited to the range considered. In the Hardin Study, it was demonstrated that a "worst-case" 4096-tone OFDM signal easily complied with the Commission's interference rules. Additionally, as the number of tones falls below the 128-tone example and approaches "1-tone" OFDM, the PMEPR falls and at the extreme the time-domain characteristic of the 1-tone signal is essentially that of a QAM signal.

[17] Similarly, the symbol density (number of bits grouped and mapped to corresponding n-QAM constellations) has no bearing on the time-domain characteristics of the

Conclusion

As the Technical Appendix makes clear, the number of tones used in an OFDM signal has little bearing on that signal's interference characteristics. The spectral emissions masks and D/U signal ratios in the Commission's rules accomplish the real control of interference. Thus, the Commission's 256 QAM-modulated carrier requirement has no utility as a means of controlling potential interference from OFDM signal.[18]

On the other hand, removing the 256 QAM-modulated requirement opens up a new range of system implementation options. For example, the option of using different "number-of-tone" OFDM modulations would allow MDS/ITFS network designers to make important bandwidth and design trade-offs to meet customer bandwidth and cost requirements. For example, some customers may not need or have the ability to pay for a 3 MHz or 6 MHz channel, while a 1.5 MHz channel might suffice. The ability to use a lower-tone OFDM would allow the provider to optimize the network for a lower channel bandwidth.[19]

Throughout the administrative history of the use of digital transmissions in MDS/ITFS services, the Commission has provided the flexibility necessary to accommodate evolving digital technologies that do not increase interference potential.

OFDM signal and, therefore, no real effect on interference potential.. Figure 2 of the attached Technical Appendix shows that using 128-tone and 2048-tone OFDM signals as examples and mapping 4-QAM, 16-Qam and 64-QAM constellations onto each, the difference in PMEPR is practically indistinguishable. Technical Appendix at 7.

[18] The 258-tone requirement can be considered an unfortunate artifact of the example signals chosen in the Hardin Study.

[19] Conversely, higher-tone OFDM might still be used for higher bandwidth channels.

The request here is squarely aligned with that policy. By declaring that a minimum of 256 QAM-modulated carriers is not required for MDS/ITFS services, the Commission would not only allow designers to optimize their systems based on various channeling, but would also allow operators to provide at various price points a wider range of services to a greater number of consumers. To allow operators to make these services available immediately, the Commission should grant this request expeditiously.

Respectfully submitted,

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Technical Annex:

Interference Properties of OFDM Signals in MMDS vs. Number of OFDM Tones

Cisco Systems, Inc.

March 13, 2001

In its Declaratory Ruling and Order[20] the Commission authorized the use of OFDM as a permissible modulation format in the MDS/ITFS band. In doing so however, the Commission set a requirement that OFDM modulations be implemented with a minimum of 256 carriers or tones. The analysis below demonstrates that the number of tones in an OFDM signal essentially has no bearing on that signal's interference potential. Rather, the ability of a signal to meet the Commission's emission mask and desired-to-undesired signal strength ratios determines that signal's interference potential. Therefore, the minimum number of tones requirement is unnecessary. Eliminating this requirement would provide additional flexibility needed in designing and deploying OFDM systems for the MDS/ITFS band.

BACKGROUND:

The Commission based its decision to permit OFDM for use in the MDS/ITFS services largely on test data that demonstrated that OFDM signals would not cause harmful interference to analog video transmissions in the MMDS band. This data was submitted to overcome a perception that OFDM signals, due to their different time-domain peak to average signal characteristics, might have a greater interference potential compared to the previously authorized QAM signals. Testing was performed that demonstrated that under the Commission's desired-to -undesired signal strength ratio limits of 45 dB for co-channel signals and 0 dB for adjacent channel signals, OFDM would not cause harmful interference to NTSC video transmissions.

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[20] *Request for Declaratory Ruling on the Use of Orthogonal Frequency Division Multiplexing Modulation by Multipoint Distribution Service and Instructional Television Fixed Service Stations ("OFDM Order"),* DA 98-2129 (1999).

Verification testing was performed with two representative OFDM signals. One was composed of 256 tones with a QPSK symbol mapped to each tone. The other was a 4096-tone signal with a 64-QAM symbol mapped to each tone. The signals were chosen to be representative of the type of OFDM signals that might be transmitted by deployed MDS/ITFS systems. The test results demonstrated that interference would not be caused to other MDS/ITFS operations. Other OFDM signals could have been chosen and would have yielded essentially identical results.

However, restrictions on the total number of frequency channels available for initial system deployments and the desire to make as efficient use of the available spectrum as possible has necessitated subdividing individual MMDS frequency channels into multiple, narrower subchannels to a degree that was not contemplated when representative signals were chosen for testing. In order to use these narrower subchannels while maintaining other system performance requirements and architectures it is preferable to use fewer than the 256 tones required by the Commission for OFDM signals in the MMDS band.[21]

[21] The reason is that there is a design trade off between unwanted phase noise and physical layer (PHY-layer) overhead. To minimize phase noise, an OFDM burst should be made short. However, for any OFDM burst, a fixed amount of overhead must be used to mitigate multipath effects. This has an effect on throughput, suggesting a longer OFDM burst. For a given RF channel bandwidth, the number of OFDM tones is inversely proportional to the OFDM burst length. Consequently, once the trade-off is made and the burst duration is fixed, the number of tones must scale with the channel bandwidth. Thus, if for a given application it is more efficient

ANALYSIS:

Once the interference characteristics of OFDM signals are understood, it becomes clear that the Commission's minimum number of tones requirement is unnecessary since it has no bearing on interference potential. As the number of OFDM tones is reduced, the time-domain characteristics of the OFDM waveforms become more like QAM waveforms. This can be understood at an intuitive level by realizing that the degenerate case of an OFDM signal with a single tone corresponds to a QAM signal. Simulation of the interference characteristics of OFDM signals with fewer tones than the 256 tone minimum currently permitted by the Commission's rules show that lower-tone OFDM signals are more benign than those currently approved for use.

In Figure 1, below, peak-to-mean envelope power ratio (PMEPR) statistics, an important predictor of interference, are presented for OFDM waveforms with 128, 256, 512, 1024 and 2048 tones. Each curve represents the probability that the PMEPR for a given OFDM burst exceeds the value (in dB) given on the abscissa (x-axis). For example, the probability that the PMEPR of a 512-tone OFDM burst exceeds 10 dB is approximately 0.02.

As the Figure 1 illustrates, the probability of an OFDM burst having a large PMEPR is somewhat higher for OFDM signals composed of a larger number of tones.[22] Consider

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to divide the available frequencies into narrower subchannels, the number of tones must be reduced accordingly.

[22] Although this relationship exists, the spread of PMEPR is small and as demonstrated in the Hardin Study even a 4096-tone OFDM signal complies with the Commission's interference rules. *See, Engineering Statement in Support of a Petition for*

the 10^{-2} probability point on the graph. The spread of PMEPR values is 9.6 dB to 10.8 dB for 128-tone to 2048-tone OFDM signals, a difference of only 1.2 dB. Thus, for OFDM modulations, the number of tones does not strongly influence the signal's time-domain characteristics. In fact, fewer tones will tend to have slightly smaller time-domain peaks. Therefore, an OFDM signal with fewer tones will have less potential to interfere with co-channel signals.

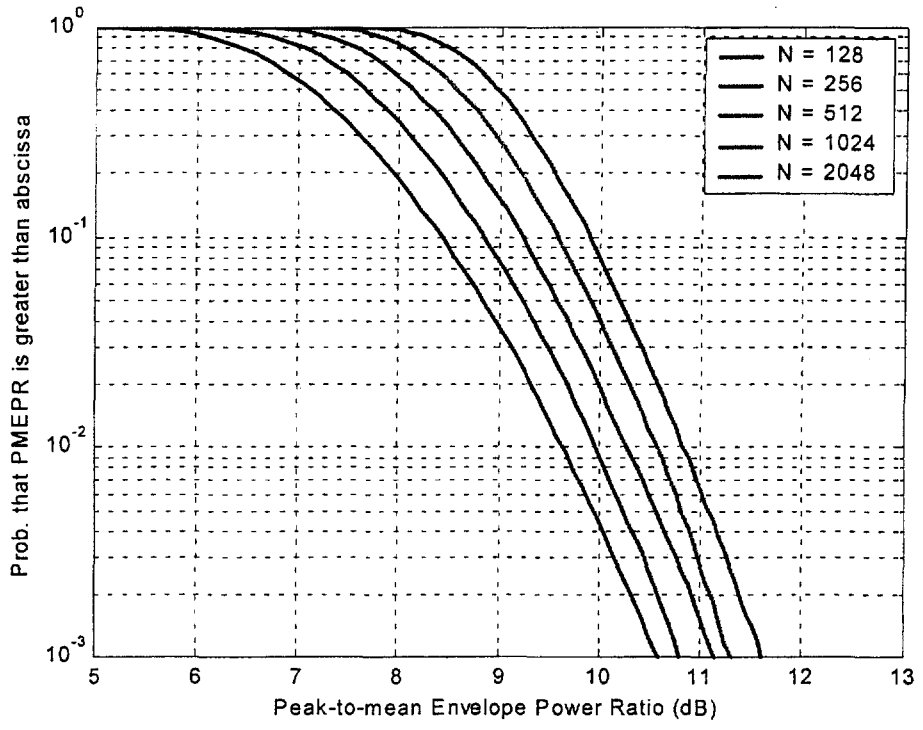

Figure 1: Peak-to-mean power ratio statistics for OFDM with 4 bits per tone, (16-QAM).

Declaratory Ruling on the Use of OFDM Modulation in MDS and ITFS Services, Hardin and Associates ("Hardin Study") (1998).

Simulations also demonstrate that the number of symbols used in the I-Q plane constellation have no effect on the interference characteristics of an MMDS signal. In OFDM, data bits to be transmitted are grouped together and then mapped to a constellation point in the I-Q plane. The constellation point (or symbol) is then applied to an OFDM tone where the tone's amplitude and phase are modulated according to the symbol's magnitude and phase. Typically, data bits are placed into groups of two, four, or six bits and mapped to the corresponding 4-QAM, 16-QAM, or 64-QAM constellations. However, the choice of I-Q plane constellation has no effect on the time-domain characteristics of an OFDM signal. This is illustrated in
Figure 2.

In Figure 2., PMEPR statistics are plotted for 128-tone and 2048-tone OFDM signals, each with 4-QAM, 16-QAM, and 64-QAM underlying constellations. In the figure, the curves for the different constellation densities overlap so closely for both the 128-tone and 2048-tone OFDM signals that they are virtually indistinguishable. Therefore, we can conclude that the underlying constellation density essentially has no effect on an OFDM signal's potential to interfere with other signals. So, while the original testing for acceptance of OFDM as an approved modulation type was performed with a 256-tone waveform with 4-QAM (or QPSK) and a 2048-tone waveform with 64-QAM, the chosen constellation was actually irrelevant.

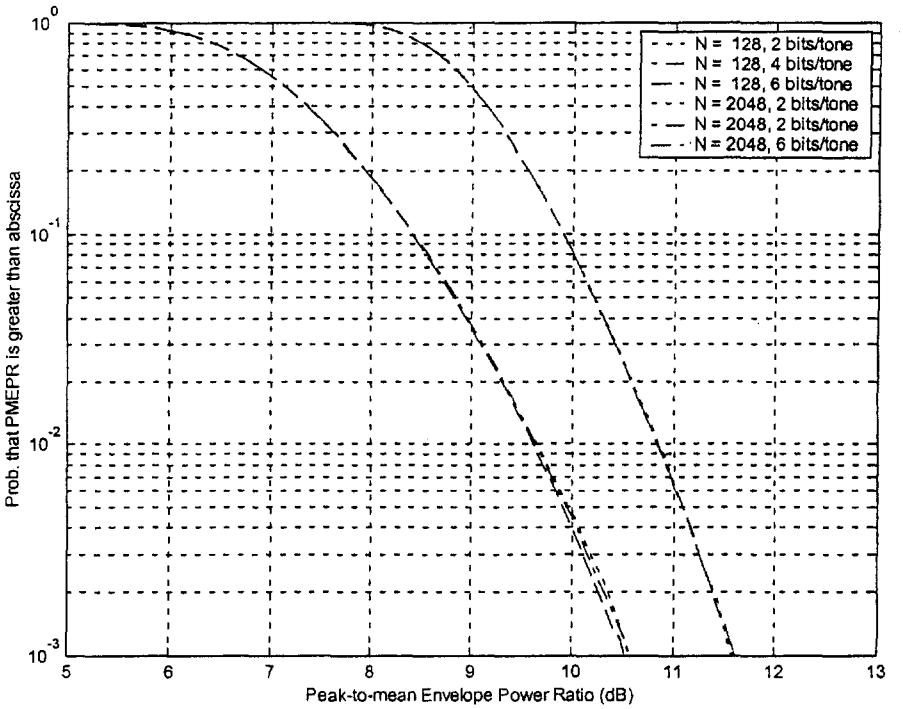

Figure 2: Peak-to-mean power ratio statistics for OFDM with various constellation densities.

More important than the characteristics of a specific OFDM signal, is the mechanism by which the Commission limits interference in the MDS/ITS bands. The Commission's rules limit interference by D/U ratios and by the emission masks that apply to all modulation types. These rules defining the MDS/ITFS emissions mask control the amount of power seen by receivers tuned to adjacent channels. A large amount of testing, using many modulation types, including OFDM, has validated the emissions mask limits' ability to protect adjacent channel users.[23] This is because the amount of

[23] *See, e.g., Declaratory Ruling and Order, 11 FCC Rcd. 18839 (1996) (where the Federal Communications Commission authorized the use of QAM and VSB modulations for MDS/ITFS. See also, Hardin Study.*

power falling in adjacent channels is identical for signals exhibiting the same emissions power spectral density characteristic which is defined by the emissions mask. Therefore, if any signal, including an OFDM signal, falls within the Commission's MDS/ITFS emissions mask and the appropriate D/U ratios are met, co-channel and adjacent channel MDS/ITFS signals will be adequately protected, independent of modulation type.

Further, for signals complying with the emissions mask, the time domain behavior of the power placed in the adjacent channel must exhibit relatively low PMEPR statistics. This is because any signal meeting the emissions mask will appear in the adjacent channel as a narrowband signal located at the band edge. The emissions mask rules dictate that the majority of the power spilling into the adjacent channel be contained in the first 250 kHz beyond the band edge – a relatively narrowband signal. Fourier principles show that a narrowband signal in the frequency domain corresponds to a relatively smooth signal in the time domain – or one with relatively small peaks.

Even if there were a concern, in contradiction to the discussion associated with Figure 1, that the signal's interference characteristics would vary unpredictably as the number of tones was reduced, the emission mask requirement would be sufficient to protect MDS/ITFS band users from harmful interference. This is another reason that the minimum number of tones requirement is unnecessary.

This paper demonstrates that as the number of tones and constellation density in an OFDM signal varies, there is very little effect on the signal's interference characteristics.

In fact, as the number of tones decreases, certain characteristics that could be considered primary indicators of interference potential become more benign. Consequently, the same conclusion the Commission has drawn based on testing in the Hardin Study of 256-tone and 4096-tone OFDM can be extended with confidence to OFDM signals that use lower tones. Therefore, the minimum tone requirement should be removed.