Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Establishment of an Interference Temperature	)	ET Docket No. 03-237
Metric to Quantify and Manage Interference	)	
and to Expand Available Unlicensed Operation	)	
in Certain Fixed, Mobile and Satellite	)	
Frequency Bands	)	

To: The Commission

COMMENTS OF VERIZON WIRELESS

John T. Scott, III
Vice President and Deputy
General Counsel – Regulatory Law

Charla M. Rath
Director – Spectrum & Public Policy

Verizon Wireless
1300 I Street, N.W., Suite 400W
Washington, D.C. 20005
(202) 589-3760

Donald C. Brittingham
Director – Spectrum Policy
Verizon Communications
1300 I Street, N.W., Suite 400W
Washington, D.C. 20005
(202) 5890-3785

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TABLE OF CONTENTS

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	)	
Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands	)	ET Docket No. 03-237

To: The Commission

COMMENTS OF VERIZON WIRELESS

Verizon Wireless hereby submits its comments in the above-referenced proceeding.[1] As detailed below, Verizon Wireless submits that the interference temperature concept outlined in the *NOI* is not technically sound and cannot be supported by any proper economic analysis. The Commission, therefore, should not create any artificial interference "temperature," "boundary," or "cap" in exclusive use, geographically licensed spectrum. Instead, it should reaffirm rather than abandon its long-established policy of giving licensees exclusive and flexible use of their spectrum, and refocus its efforts on further clarifying and strengthening those rights. This course will promote the public interest goals of efficient spectrum use that best serves customers. Imposing any interference temperature would, in contrast, block efficient spectrum use and thereby harm the public interest.

[1] *Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands,* ET Docket 03-237, *Notice of Inquiry and Notice of Proposed Rulemaking,* 18 FCC Rcd 25309 (2003) ("*NOI*"), *summarized*, 69 Fed. Reg. 2863 (Jan. 21, 2004), *correction,* 69 Fed. Reg. 5945 (Feb. 9, 2004).

INTRODUCTION AND SUMMARY

On November 13, 2003, the Commission released the interference temperature *Notice of Inquiry and Notice of Proposed Rulemaking ("NOI")* to consider policies that would authorize "underlay" operations in licensed spectrum bands – potentially including commercial mobile radio service ("CMRS") bands that are currently licensed for exclusive use by Verizon Wireless and other wireless carriers. To allow "opportunities for other transmitters . . . to operate in [a] band," the Commission sought comment on the adoption of "an upper bound or 'cap'" on these underlay transmissions.[2] The *NOI* strained to suggest this would benefit existing licensees too, by providing "greater certainty regarding the maximum permissible interference."[3] But the only certainty in the interference temperature proposal is that it would take away rights from existing licensees and assign them to unlicensed operators. The proposal is based on faulty engineering theories that, if implemented, would seriously impede the efficient use of spectrum by current geographic based, exclusive use licensees and undermine consumer welfare to the tune of billions of dollars.[4]

The interference temperature concept assumes there is some definable, empty space between the ambient noise in a particular band and the power at which the existing licensee operates. Under the something-for-nothing logic of the *NOI*, the Commission would carve out this useful but allegedly unused bandwidth from existing licenses and allocate it for use by unlicensed devices. The 550 MHz of spectrum already devoted to unlicensed uses below 6 GHz apparently is not enough; under the *NOI's* concept, unlicensed users could access, as well, the

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2 *Id*. at ¶ 1.

3 *Id*.

4 *See* Comments of Thomas Hazlett and Matthew Spitzer, *Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands,* ET Docket No. 03-237 (filed Apr. 5, 2004) (hereinafter "Hazlett and Spitzer").

roughly 190 MHz currently used by CMRS providers to serve a growing base of 150 million customers.

But the *NOI*'s technical premise insofar as it would encompass CMRS spectrum is completely false: Existing CMRS licensees are investing huge sums of money to use their spectrum efficiently; there is no empty white space that would permit the opening of spectrum to underlays in the manner the FCC proposes. The interference temperature proposal would inflict significant harm to the existing network, impede the deployment of high-speed wireless technologies such as Verizon Wireless' EV-DO, and impose large economic costs going forward.

The *NOI* labors to present the interference temperature proposal as a mere attempt to formalize a boundary that already exists, between licensed use and background "noise." But there is a profound difference between inadvertent or unintentional interference and the deliberate introduction of new transmitters operating in spectrum bands that are currently licensed exclusively to others. Noise is something everyone in the industry collaborates to reduce – no one more so than licensed service providers, because the quieter their spectrum, the more service they can sell. The *NOI*'s proposal is not about tolerating noise, still less about suppressing it – the *NOI* proposes to formally authorize it, and approve more of it.

The *NOI* proposes a concept that is not only technically unsound, but cannot be supported by economic analysis. It represents a radical and unjustified reversal of well-established, successful policy. For example, in the cellular, ESMR, and PCS proceedings over the last two decades, the Commission has promoted efficient use of spectrum by issuing licenses that provide wireless carriers the authority to determine on what terms cell phones, pagers, wireless modems, and so forth, will transmit and receive in each band licensed to each carrier. Over the years, the Commission has taken similar action in many other bands, increasing licensee flexibility and espousing market forces as the best means to ensure efficient use of spectrum. Here too, the *NOI* pays lip service to licensing schemes that assign spectrum "on a geographic basis," giving licensees "flexibility to determine the types of services and the technologies and technical implementation designs used to provide those services."[5] The *NOI* then proposes, however, to limit and curtail licensee choice of technology, licensee flexibility, and licensee authority to determine which services will be offered, and by whom. The *NOI* does not explain why efficient use will be promoted by having the Commission seize control of transmissions in these same bands that fall below some "low power" threshold that the Commission now proposes to define for the first time. The *NOI* fails to examine the economic, cost-benefit considerations – including opportunities foreclosed to existing licensees – that would necessarily result. Such an analysis is an essential predicate to reversing long established policy – policy that existing licensees have relied on in making the multi-billion dollar investments in spectrum, R&D, network equipment, and service development that have spurred innovation and created a robust, vibrant, fast-growing market for wireless services.

The Commission should instead give existing licensees the flexibility to reduce noise, lower the power of their own transmissions, collaborate with equipment vendors to develop new devices suitable for very-low-power operations, and engage in secondary-market transactions as appropriate to facilitate the shared use of licensed spectrum.

For these reasons the companion *Notice of Proposed Rulemaking ("NPRM"),* which would apply the interference temperature concept to specific bands, is premature as well as ill-advised. Proposing rules to adopt a specific temperature in two spectrum bands, before the

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[5] *NOI* at ¶ 6.

concept of interference temperature is even thought through, is classic cart-before-the-horse policymaking.

I. THE INTERFERENCE TEMPERATURE CONCEPT IS TECHNICALLY INVALID AND SHOULD BE REJECTED.

Interference temperature is a pure regulatory invention – created out of the blue in the Spectrum Policy Task Force Report (*"SPTF Report")* and a staff working group report[6] - that attempts to mix practical, real-world engineering - implicit in "interference" – with the pure physics of "temperature." It assumes that existing licensees transmit only at relatively high power, that they fail to fully occupy the geographic contours that their licenses authorize them to occupy, or that they occupy this spectrum space only part of the time. The *NOI* assumes that the RF environment is inherently noisy, that licensees use technology that not only accepts existing noise levels but operates at power levels well above them, and that there is therefore substantial room for a new class of opportunistic transmitters. As discussed below, and in the attached Declaration of Dr. Charles L. Jackson and the separate comments of V-COMM, L.L.C., these premises are diametrically contrary to fact for CDMA 2G systems and all 3G systems. In addition to the specific issues we raise below, Dr. Jackson explains in his Declaration how the interference temperature *NOI* contains several flaws: it is based on an obsolete system architecture; the analysis of interference is incorrect; and the interference temperature concept itself has fundamental flaws. Further, the *NOI* fails to quantify the losses created by increased interference.

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6 *See* FCC, Spectrum Policy Task Force, Report of the Interference Protection Working Group, Nov. 12, 2002, at 12-13.

A. CMRS Systems Are Designed to Fill the Available Spectrum Space.

The *NOI* posits that there is some existing peak noise level that is currently tolerable in each licensed band, that this peak can be defined by a single, simple metric like temperature, and that so long as new unlicensed users do not make things any noisier than the current acceptable peak, existing licensees will not notice the difference. The *NOI*'s Figure 1 attempts to portray this logic graphically.[7] It is completely divorced from engineering reality.

For example, the CDMA systems that have been widely deployed, at great expense by companies like Verizon Wireless, use advanced power control algorithms to operate at levels that are just high enough to operate with the noise and interference in the vicinity of the mobile device and cell site. CDMA transmitters adjust power levels 800 times per second – to ensure that only the minimum power necessary is used to maintain a connection.[8] Verizon Wireless and other CDMA carriers continuously invest and upgrade to extend service down into the spectrum space that the *NOI* presumes is empty. The "margin" that the *NOI* posits can be used to accommodate underlay devices is the margin that CDMA technology was expressly developed to fill.[9] Furthermore, noise levels will continue to fall. CDMA technology is continuously improved to further expand the capacity of the system, to serve more customers, to provide greater service reliability at the edge of cell sites, to provide in-building coverage throughout the service area, and to support the growing demand for wireless broadband services.

These are not theoretical assertions. They are backed up by direct, real-world measurement. V-COMM, a wireless telecommunications consulting company experienced in RF

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7 *See NOI* at ¶ 15.

8 *See* Exhibit A, Declaration of Charles Jackson at 7 (hereinafter "Jackson Declaration").

9 Verizon Wireless deploys CDMA technology – the most spectrally efficient mobile technology available today – in cellular and PCS bands.

engineering and wireless system design, has conducted extensive spectrum noise studies in the cellular and PCS bands over the past several years.[10] These studies were conducted in a variety of diverse market conditions, including dense urban, suburban, and rural markets. Noise floors and current radio environments in which CMRS providers operate were precisely measured at each location over a 24-hour period. The measurements show very low operating noise floor conditions. In the cellular band, for example, interference levels were measured from -127 dBm to -119 dBm, with an overall operating noise floor average of -126 dBm. For PCS, interference levels were measured from -129 dBm to -123 dBm, with an overall operating noise floor average of -128 dBm. These noise floor averages are only slightly above the thermal noise floor of -129 dBm at (300K, 30 kHz bandwidth).

Thus, as Dr. Jackson describes, the *NOI's* Figure 1 is squarely at odds with CDMA engineering reality.[11] There are no areas in which a CDMA signal is significantly more powerful than is needed to penetrate ambient noise levels. CDMA transmitters do not attempt to stay above some average "interference temperature" – they ratchet down their own power to transmit as quietly as they possibly can, however quietly that may be. Drawn properly to reflect CDMA engineering reality, the *NOI's* Figure 1 would lose all its white space:[12]

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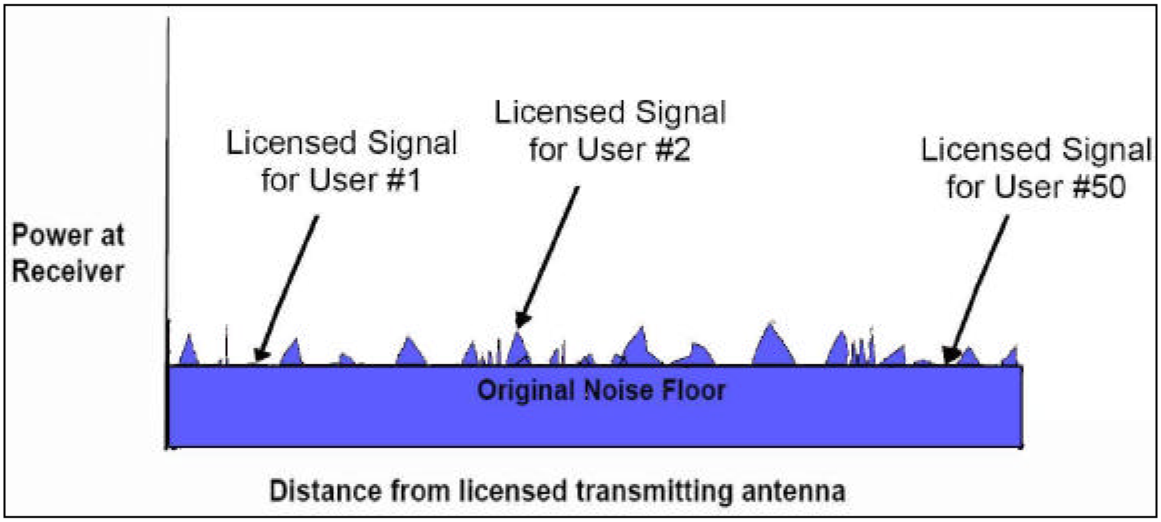
10 *See* Comments of V-COMM, L.L.C., *Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands*, ET Docket No. 03-237 (filed Apr. 5, 2004) at 3, 11-15 (hereinafter "Comments of V-COMM").

11 *See* Jackson Declaration at 4-5, 7-8.

12 *Id.* at 9-10, Figure 4.



In sum, the CDMA technology already deployed by existing licensees has been deliberately designed to do precisely what the *NOI* wants to accomplish. The interference temperature concept will thus be useless in bands using this technology. Worse, it will actually harm existing services.

B. Existing Licensees Are Steadily Reducing Noise Levels.

CDMA technology gives existing licensees powerful incentives to lower the noise floor in the CMRS spectrum bands. Through deliberate, expensive improvements, that is exactly what CMRS providers have been doing.[13] As a direct result, today's CMRS base stations and mobiles operate at significantly lower power levels than previously employed. Spectral efficiencies have improved year by year. In 2003, for example, Verizon Wireless completed its implementation of cdma2000 1xRTT technology, which provides a two-fold increase in spectral efficiency over earlier CDMA systems, and initiated its deployment of cdma2000 1xEV-DO technology, which provides further increases in efficiency and allows for the introduction of broadband wireless services.

13 *See* Comments of V-COMM at 16-19.

V-COMM's measurements confirm that noise levels in CMRS bands have been going down, not up, even as the number of base stations and wireless devices has continued to increase.[14] This trend will need to continue if operators expect to meet the growing demands for wireless services, especially high-speed data services.[15] In short, licensees are finding new ways to "mine" existing spectrum, resulting in steadily more efficient, intensive use. The *NOI's* proposal would stop this consumer-benefiting trend in its tracks.

C. The Interference Temperature Concept Would Not Provide Adequate Interference Management.

The *NOI* implicitly assumes that interference temperature can be set by taking measurements at some small number of locations, most particularly, at the locations where the new, unlicensed transmitters happen to be. The *NOI* posits that unlicensed devices will continuously monitor the ambient "temperature," and transmit only when their immediate surroundings are suitably "cool." But again, the proposal is squarely at odds with engineering reality.[16] Its flaws are particularly obvious in the context of mobile services.

How exactly will any reasonably-priced autonomous device distinguish between noise and traffic in CMRS bands?[17] Current CDMA systems transmit over a 1.25 MHz wide band and each base station typically transmits between 10 and 40 traffic channels, each spread across that band.[18] The number and strength of the signals changes whenever calls begin and end, and whenever callers move. To differentiate between ambient noise and ambient licensed signal and calculate the temperature of each, an unlicensed device must ascertain energy levels in every one

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[14] *Id*. at 7, 16.

[15] *Id*. at 19.

[16] *See* Jackson Declaration at 13-19; Comments of V-COMM at 47-51.

[17] *See* Jackson Declaration at 13-15.

[18] *Id*. at 14.

of these traffic channels.[19] To do that, the device must – at the very least – *pick up* all 40 signals. It must, in other words, perform more or less the same reception function as 40 licensed CDMA devices.[20] Because the energy from each traffic channel is spread over the entire 1.25 MHz bandwidth, if the unlicensed device cuts any corners – by, for example, ignoring half the channels – it could end up interfering with all of them.

Moreover, noise levels and interference depend on where the transmitter and receiver are, and of course vary from one moment to the next.[21] Any crude spatial or temporal averaging will provide no useful protection against interference.[22] There may be, for example, a clear transmission path between a source of interference and a licensed receiver, but an obstructed path between the source of interference and the underlay monitoring equipment. Since the obstruction hides the interference source from the measuring device, the interference source is a "hidden node."[23] The interference temperature at the licensed receiver will in fact be substantially higher than the measuring device discerns, the underlay device will go ahead and transmit, and the licensed receiver will lose its connection.

Finally, the additional noise that an unlicensed transmitter may add depends strongly on how close it is to the nearest licensed receiver.[24] Without complete, accurate information about where everything is, every unlicensed transmission will be, as Dr. Jackson explains, a pure gamble.[25]

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[19] *Id.*

[20] *Id.*

[21] *See generally* Jackson Declaration at 17-19; Comments of V-COMM at 47-51.

[22] *See* Comments of V-COMM at 47-51.

[23] Also referred to as a "hidden terminal."

[24] *See* Jackson Declaration at 15-16.

[25] *Id.*

D. The Interference Temperature Concept Would Significantly Increase Interference to CMRS Networks.

The V-COMM study systematically assesses the impact of the Commission's interference temperature proposal on the coverage and capacity of a CMRS system. The study examines the interference potential in urban, suburban and rural markets, and considers the impact for a variety of interference scenarios ranging from one where the interference is 11 dB below the internal system noise floor (an increase in the total cumulative system noise floor of only 0.33 dB) to one where the interference is at the noise floor (an increase in the total cumulative system noise floor of 3 dB).[26] Under this last scenario, the system noise power level is increased by 100 percent.

V-COMM concludes that, even under these seemingly low levels of interference, the impact on CMRS systems would be little short of disastrous to CDMA customers. Under the 3 dB scenario, CDMA coverage would be reduced by as much as 32 percent in urban markets and 38 percent in rural markets.[27] The cell site capacity of the CDMA system would be reduced by as much as 61 percent.[28] Faced with these significant levels of interference, a CMRS operator would have two choices – either provide poorer quality service (reduced coverage, serving fewer customers) or construct additional cell sites to overcome the new sources of interference. V-COMM estimates that a CMRS operator would have to increase its cell sites by 1.5 times to provide comparable coverage, and 2.5 times to make up for needed capacity.[29] This would entail as much as a 390 percent increase in capital and operating costs.[30]

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26 Comments of V-COMM at 55.

27 *Id.* at 56, Table 3.

28 *Id.*

29 *Id.* at 56.

30 *Id.* at 58-59, Table 7.

The interference temperature concept would also have a significant adverse impact on the provision of high-speed data and other broadband wireless services – services of great interest to consumers, because they enable wireless connections at speeds that are competitive with DSL and cable. Increased interference would result in decreased system throughput, increased latency, and reduced reliability.

Like all high-speed wireless broadband services, EV-DO requires extremely efficient use of all available spectrum. A cdma2000 1xEV-DO system delivers peak data rates of 2.4 Mbps. But these systems, and all 3G wireless systems, operate by intense use of the radio spectrum and can attain these rates only by tailoring the transmissions to the available radio path. For a user in an office with a window facing a nearby base station, EV-DO will establish a 2.4 Mbps link. For another user at the edge of a cell, the system may only be able to establish a much slower, 240 kbps, connection. Doubling the system noise temperature would cut both rates by 50 percent.[31]

In sum, V-COMM's estimates of likely harms of raising the interference temperature are probably much too low. Unlicensed devices cannot be controlled, and once they are permitted to operate there is no way to limit their proliferation. In this regard, the harm to CMRS systems would be permanent since there would be no ready or easy means for recalling the unlicensed devices once they are out in the market.

II. THE INTERFERENCE TEMPERATURE CONCEPT CANNOT BE SUSTAINED UNDER ANY PROPER ECONOMIC ANALYSIS.

The *NOI* focuses exclusively on the introduction of autonomous devices using new low-power technologies – including agile radios, smart antennas, software defined radios, and other "opportunistic devices." The *NOI,* however, ignores the fundamental reality that wireless

[31] *See* Jackson Declaration at 28-29.

communications companies like Verizon Wireless have every economic incentive to deploy innovative technologies or undertake leasing arrangements that will allow them to achieve even more intensive use of their spectrum. If lower power devices can convey more traffic, allowing more users on its licensed spectrum, Verizon Wireless has every incentive to pursue such technologies. By ignoring these economic realities, the *NOI* implicitly, and erroneously, assumes that the interference temperature construct is a better spectrum management tool than marketplace drivers.

A. Application of the Interference Temperature Concept in Geographically Licensed Spectrum Would Reverse Long-Standing and Successful Spectrum Policies.

The interference temperature proposal marks a sharp break from established – and altogether successful – spectrum policy. For the last two decades, the Commission has endeavored to put in place market-driven procedures and then step back from what its own economists call the "shortages and waste" that the administrative allocation of spectrum entails.[32] The *NOI* itself approvingly summarizes that policy as one of assigning licenses "on a geographic basis" and giving licensees "flexibility to determine the types of services and the technologies and technical implementation designs used to provide those services."[33] In the *Secondary Markets* decision adopted last year, the Commission took important steps "to facilitate significantly broader access to valuable spectrum resources" by enabling spectrum licensees to

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[32] *See* Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, FCC Office of Plans and Policy Working Paper Series (November 2002) at iv (hereinafter "Kwerel and Williams"); Hazlett and Spitzer at 31-36. The one – very limited -- recent departure from that consistent policy was in the ultra-wideband proceeding. *See Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, *First Report and Order*, 17 FCC Rcd 7435 (2002), *reconsid. granted in part and denied in part*, 18 FCC Rcd 3857 (2003).

[33] *NOI* at ¶ 6.

enter into spectrum leasing arrangement with "a wide variety of facilities-based providers of broadband and other communications services."[34]

The economic literature has consistently endorsed these policies of strong spectrum rights and flexible use.[35] The Commission's own economists agree that such policies produce large efficiency gains, because they (a) give spectrum users incentives to internalize most of the costs and benefits of their actions, and (b) minimize coordination and other transaction costs.[36] To that end, the Commission has embraced the geographic-based, exclusive use licensing model that grants the licensee sole use of its assigned spectrum and the flexibility to "mine" the spectrum to the maximum extent feasible, subject to interference restrictions. The exclusive use licensing model increases the value of spectrum, fosters the development of innovative equipment and services, provides certainty to the capital markets, and facilitates the creation of secondary markets – all to the benefit of U.S. consumers of wireless services.

Relying on these long-standing and well-established rights, Verizon Wireless has invested billions of dollars in new capital equipment every year to make increasingly efficient use of its licenses. These investments have permitted Verizon Wireless to continuously expand both its customer base – nearly forty million customers at present – and the total volume of

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34 *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, Report and Order and Further Notice of Proposed Rulemaking*, 18 FCC Rcd 20604 (2003) at ¶ 2.

35 *See, e.g.*, Ronald Coase, *The Federal Communications Commission*, 2 J.L. & ECON. 1 (1959); Arthur S.De Vany *et al.*, *A Property System for Market Allocation of the Electromagnetic Spectrum*, 21 STAN. L. REV. 1499 (1969); Douglas Webbink, *Radio Licenses and Frequency Spectrum Use Property Rights*, COMM. & THE LAW 4 (1987); Gregory Rosston and Jeffrey Steinberg, *Using Market-Based Spectrum Policy to Promote the Public Interest*, 50 FED. COMM. L.J. 87 (1997); Thomas Hazlett, *The Wireless Craze, the Unlimited Bandwidth Myth, the Spectrum Auction Faux Pas, and the Punchline to Ronald Coase's "Big Joke": An Essay on Airwave Allocation Policy*, 14 HARV. J.L. & TECH. 335 (2001).

36 *See* Kwerel and Williams at 5; *see also* Hazlett and Spitzer at 18-21.

wireless traffic it handles. Hazlett and Spitzer calculate that under these policies the wireless service market as a whole has created consumer benefits worth some $900 billion.[37]

While disclaiming any intention to do so, the *NOI* unequivocally backs away from this market-oriented approach, and embraces, once again, technology preferences and "command and control" regulation. Exclusive use is out, in at least part of the band; sharing – under highly technical terms and conditions to be minutely prescribed by the FCC – is back in. As a result, application of the interference temperature concept would unlawfully strip licensees of the exclusive use rights and flexibility granted with their licenses, and effect an unconstitutional taking. The Commission would be unlawfully granting access to licensees' spectrum to other parties and enabling those parties to reap the benefits of an asset held by the licensees.

B. Application of the Interference Temperature Concept in CMRS Spectrum Is Not Economically Justifiable.

Spectrum is already shared, of course – as Hazlett and Spitzer point out, it is shared by the existing licensees and their tens of millions of customers.[38] The interference temperature concept would create mechanisms to produce new communications services only by sacrificing other wireless services of proven significance to consumers.[39] And the consumer welfare costs of applying the interference temperature concept in CMRS spectrum would exceed, by billions of dollars, any possible gains in the CMRS band. Even a .33 dB increase in noise from current levels would reduce current capacity on CDMA networks by 5 percent; a 1 dB increase would reduce capacity by 16 percent.[40] Hazlett and Spitzer calculate that to overcome a minimal .33 dB increase in noise would require $2.2 billion in additional capital expenditure for a hypothetical

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37 *See* Hazlett and Spitzer at 33.

38 *Id*. at 33.

39 *Id*. at 3-4.

40 *Id*. at 38, Table 3.

CDMA carrier. A 1 dB increase in noise would require a capital expenditure of $7.4 billion to overcome. This calculation does not estimate the industry-wide costs let alone the resulting harm to consumer welfare.[41]

The adverse impact would be even greater going forward. As already noted, existing licensees currently devote enormous resources to expand usage across the entire spectrum, including low power portions.[42] Verizon Wireless has made the huge investments in spectrum-efficient CDMA technology precisely *because* Verizon Wireless's own engineers understand that this technology permits them continuously to expand output system wide. Verizon Wireless has the most powerful incentives *today* – under the market-based, flexible use regulatory scheme *already* in place – to continuously expand the number of users and devices – laptops, personal digital assistants, smartphones, machine-to-machine monitoring devices, and cellular telephones – that communicate in "Verizon Wireless" spectrum.[43] If lower power devices can convey more traffic, for more users in these bands, Verizon Wireless has every incentive to get equipment vendors to build such devices, and to encourage Verizon Wireless's own customers to buy, and use them within Verizon Wireless's already licensed bands. Verizon Wireless likewise has every incentive to pursue more intensive use of its licensed spectrum under leasing arrangements, where economically efficient.

Verizon Wireless also has every incentive to continue *lowering* the noise levels that the *NOI* treats as fixed – as Verizon Wireless has been doing almost since the day it began building its network. Had the Commission set an interference temperature at some earlier date, based on noise levels prevailing at that time, Verizon Wireless's own expansion into the lower-noise space

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41 *Id*. at 41, Table 5.

42 *See* Comments of V-COMM at 6-7, 16.

43 *See* Hazlett and Spitzer at 34.

would have been seriously impeded. In the years since, Verizon Wireless would have been spending heavily, instead, just to maintain the (much lower) output and service quality that were possible back then. Going forward, the harms from setting an interference temperature are just as great, if not greater. As described above, EV-DO is a concrete technology, incorporated in a concrete business plan, with the market roll-out already underway, that makes the fullest use of available spectrum that is technically possible today. The *NOI*, by contrast, assumes that the Commission can concoct better spectrum-management practices that produce greater consumer benefit than can companies competing in the highly competitive wireless communications market. Without any foundation for doing so, the *NOI* assumes that licensees – including many companies that bid and paid for right to use the spectrum – have somehow ended up using it far less efficiently than it would be used by companies that never showed up for auctions at all. As Hazlett and Spitzer have shown, this assumption is invalid.

C. The Commission Should Confirm the Importance of Market-Oriented Spectrum Management Models.

The Commission's fundamental objective should be an interference temperature as close to zero as possible. This is of course unattainable in the real world, but regulatory policy should consistently press in favor of stronger spectrum rights, not weaker ones. Rather than prescribe an unworkable, regulatory interference temperature, the Commission should strongly reaffirm the integrity of geographic, exclusive use licenses. Any other approach, however dressed up, is simply one of picking winners and losers among technologies, equipment vendors, network architectures, and service models. The Commission should stick to the technical neutrality it has so often endorsed heretofore.

If alternative system designs can make better use of existing bands than the ones currently deployed, market forces will impel existing licensees to adopt such systems and to facilitate their support by equipment vendors, and use by customers. Market forces already give licensees every incentive to make efficient trade-offs;[44] market forces should determine how sharing arrangements are created, monitored, and adjusted going forward. This is exactly the direction the Commission has taken in its *Secondary Markets* proceeding. This will achieve the benefits the *NOI* seeks to promote, with none of the harms.

III. THE *NPRM* IS PREMATURE AND SHOULD BE TERMINATED.

The nature of the questions posed in the *NOI* demonstrates that the Commission is exploring a purely theoretical concept at this time which could, in its view, constitute a "fundamental shift in spectrum management."[45] Nonetheless, the Commission is forging ahead with an *NPRM* seeking comment on technical rules to introduce the interference temperature approach in the 6525-6700 MHz and 12.75-13.25 GHz bands.[46] Verizon Wireless believes that it is premature for the Commission to issue an *NPRM* here at the same time it adopts an *NOI* to shed light on whether the underlying theory is even technically feasible, let alone worthwhile. The Commission should terminate the *NPRM* portion of this docket.

The Commission does not know how to define interference temperature or even how to measure the effects that an interference temperature approach would have. It is self-evident that moving forward with the *NPRM* would illogically (and wrongly) put the cart before the horse. As Commissioner Adelstein recognized, "it is quite premature to actually discuss proposed rules when the Commission has not even engaged in a preliminary discussion on the interference

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44 *Id.*

45 *NOI* at ¶ 19. The Commission, for example, asks commenters to address what "elements should the Commission consider in setting temperature limits for different bands and locations" and what "if any, technical factors (*e.g.*, power, field strength at boundary areas, antenna requirements) should be considered in determining the 'interference temperature' limits for a given service, frequency band and geographic area."[45] *Id.* at ¶ 21.

46 *See id.* at ¶ 29.

temperature approach as a whole."[47] The Commission must confront the difficult concepts involved in the evaluation, implementation, and measurement of the interference temperature metric, *before* it could even consider an interference temperature rulemaking.

CONCLUSION

For the foregoing reasons, the Commission should not create any artificial interference "temperature," "boundary," or "cap" in exclusive use, geographically licensed spectrum. Instead, it should reaffirm its long-established policy of giving licensees exclusive and flexible use of their spectrum, and in this light, refocus its efforts on further clarifying and strengthening those rights. The Commission should also terminate the *NPRM* without action.

Respectfully submitted,

VERIZON WIRELESS

By: /s/ John T. Scott, III
John T. Scott, III
Vice President and Deputy
General Counsel – Regulatory Law

Charla M. Rath
Director – Spectrum & Public Policy

Verizon Wireless
1300 I Street, N.W., Suite 400W
Washington, D.C. 20005
(202) 589-3760

Donald C. Brittingham
Director – Spectrum Policy
Verizon Communications
1300 I Street, N.W., Suite 400W
Washington, D.C. 20005

Date: April 5, 2004

[47] *Id*. (separate statement of Commissioner Jonathan S. Adelstein Approving In Part, Concurring In Part).

EXHIBIT A

Declaration of

Dr. Charles L. Jackson

regarding

Limits to the Interference Temperature Concept

April 4, 2004

Prepared for Verizon Wireless

Table of Contents

1. Summary

The analysis in the FCC's Interference Temperature Notice of Inquiry contains several flaws:

- It is based on an obsolete system architecture,
- The analysis of interference is incorrect,
- The interference temperature concept has fundamental flaws,
    - interference temperature cannot be defined in analogy to noise temperature,
    - monitoring interference temperature is impracticable in CDMA bands,
    - more generally, combining interference temperature with underlay device operation poses insurmountable practical challenges,
- The benefits of underlay operation are limited, and
- The Notice fails to quantify the losses created by increased interference.

Basic theory and system engineering each provide tools to quantify the losses from increased interference. Both tools show that any significant increase in interference will impose enormous costs on cellular/PCS service providers and their customers. A cost estimate based on Shannon theory indicates that a 3 dB increase in interference above the thermal noise level would be equivalent to loss of one-third to one-half of a cellular/PCS system's radio spectrum. Cost estimates based on CDMA engineering models using today's technology indicate that a 3 dB increase in interference would require a 50% increase in the number of bases if capacity were to be preserved.

Despite these flaws, the Notice does contain a fundamental insight of value. The FCC should monitor the degradation of the radio spectrum due to interference created by out-of-band emissions by poorly-maintained authorized transmitters and by the multitude of consumer electronic devices—such as computers, video games, PDAs and wireless LANs—and, if necessary, take further action as necessary to prevent harmful increases in such interference.

2. Introduction

Figure 1 from the Commission's Notice of Proposed Rulemaking (Notice), reproduced below, provides a good tool for understanding the implications and flaws of the interference temperature concept. It shows a situation in which a transmitter, located at the left side of the figure, emits a radio signal that weakens with distance to the right. The curve labeled "Licensed Signal" represents the weakening licensed signal. The rectangular blue region (dark grey in black and white copies of this document) at the bottom of the figure illustrates the distribution of natural noise power with location.

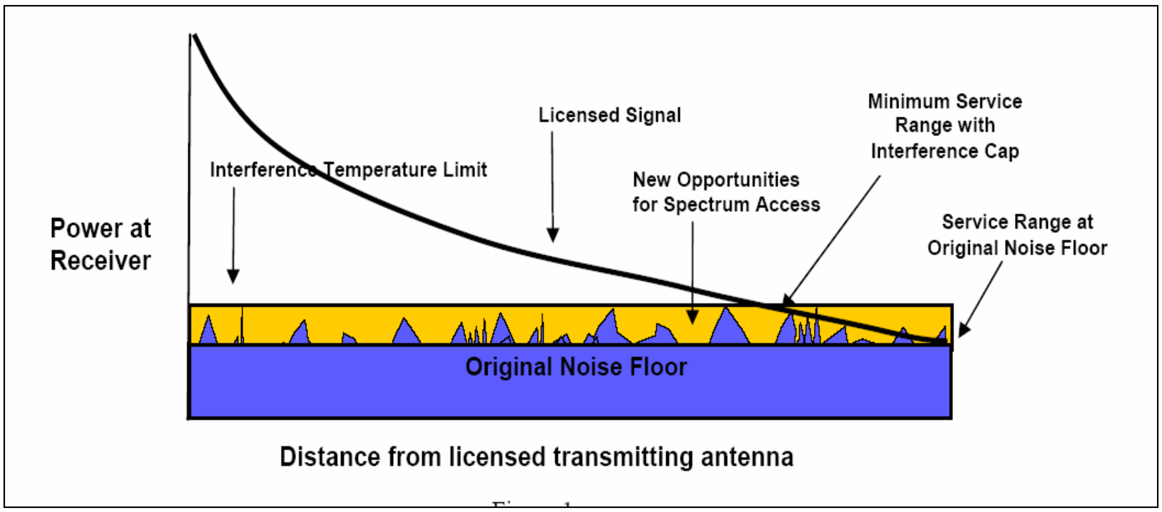

Figure 1. Figure 1 from the Notice

Even before humans began operating radio systems, there was noise all across the radio spectrum. The familiar crackle of static that comes into an AM receiver when lightning appears nearby is a common example of such noise. Many other natural phenomena also generate static or radio noise. The circuits in a radio receiver add noise as well. The combination of natural noise and receiver-generated noise that occurs in a specific receiver is often called the *noise floor*. Typically, the noise floor does not vary significantly by location.

In Figure 1, a number of jagged areas—looking a little bit like mountain peaks—jut up from the noise floor. These represent areas where man-made devices—such as hair dryers or transmitters on adjacent bands—generate small amounts of interference.

The orange area (light grey in black and white copies of this document) shows how much more interference would be added if the worst external interference were matched everywhere.

As the figure is drawn, a point receives service from the transmitter if the black line, marked *licensed signal,* is above the blue area. Originally, service extended all the way to the right side of the solid blue block. But, with the addition of man-made interference there are a few locations, on the right-hand side of the figure, where the combination of noise and interference makes the licensed signal unusable—that is, where harmful interference occurs. Figure 2 points out with circles the regions of the figure from the Notice where man-made interference limits coverage.

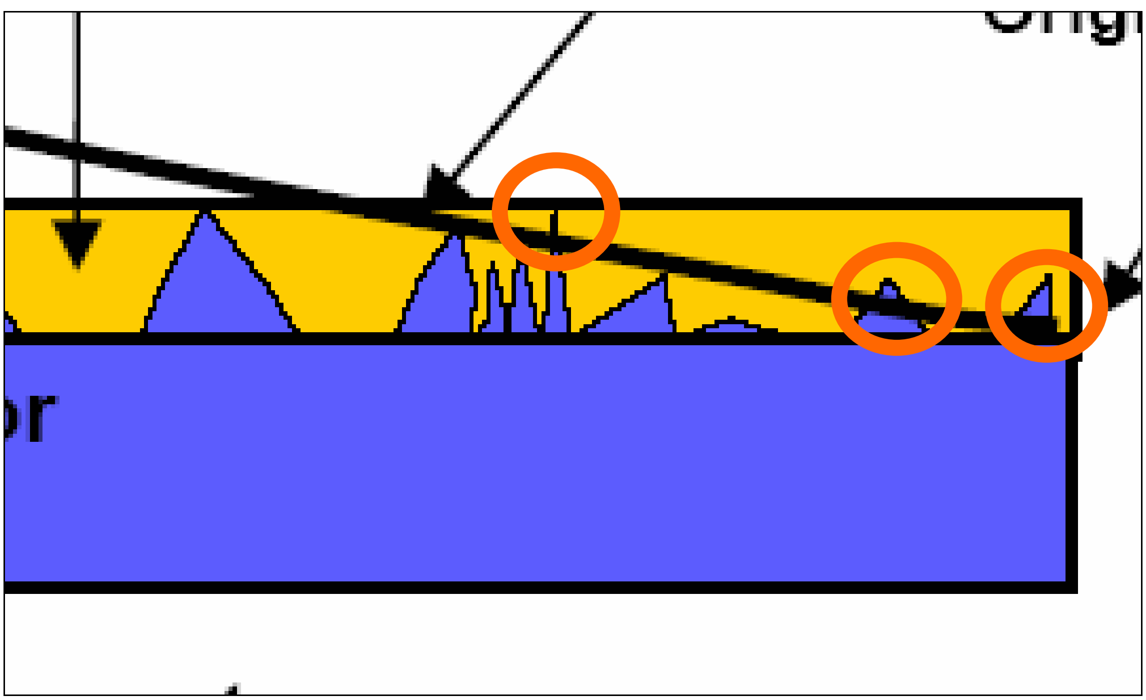

Figure 2. Regions Where Service Is Lost

By measuring the figure, one can determine that such interference reduces the original coverage along the line at about 3% of the locations originally served.

The next step in the analysis in the Notice is to assume that society (or the licensee and the FCC) decides that of all the possible remedies for this interference—including removing the interference, reducing the power transmitted by the interference source, and improving the design of unintentional radiators—the optimal choice is to give up and accept the interference. Accept is too weak a word—the proper phrase would be embrace. The solution set forth in the Notice to a small amount of interference is to cut the service region back toward the left until the licensed signal in the service region is everywhere above the worst-case interference. In the figure of the Notice, this reduces the covered region by about 20%. That is, the remedy for interference blocking service in 3% of the original service region is to declare defeat and give up on an additional 17% of the service region.

Having accepted the interference, the Notice identifies the gap between the maximum interference and the original noise floor by coloring it orange and describing it as a region where "opportunities would exist for additional operation by 'underlay' transmitters,'" with the implication that such additional operation comes at no cost to the licensed service.[1] That may be true under some scenarios, but as a general proposition, it is false. In the case of CDMA wireless systems, such underlay operations would degrade performance and increase costs. It is the view in the Notice that the interference creates opportunities for additional operation that I refer to as *embracing interference.* The Notice does not treat harmful interference as a problem to be solved but rather as justification for more interference.

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1 Notice, para. 16.

In short, the Notice's analysis contains several flaws:

- It is based on an obsolete system architecture;
- The analysis of interference is incorrect;
- The interference temperature concept has fundamental flaws:
    - interference temperature cannot be defined in analogy to noise temperature;
    - monitoring interference temperature is impracticable in CDMA bands;
    - more generally, combining interference temperature with underlay device operation poses insurmountable practical challenges;
- The benefits of underlay operation are limited; and
- It fails to quantify the losses created by increased interference.

Despite these flaws, the Notice does contain a fundamental insight of value. The FCC should monitor the degradation of the radio spectrum due to interference created by out-of-band emissions from poorly-maintained authorized transmitters and by the multitude of consumer electronic devices—such as computers, video games, PDAs and wireless LANs—and, if necessary, take further action as necessary to prevent harmful increases in such interference.

3. Flawed Basis

Most important, the Notice's Figure 1 does not represent the operation of modern wireless systems such as the 2-G and 3-G CDMA[2] systems operated by Verizon Wireless. Rather, it more-or-less matches an FM-radio broadcasting station or the forward link operation of a traditional land-mobile system. Modern CDMA systems adjust the power of the signals transmitted to each wireless subscriber—transmitting at the minimum power needed to provide acceptable service.[3] [4] CDMA systems overcome small

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[2] In this document, *CDMA* is used to refer to IS-95 and other cellular/PCS systems that use code division multiple access in part of the system design.

[3] The analysis in this paragraph is simplified without loss of any important aspect. CDMA systems apply power control on both the forward and reverse links. Portable units, transmitting on the reverse link, are commanded by the base station every 1.25 milliseconds to increase or decrease transmitted power. A wireless portable used in a car traveling 60 miles per hour moves only about 1 inch between power

localized areas of interference by transmitting to the mobile near such interference at the power needed to overcome that interference.

If interference were added to the noise floor everywhere in a CDMA system, it would cause all the portables to receive increased interference. To counter this interference, the CDMA system would increase the power transmitted to all portables. But CDMA cells are designed for a specific mix of coverage and capacity, and there are limits on the total power of base-station transmitters. Increasing average transmitted power at a cell would reduce the number of portables that could be served from the cell site, reduce coverage in buildings, urban canyons and rural areas, and would generate more interference to callers being served from other cells. In such a situation, the system operator would be faced with a choice between providing poorer service (more blocked and lost calls) and making substantial investments in new cells to replace the lost capacity.

4. Incorrect Analysis of Interference

If one accepts the logic of Figure 1 from the Notice, then it is apparent that substantial opportunities for additional spectrum use were not identified. In that figure, useful service is provided at any location at which the licensed signal exceeds the combined noise and interference. But there is a large region where that occurs. The farther to the left one goes on that diagram, the greater the possibilities for spectrum underlays.

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adjustments. CDMA's tight power control—always using just the power needed—keeps the power near the optimum level.

[4] Such power control is not unique to CDMA. Most other wireless telephony systems in use today also adjust mobile and base station transmitted power in order to use only the minimum power needed on each path.

Figure 3 shows missed opportunity as colored red (cross-hatched grey in a black-and-white copy).

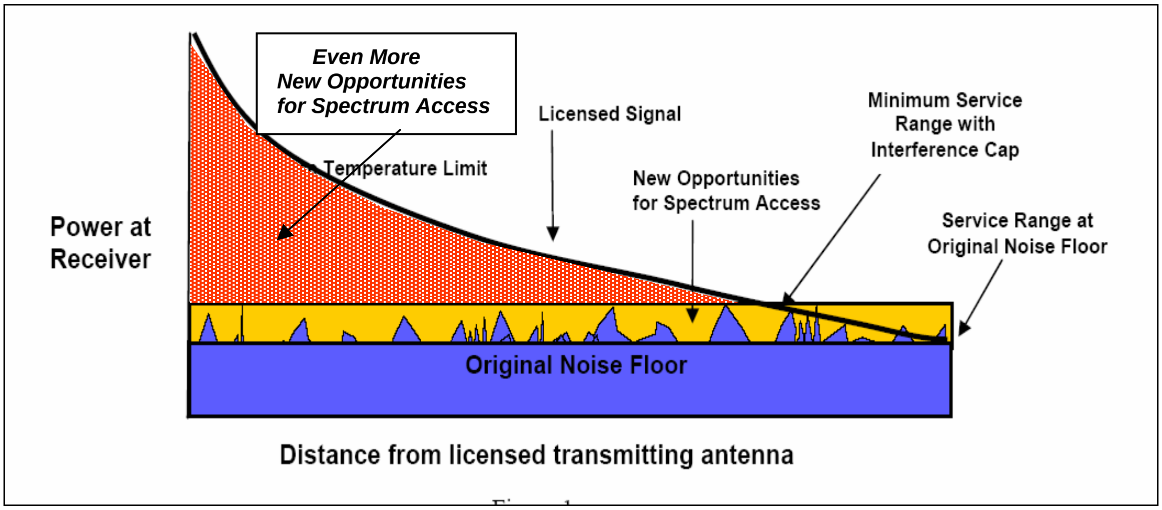

Figure 3. Missed Opportunities!

Well, of course this is nonsense—there is no such opportunity in practice. Theory and experience teach us that added interference degrades system performance and that massive added interference degrades performance substantially. It is instructive that the Spectrum Policy Task Force did not draw such a diagram. Rather, their approach was to suggest nibbling away at the bottom—creating a diagram that looked more benign.

In the case of CDMA, the benign diagram of Figure 1 makes no sense. Recall that CDMA systems adjust transmitted power to the minimum needed on each connection. Thus, a version of Figure 1 corresponding to a CDMA system looks like Figure 4.

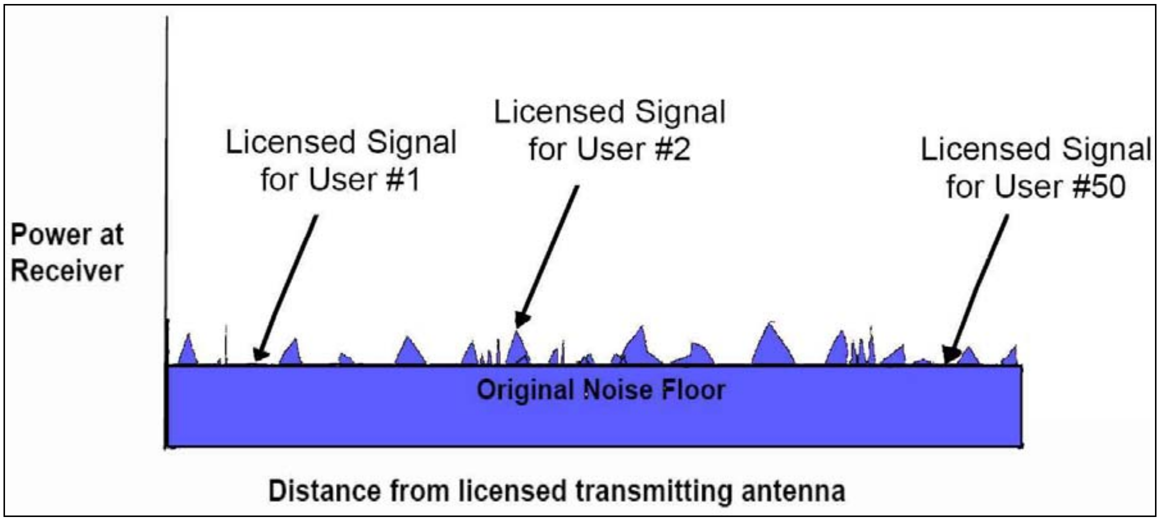

Figure 4. CDMA Signal Levels

Unlike earlier system designs, CDMA systems do not operate with huge unneeded power margins for the majority of users—rather, they transmit just enough energy to do the job.[5] There is no vast region in which the CDMA signals are far stronger than needed to overcome noise and interference. Similarly, satellite systems transmit signals that arrive at the earth's surface at roughly the same level over large regions.

Footnote 17 of the Notice reads:

> Note that unlicensed devices can operate successfully across a frequency band occupied by a higher level signal only if the bandwidth occupied by such devices is greater than that of the higher level signal (which is reasonable to assume in the case of direct sequence digital spread spectrum systems and digital transmission systems that have similar spectrum occupancy characteristics).

This is incorrect—if it were true CDMA and GPS would not work. The requirement is not that the bandwidth be greater but that the lower-level signal be sufficiently strong that the information can be recovered from the noise. The criterion for this to occur is that the energy in each bit be sufficiently high relative to the noise in the band carrying the signal.

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[5] This assertion is correct regarding the traffic channels on the forward link. CDMA forward link signals also contain a pilot signal that is transmitted at a constant power in order to permit portable phones anywhere in the cell to find the pilot signal. This analysis considers only the traffic channels. The CDMA reverse-link channels are also operated at the minimum power needed to communicate.

If a licensed signal were much stronger than an unlicensed signal in the same band, then the unlicensed system would have to transmit relatively few bits per second in order for each bit to have enough energy to punch through the licensed signal. Practical communications systems that transmit at high data rates must have signal powers that are about as high as or higher than the average noise in the radio channel.[6]

5. The Interference Temperature Concept

5.1. Defining Interference Temperature

Noise temperature is a familiar and well-defined engineering term. It is recognized, however, that noise temperature varies depending on the specific equipment involved, the region of the spectrum, and the direction an antenna is pointed. The noise temperature associated with a system is partially determined by nature—the amount of natural noise present at the frequencies of interest—and partially by the system designers—the quality of receiver front-ends that the designers incorporate into their systems. Thus, home satellite receivers have a low noise temperature—in the neighborhood of 140 K—in order to be able to pick up signals from satellites 23,000 miles away. Home analog TV receivers have much higher noise temperatures—perhaps 3,000 K—reflecting many factors, including the fact that they are designed to pick up powerful signals transmitted from 10 or 20 miles away and that the terrestrial TV broadcast system was designed more than 50 years ago when electronics was far less developed.

There are several fundamental problems with the very different concept of interference temperature. First, interference temperature is not well defined over an area or region.

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[6] The Shannon capacity of a channel is $W*\log_2(1+SNR)$, where W is the channel bandwidth and SNR is the signal-to-noise ratio. If the signal-to-noise ratio is significantly less than one, then the capacity is relatively low and grows linearly with increases in the SNR. Valuable systems can operate with signals well below the noise floor. For example, a typical received signal from the GPS satellite navigation system is about 15 dB below the thermal noise floor. (This is with a receiver noise temperature of 220 K! See *Global Positioning System: Theory and Applications Volume 1,* AIAA, B.W. Parkinson and J. J. Spilker, Eds, p. 89). The price paid for operating below the noise floor is a low data rate. Looking at it another way, GPS uses 5 MHz of bandwidth to carry about 1,200 bits per second of data. GPS trades off use of wide bandwidth for the ability to operate at low power. GPS also uses the wide bandwidth to provide the high-resolution time measurements that are essential to accurate navigation.

That problem with any definition of interference temperature is fundamental. The energy received from interfering devices varies rapidly in regions near the interfering device. At a location 10 yards from an interfering device, that device might contribute *X* to the total interference temperature. Ninety yards farther away, that device would probably contribute between *X*/100 and *X* /1,000 to the interference temperature.

The Commission's Notice recognizes that *interference temperature* is an ill-defined concept. For example, it asks how the interference temperature should be measured.[7] Consider a basic question: How should the FCC combine multiple interference temperature measurements made at different times and locations in order to derive a single interference temperature representative of an area? Should measurements made at midnight be averaged with measurements made during the business day? Should measurements made in Rock Creek Park be averaged with measurements made on M Street?

Different kinds of interference have different effects. Consider an analogy. A few seconds of a nearby fire siren might generate as much acoustic interference (measured by sound energy) as a day of quiet with birds chirping in the distance. But most people would find a few seconds of a loud siren (especially at 2:00 AM) to be far more objectionable than a day's worth of bird chirping. The nature of an interfering signal—for example, whether it occurs in bursts or is spread out evenly—affects how it interferes with a receiver. There is no one rule for converting bursts into harmful effects—different systems respond differently. Any measurement system will be merely an arbitrary rule for creating a single number from many measurements—it will not reflect the impairments created by interference on any specific system.

The familiar *noise temperature* concept does not suffer from some of these infirmities. Noise temperature is associated with what is called *thermal noise,* which has a unique and well-understood mathematical model (band-limited Gaussian noise) that represents well the characteristics of thermal noise. Engineers can design a system to work with

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[7] Notice, para. 23.

thermal noise of a certain level—say –110 dBm—and trust that, if the system encounters thermal noise at that level, it will work as predicted. Not so with interference temperature. Some interference sources are steady; others are pulsed. Some have all their energy concentrated at a single frequency; others spread their energy across the band. Unlike thermal noise—which always takes the same form—interference comes in many shapes and sizes. An automobile ignition generates about 50 to 100 interference bursts each second. In contrast, a personal computer generates a constant hum of radio interference.

If the total interference generated in New York City were measured by an antenna located far from New York—say in geostationary orbit—the various interference sources in New York City would combine to generate an interference signal that would be much like band-limited Gaussian noise. But, wireless users in New York City are not harmed by the average signal measured from 20,000 miles away; they are harmed by the signals from the interference sources that are nearby.

5.2. Impracticality of the Interference Temperature Concept in CDMA Bands

In many circumstances, the interference temperature concept cannot be implemented in a practical fashion. The Notice describes the concept of "operation by 'underlay' transmitters equipped to monitor the interference temperature and to control their operations so that they do not contribute to a condition where the interference temperature cap would be exceeded." For two reasons, that concept is impracticable in bands served by CDMA wireless today: (1) it is beyond the capabilities of a reasonably priced autonomous device to distinguish between interference and useful traffic in a CDMA band and (2) even if a device were able to distinguish between interference and useful traffic in a CDMA band, the harm that it could do to a CDMA wireless system would vary enormously, depending on the distance between the autonomous device and the nearest wireless receiver.[8]

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[8] The quoted text is from paragraph 16 of the Notice.

Consider the practicability of measuring the level of interference in a band carrying CDMA base-station transmissions. Measuring the level of interference in a band of frequencies requires three steps:

- Step 1: measure the entire energy in the band—call it *E*.
- Step 2: measure the energy of the licensed signals in the band—call it *L*.
- Step 3: subtract *L* from *E* to get a measure of the combined noise and interference.

Steps 1 and 3 are straightforward and can be implemented in practical systems. However, Step 2—measuring the energy of the licensed signal—is impracticable.

Current generation CDMA systems transmit over a 1.25-MHz-wide band. Each base station transmits multiple signals—literally dozens—spread across that band. One of these signals is the pilot channel, which has a well-defined structure and is often transmitted at a constant and relatively high power. Consequently, it would be feasible for an autonomous device to detect the presence of a pilot channel signal, estimate the level of the pilot channel signal, and subtract that level from the total power measured in the band. Also present in the transmission from the base station and spread across the 1.25-MHz band are the traffic channels carrying voice and data to subscribers. Typically, there might be between 10 and 40 such traffic channels. Both the number and strength of the traffic signals varies as subscribers start and make calls and move about. CDMA systems adjust the power of the traffic channels several times per second in order to transmit to each subscriber the power needed, but only the power needed—not too much, not too little. An autonomous device that was attempting to determine the level of interference at its location would first have to determine the energy in each and every traffic channel in order to calculate the total licensed energy. That is, the autonomous device would have to perform more or less the same reception function as is performed by the receivers in 40 CDMA portable units.

In addition, most of the land area served by a CDMA system receives useful signals from two or three base stations. This overlapping coverage improves call quality and is needed to permit conversations to continue as the user moves from cell to cell (handoff). But it means that the autonomous device would have to be able to perform simultaneous measurements of the signals from at least three base stations—with perhaps a total of 120 active traffic channels.

There is another constraint. The autonomous device may be moving—for example, the user may be carrying it down the street. If the user walks around the corner of a building, the strength of the radio signals from the various base stations is likely to change substantially in a second or two. Thus, the autonomous system must be able to identify the presence and measure the average strength of 120 or more CDMA traffic channels within a few seconds. This measuring task is not impossible but it is impractical—it requires the processing power and battery power of a hundred CDMA portable units.

One could argue that, sometime in the future, improved technology will permit such processing power to be implemented in the autonomous device at reasonable cost. But for that to be true, one must also assume that CDMA system architectures will stand still. CDMA system designers have continually refined CDMA systems in order to extract more capacity from the limited spectrum available to the system operators and to deliver better performance. It is natural to expect that they will continue to do so in the future—building systems that use complex processing in the receivers to obtain maximum performance. Waveforms will become more complex and even harder to distinguish from random noise or from the sum of multiple weak interfering signals. Improved technology will make the interference temperature measurement task of the autonomous devices more difficult.

There is a second problem. Assume that somehow a commercially practicable autonomous device could measure the interference temperature in a CDMA band. The harm it would cause to the operation of the CDMA system would depend on its location in the CDMA service area. If the autonomous device were sufficiently close to a CDMA receiver, its operation would render the receiver inoperable. If it were far from the receiver, its operation might be harmless. At in-between distances, operation of the autonomous device would steal resources from the CDMA system—perhaps causing a call at the edge of the cell, a half-mile away, to be lost. Without specific knowledge of the relative separation of the autonomous device and the receivers with which it will interfere, any action by the autonomous device that increases the interference temperature significantly will be a gamble—sometimes it will cause harmful interference, and sometimes it will not.

There is a better solution to this problem—one that is used millions of times each day. An autonomous device wishing to transmit in a CDMA reverse-link band can send a short message to the nearest base station requesting permission to transmit. The base station can transmit an authorization that specifies permitted power. That is exactly the process used by CDMA portable units today when they begin to transmit. It could easily be extended to low-power autonomous devices that wish to transmit in the CDMA uplink bands. Such devices could operate under control of the licensee's base station. The device would then receive permission to operate and also receive the precise power control commands (limiting power when necessary) and thereby be able to operate without interfering with phones used by other users of the spectrum. The device would also have the option of using the cell site's back haul facility. Instead of requiring an autonomous spectrum monitoring capability with 100 to 1,000 times the complexity of a PCS receiver, such devices would merely require a PCS receiver. Rules that permit and facilitate subleasing of radio spectrum by licensees would encourage the development and use of such efficient sharing technologies. A subleasing regime that controls interference must be distinguished from an unlicensed underlay system that would create uncontrolled harmful interference.

It is interesting to contrast the situation in a CDMA band with that in a TV band. Consider an autonomous device that wants to operate on TV channel 38. TV transmitters transmit a single signal, one much simpler than a CDMA signal, at an almost constant power.[9] Signals from two or more transmitters on the same TV channel do not overlap at any geographical location that gets a usable signal. Regions where useful signals from two different transmitters provide service are typically separated by tens of miles rather than overlapping, as is the case in CDMA wireless systems. One can envision an

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[9] Actually, two signals if one counts the audio and video carriers separately. But those two signals remain in a fixed ratio and at fixed positions in the band.

autonomous device that, given a second or two to make measurements, can estimate with substantial accuracy the strength of the licensed TV signal on channel 38. But this task is thousands of times simpler than making comparable measurements of licensed signals in a CDMA band. Thus, it is possible to imagine a reasonably priced autonomous device that is able to reasonably accurately estimate the level of interference present on TV channel 38.[10]

5.3. Monitoring Interference Temperature over a Region

Some of the problems described above could possibly be circumvented if more complex fixed monitoring equipment were used to measure the interference temperature in a CDMA band. The monitoring system could then transmit its measurements to nearby underlay devices, and they could then transmit at the permitted levels. Of course, at this point, the underlay devices are now not autonomous—rather, they transmit at the levels permitted by the fixed monitoring equipment. CDMA base stations provide such central control to CDMA portable units—there is no need for new infrastructure to provide central control of units that transmit in the CDMA reverse band.

There is another problem with fixed monitoring equipment. One can easily picture individuals, aware that the measurements from the monitoring equipment ultimately controlled the reliability of their wireless service and increased the cost of that service, duct taping some interference sources—perhaps used PDAs—to the wall near the monitoring equipment. Those interference sources would raise the measured interference temperature and thereby lower the permitted interference to wireless service from underlay devices. The reduced interference would improve the quality of wireless delivered to consumers.

One can also imagine other individuals, valuing the benefits of higher power from the devices governed by the monitoring equipment, going out into the neighborhood around

[10] An autonomous underlay device operating on TV channel 38 and using such measurements would still pose a threat of interference for the other reasons discussed herein.

the monitoring equipment and cleaning up any nearby sources of interference—thereby permitting higher power operation by underlay devices. More generally, fixed monitoring equipment would only measure the interference temperature at specific locations, which might not be representative and could be subject to manipulation.

Any system for measuring existing interference faces a well-known difficulty called the hidden-terminal problem. An interference source may have a good transmission path to a receiver that its transmissions will harm but have a poor transmission path to the monitoring equipment. Figure 5 illustrates a configuration in which this could occur.

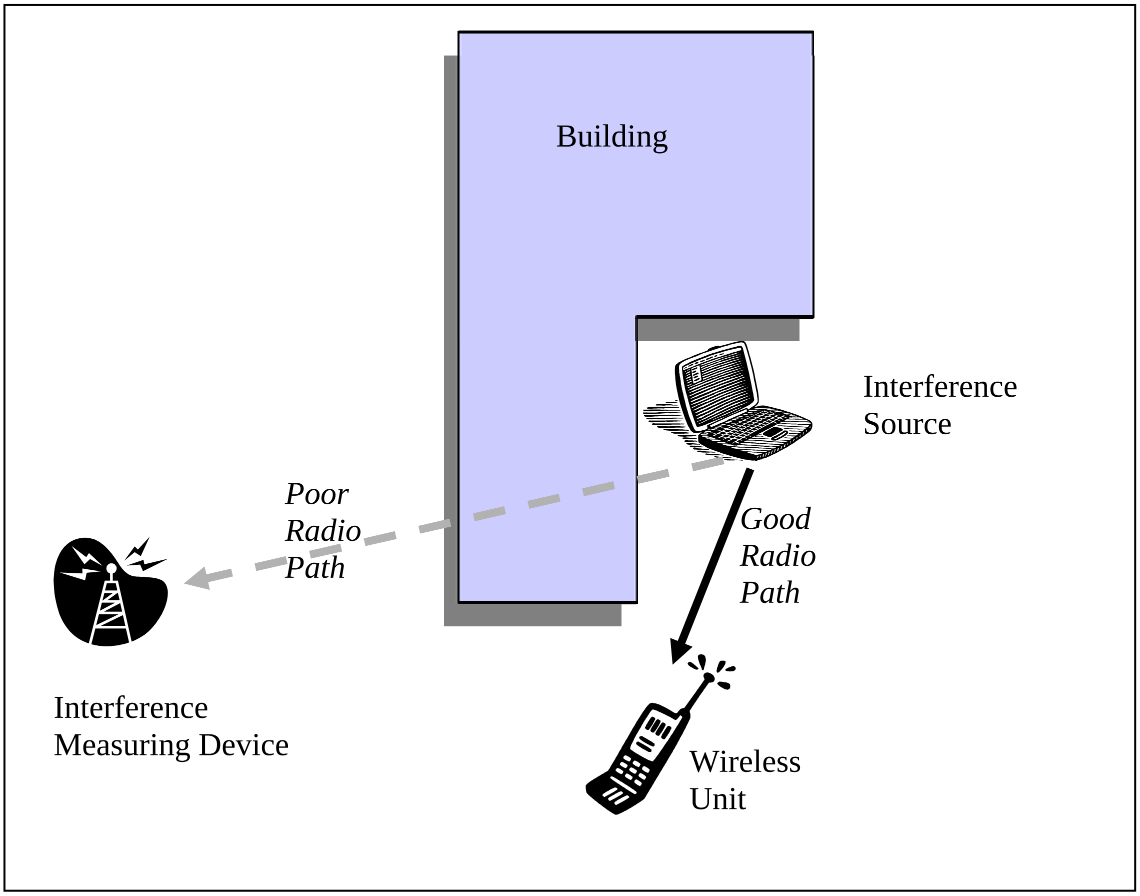

Figure 5. Hidden Terminal Problem

The wireless unit receives interference from the incidental radiation generated by the personal computer. There is a direct path from the computer to the wireless unit. However, the building blocks the path from the computer to the interference monitoring device. Consequently, the interference signal is much stronger at the wireless unit than at the interference measuring device. The building hides the interference source from the measuring device—the interference source is a hidden terminal. Under any reasonable definition of interference temperature, the interference temperature at the wireless terminal differs substantially from that at the measuring device. If the measuring device is an autonomous underlay device, it will make an incorrect assessment of the interference temperature that counts—the interference temperature at the receiver—and operate to raise the interference temperature above the limit. If the measuring device is part of a monitoring system, it will report a measurement that does not represent the interference temperature for nearby devices.

6. Limited Benefits

The Notice proposes using the interference temperature concept to permit operation of underlay devices. The performance of any reasonable underlay device operating in the PCS/cellular bands would be extremely limited—the word pathetic springs to mind. Devices meeting current part 15 limits are (or should be) the source of the peaks in the Notice's Figure 1. By the logic of the Notice, underlay devices should not create anymore in-band energy than the current interference sources—such as Part 15 devices. The usual interpretation of the current part 15 rules is that they permit devices to emit at -41.3 dBm/MHz in the PCS band.[11] In contrast, a low-power 802.11 device transmits at *much* higher levels than this.

For example, Cisco states that their Aironet 350 client adaptors transmit at powers between 1 mW (0 dBm) and 100 mW (20 dBm). These devices spread their energy out over 20 MHz, so they emit between -13 dBm/MHz and +7 dBm/MHz. That is, they emit somewhere between 1,000 and 100,000 times more power per MHz than the current part 15 limits permit in the PCS bands. However, if the maximum power of an 802.11-like

[11] See http://www.its.bldrdoc.gov/meetings/art/art02/slides02/roo/roo_slides.pdf, slide 17 for example.

underlay device were set to be no more than -41.3 dBm, either its range would fall or its data rate would be far less than is the case for 802.11.

Another way to quantify the limited benefits is to consider an hypothetical underlay device operating across the PCS band. We understand how powerful a radio has to be if it is to be able to deliver a high-bit-rate signal any reasonable distance. A low-cost radio built today that can send a signal at 100 megabits/second over a range of 10 yards would necessarily have properties much like those of 802.11 wireless LANs. The effect of a co-channel 802.11-like device on the local noise temperature depends on the assumptions, but under reasonable assumptions an 802.11-like device raises the interference temperature within 50 meters to above 3,000 K. Figure 6 shows the interference temperature as it slowly tapers off around such a hypothetical underlay device.[12] The maximum temperature has been clipped to allow a reasonable scale in the figure. The noise temperature at the corners of that figure is more than 2 dB above the 300 K natural limit. A single 802.11-like device wipes out use of the band for a region the size of a football field and generates harmful interference—interference that would raise the cost of wireless service by a factor of two—over a much larger area.

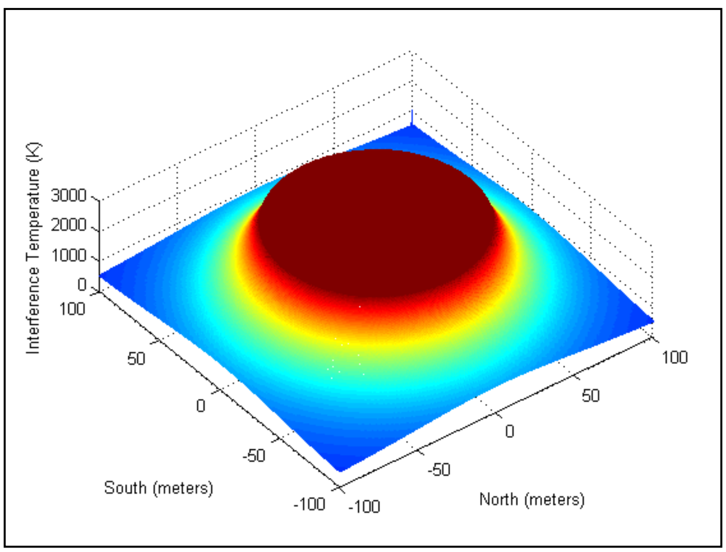

Figure 6. Interference Temperature in a Square with 200-meter Sides containing a Co-channel 802.11-like Device

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[12] This model assumes a radio transmitting at 1/100 watt in a 20 MHz-wide band. Received power is assumed to decline according to the free-space law for 3 meters and at 30 dB/decade after that. Interference temperature is the sum of thermal noise (300 K) and the noise power divided by the bandwidth.

Below is an alternate view of Figure 6 that reproduces well on black and white printers.

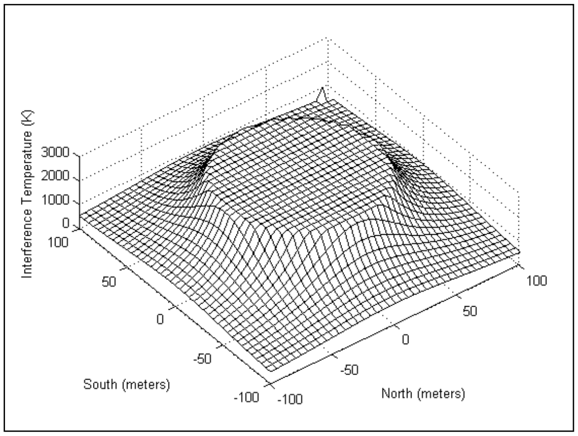

Figure 7. Interference Temperature in a Square with 200-meter Sides containing a Co-channel 802.11-like Device (version that reproduces well in black and white)

Obviously only a few such underlay devices could operate in a wireless service area before causing catastrophic loss of wireless service. Many would regard the operation of one such device to be a catastrophe if it denied wireless service in an emergency.

The physics of radio imply that the benefits of underlay operation must be minimal. If underlay devices operating on PCS/cellular spectrum are not to cause catastrophic interference either they must be extremely low-power devices (i.e., short range [inches], low-data rate [sub-megabit speeds] devices) or, if underlay devices are to have performance similar to that of 802.11 devices, only very a few devices—perhaps half a dozen or a dozen in an area the size of Manhattan—can operate without rendering the PCS/cellular band useless. But, the current unlicensed bands at 2.4, 5, and 60 GHz support hundreds of thousands of such devices in an area the size of Manhattan. Any added benefits of underlay devices are trivial.

7. Quantifying the Spectrum Loss from Added Interference

Modern CDMA systems provide the economic advantages of constant adjustment to the interference environment suggested in paragraphs 10-14 of the Notice. In a CDMA system, the orange area of the Notice's Figure 1 is being used efficiently. It does not represent idle spectrum—rather, it is useful spectrum. Thus, underlay operations in bands used by CDMA systems can add little or no value—any spectrum they gain represents spectrum denied to others. Adding interference takes away that useful spectrum from the licensed operator. Permitting underlay equipment to raise the *interference temperature* would take away spectrum just as surely as would taking 10 MHz from a 30-MHz license. This section below looks at two separate approaches to quantifying such losses.

There is a famous formula—really a family of formulas—known as the Shannon capacity formula. That formula provides an upper bound on the information that can be transmitted over a communications channel such as a radio link. The Shannon capacity in bits per second is a function of (1) the channel bandwidth, (2) the power in the desired signal, and (3) the power of the noise or interference. In the case of a PCS channel limited by thermal noise and characterized by a noise temperature, the formula is

$$C = BW \log(1 + \left(\frac{received\_power}{k \bullet noise\_temperature \bullet BW} \right))$$

where C is the capacity in bits per second,
BW is the bandwidth,
received_power is the power picked up by the PCS antenna,
k is a constant called Boltzman's constant,
and *noise_temperature* is the measure of the thermal noise.

This formula gives us a tool to understand, at a fundamental physical level, the impact of any action by the FCC that would result in an interference temperature that had the effect of increasing the *noise temperature* in that equation.

7.1. Shannon Capacity for a 30-MHz Channel

The table below shows the Shannon capacity for a single 30-MHz wide point-to-point channel for a variety of received power levels and noise temperatures.[13]

Shannon Capacity of a 30-MHz Channel,
as a Function of Noise (or Interference) Temperature
(capacity in megabits/second)

	Received Power (dBm)				
Noise or Interference Temperature (K)	-110	-100	-90	-80	-70
300	0.34	2.56	9.53	19.05	28.96
600	0.17	1.46	6.99	16.10	25.97
900	0.11	1.03	5.64	14.40	24.22
1,200	0.09	0.79	4.77	13.20	22.98

The table above shows that increases in the noise temperature substantially reduce the channel capacity. A noise temperature of 300 K is approximately the lower limit on PCS system noise and is set by nature.[14] That noise temperature is the base level in the table, and the capacity reductions are measured relative to that base level. The amount of the reduction, measured in bits/second, depends on the power level at which the PCS system is assumed to operate. At lower powers, the capacity is lower and there is less to lose. The range of power levels considered corresponds to receive power levels at or above the levels used in PCS systems today.

[13] This table measures the capacity of a single connection. The bandwidth of 30 MHz was chosen because PCS block A and B licenses comprise 30 MHz. Real system capacity calculations are more complex because they must take into account the problems of geographic reuse of the radio channel.

[14] In this report, we use 300 K as the base noise temperature from which to calculate any impairment. Some authors use 290 K as this base level. Using the 290 K base value would slightly increase our estimates of harm from increased interference. Given that 290 K = 16.85 Celsius (62 F) and 300 K = 26.85 Celsius (81 F), the difference is not material—it is the difference between spring and summer.

Below, those same losses are restated in percentage terms. That is, the table below shows, for five possible operating points, the fraction of total capacity that would be lost if the noise temperature increased.

Loss of Shannon Capacity of a 30-MHz Channel,
as a Function of Noise (or Interference) Temperature
(loss relative to capacity at 300K)

	Received Power (dBm)				
Noise or Interference Temperature (K)	-110	-100	-90	-80	-70
300	0%	0%	0%	0%	0%
600	49%	43%	27%	15%	10%
900	66%	60%	41%	24%	16%
1,200	74%	69%	50%	31%	21%

Figure 8 graphs the amount of quiet spectrum that would be lost from a 30-MHz PCS license as the interference temperature rises by an amount varying from 0 dB to 10 dB.[15] That is, the figure shows the amount of equivalent, non-interference-polluted spectrum that could be removed from the original 30 MHz and leaving a remainder with the same Shannon capacity as would be provided by 30 MHz of interference-polluted spectrum.

[15] This chart is calculated assuming a received power level of -90 dBm and noise power equal to 300*k*(30 MHz)**Interference_Temperature*, where the *Interference_Temperature* ranges from 300 K (representing a 0 dB increase above natural noise) to 3,0 00 K (representing a 10 dB increase above natural noise).

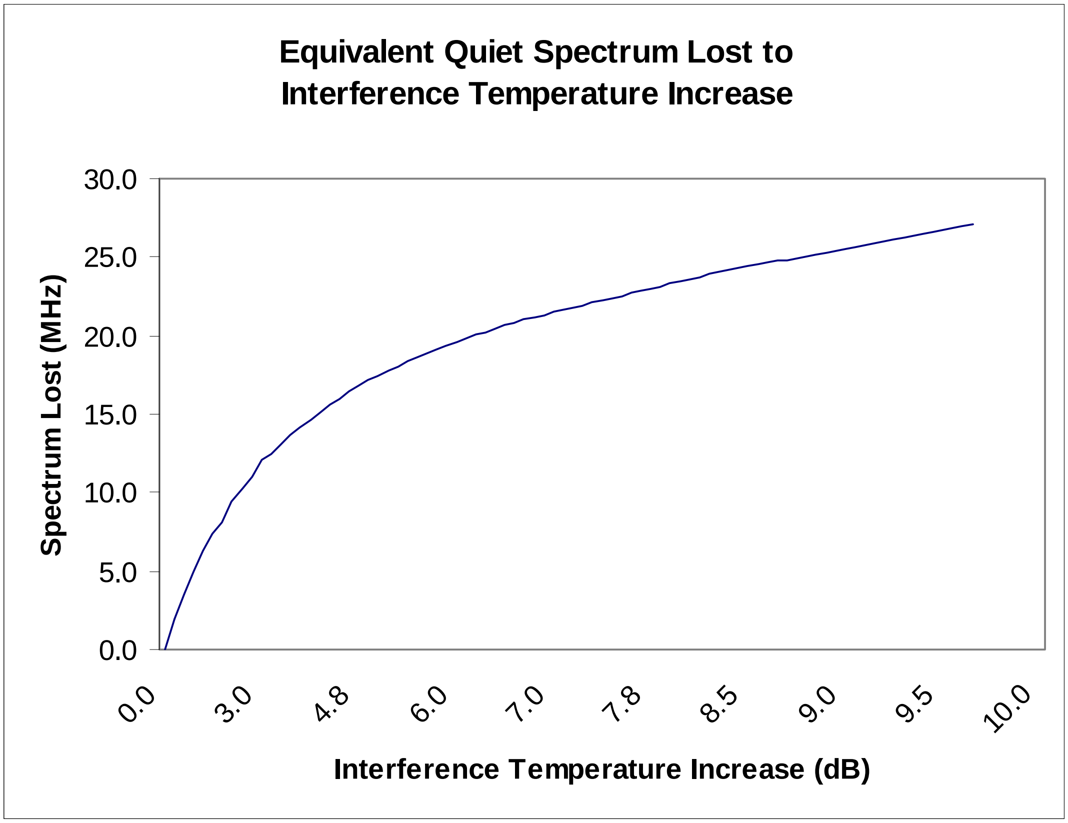

Figure 8. Equivalent Quite Spectrum Lost to Interference Temperature Increases

One way to look at a 30-MHz PCS license is to consider it a building lot on which a PCS operator can build communication systems. Those communication systems are limited by the size of the lot (30 MHz in the bandwidth direction) and the noise in the band. The system operator has a variety of options in system design. For example, the system operator might choose to operate with a few high-power transmitter–receiver links with wide geographic separation (say, characterized by received powers of -90 dBm) or many low-power transmitter–receiver links packed closer together (say characterized by receive powers of -120 dBm). But, whatever the system operator chooses to build, whether operating at -120 dBm or at -90 dBm received signal levels, there is a fundamental limit on the data rate that can be delivered to a receiver—a limit set by the presence of natural noise. For land mobile systems, that limit is associated with a noise temperature of 300 K—the everyday temperature on the surface of the Earth. Practical systems are starting to get close to that limit. For example, wireless carriers deploy tower top mounted low noise amplifiers and also cryogenic low-noise amplifiers—units that add little noise to the inescapable natural noise.[16]

If the FCC were to act to raise the total noise and interference temperature from 300 to 600 K, then the maximum communications capacity the PCS operator can ever extract with any given technology from the PCS spectrum will fall. The amount of the fall will depend on the technology. For example, if the PCS operator has chosen a system design that uses a received signal level of -90 dBm, then raising the interference (noise) temperature to 600 K will cut maximum capacity on radio link by 27%. In comparison, cutting the system bandwidth from 30 MHz to 18 MHz would cut the maximum capacity by 27%. That is, in this example raising the interference (noise) floor by a factor of two is as destructive as cutting the bandwidth by 40%! To put these numbers in perspective, the typical received power at a Verizon Wireless PCS base station from a CDMA portable unit is -126.2 dBm. The theoretical capacity losses discussed above are conservative because they reflect a higher-power received signal level (one less sensitive to added noise) than is the received signal level of today's CDMA systems.[17]

This analysis above, based on Shannon capacity, fails to take into account many of the complexities of real-world communication systems, including interference from other transmitters in the same system, the effects created by transmitters and receivers being in motion, and the use of multiple antennas to receive a signal. Nevertheless, this analysis indicates how profoundly damaging an increase in the interference (noise) floor would be to the ultimate capabilities of PCS systems.

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[16] Noise figures for these systems lie in the 1 to 2 dB range. Superconducting Technology reported selling 1,884 units of their SuperLink Rx product in 2003—a 100% increase over units sold in 2002. See Superconducting Technology, SEC Form 10K for 2003.

[17] Significant use of ultra-wideband (UWB) systems in the PCS and cellular bands would create similar capacity losses. The FCC's current UWB rules permit UWB systems to operate at relatively high powers on the frequencies from 3.1 to 10.6 GHz and at lower powers on frequencies below 960 MHz. Widespread adoption of UWB systems operating in 3.1 to 10.6 GHz may preclude use of frequencies in that range for personal mobile communications or for wireless last-mile applications.

7.2. Interference and Today's Hardware

The damage is not just theoretical. Analyses by equipment manufacturers show the gains that are possible by lowering the noise generated within PCS receivers. Figure 9 below was taken from "Benefits of Superconducting Technology to Wireless CDMA Networks" by M.I. Salkola and D.J. Scalapino.[18] Dr. Salkola is with Superconductor Technologies, Santa Barbara, California. Professor Scalapino teaches physics at the University of California, Santa Barbara.

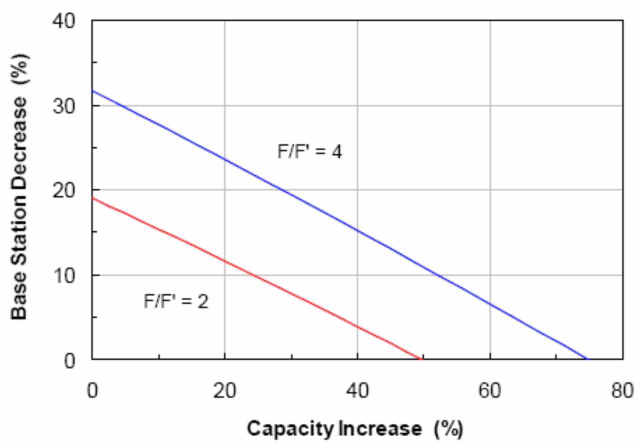

Fig. 3. The relative decrease in the number of base stations as a function of the capacity increase, when the noise factor is decreased by a factor of 2 and 4, for $X_o = 0.5$ (without HTS) and $\gamma = 4$.

Figure 9. Manufacturer's Claims for Capacity Increase as Noise Is Lowered

The authors state that their firm's cryogenic, superconducting receiving equipment has a noise figure of 0.5 dB. The receiver noise figure is a measure of the noise that the receiver adds to the naturally existing noise. The 0.5 dB noise figure of this equipment is low—it corresponds to raising the system noise temperature from 300 K to 336K. They designed their figure to show the benefits of replacing the input stage of a conventional CDMA receiver with their equipment, which eliminates much of the noise generated

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18 Available at http://www.suptech.com/pdf/technical_library/quicklinks/BenefitsSuperconductingCDMA.pdf. An earlier version of this paper was presented at the IEEE Wireless Communications and Networking Conference, 2002, and appears at pages 768-773 of volume 2 of the conference proceedings.

within the receiver itself. But their figure can also be read in the opposite direction to show how an increase in the interference (noise) temperature near a PCS base station would degrade the capacity of a system using their equipment—equipment that permits a system to operate near the thermal noise limit. The authors base these claims on analysis and simulation of the coverage of an IS-95 CDMA system. That is, these numbers are based on today's (well, last year's) technology—not on a general theoretical concept as in the Shannon capacity analyses above.

Figure 9 shows that increasing system noise temperature by a factor of two, from say, 336 K (the noise temperature associated with using a cryogenic front end) to 672 K, would cut capacity, require more base stations, or some mix of the two. Doubling the noise would require 25% more base stations to keep capacity the same.[19] If the number of base stations is kept constant, then capacity falls by 33% as the noise rises. These results, obtained from a document prepared for normal business purposes rather than for a regulatory filing, are similar to those presented by Lucent to the Commission in a 2002 study.[20] Lucent concluded that at 3 dB increase in noise would reduce cell capacity (assuming constant cell radius) by 80%. Similarly, a 2001 study by Qualcomm concluded that that a 3 dB increase in noise would require increasing the number of base stations in a CDMA system by 40% to 60% if the coverage and capacity were to be kept constant.[21]

High-speed data service provides an example in which it is relatively easy to understand the harm—no equations needed. The 3-G standards support data services that are fast enough to compete with DSL and cable. A CDMA2000 1xEV-DO system delivers peak data rates of 2.4 Mbps; CDMA2000 1xEV-DV will deliver slightly over 3 Mbps. But all

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[19] Because the authors drew their graph to show the benefits flowing from of a decrease in noise, reading out the percentage benefits of an increase in noise can be confusing. For example, a factor of two decrease in the noise is associated with a 20% decrease in the number of base stations needed to cover a region—say from 50 to 40. But, going in the other direction, from 40 to 50, is a 25% increase. With respect to capacity, halving the noise is associated with a 50% increase in capacity, say from 20 to 30 active conversations per cell. So, an increase in noise would be associated with a move from 30 to 20 conversations—a 33% decrease.

[20] See Appendix A of Lucent's Comments in Docket No. 02-86, April 10, 2003.

[21] See Qualcomm ex parte filing in ET Docket No. 98-153, March 5, 2001.

of these systems operate close to the theoretical channel capacity and can attain these rates only by tailoring the power and bit rate to the available radio path. For a user in an office with a window facing a nearby base station, EV-DO will establish a 2.4 Mbps link, For another user at the edge of the cell, the system may only be able to establish a much slower, 240 kbps, connection. That is, EV-DO adjusts the transmitted data rate for each user—matching the data rate to the path loss, noise, and interference of that user. EV-DO copes with added interference by cutting the data rate—sending fewer but louder bits—in order to punch through the added interference. Doubling the system noise temperature would cut the data rates to all users by 50%.

The above analysis does not apply directly to traditional broadcast operations such as analog television—the type of operation illustrated by the Notice's Figure 1. The system architecture of analog television was selected over a half century ago, and it reflects the technical limitations of that time. Traditional broadcast systems send a single signal carrying the same information to all destinations. Most broadcast receivers are located relatively close to the transmitter and receive signals substantially higher than are needed for acceptable performance. Consequently, the average broadcast receiver does not need to have a low-level of internal noise.[22] Because TV broadcast receivers are located at a fixed location, it is possible to use outside antennas to pick up a better signal than is available inside the house. In many distant signal situations—situations in which the quality of the displayed signal suffers because the signal is too weak relative to the noise—installing a higher antenna permits the viewer to pick up a substantially stronger signal. Thus, in the case of television broadcasting, increasing antenna height often provides an economic solution to the weak signal problem.[23] Finally, the viewers most distant from the transmitter, those who are most susceptible to added interference, are only a small fraction of the total audience. This is not to say that the interference temperature is a sound policy option for broadcast bands. Rather, this is merely an

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[22] The FCC's rules require that analog UHF TV sets have a noise figure no greater than 14 dB. See 47 CFR 15.117(g). This corresponds to a noise temperature of 7,000 K. In contrast, the cryogenic CDMA receivers discussed above have a noise temperature of about 36 K.

[23] Use of outside antennas and higher antennas to compensate for noise generated in the receiver also has the advantage that the costs of receiving weak signal are incurred only at those locations that have weak signals.

observation that the design of TV broadcast systems, the radio system familiar to most people, make those systems less susceptible to harm from the interference temperature concept. The Notice mistakenly uses an analysis, implicitly based on 1950's broadcast technology, and applies it more generally to all modern radio systems.

7.3. Conclusions Regarding Capacity Loss

A fundamental tool of communications engineering, the Shannon capacity, shows that an increase in the interference temperature would take resources away from a PCS operator just as reducing the allowed bandwidth would take away resources. In fact, bandwidth reductions and noise increases can be converted one to the other. Considering real-world signal powers, doubling the interference temperature would take away just as much capacity as would cutting the PCS license almost in half—from 30 to 18 MHz.

The analysis of current-generation CDMA wireless system capacity by Drs. Salkola and Scalapino shows that such capacity loss in not just theory—their analytic and simulation models predict capacity losses of the same scale from doubling the noise temperature. Studies by Lucent and Qualcomm reach similar conclusions—doubling the noise temperature takes away about half the system capacity.

8. Proper Use of the Interference Temperature Concept

Although the concept of underlay transmitters that would operate to raise the interference temperature is flawed, the idea that the FCC should limit the rise of the interference temperature is sound. The FCC should track the degradation of the radio spectrum due to the combined effects of all interference sources, including (1) out-of-band emissions from poorly-maintained authorized transmitters, (2) incidental radiators, and (3) unintentional radiators. The interference temperature as defined in the Notice may provide the basis for a reasonable metric for this tracking.

If the interference temperature rises, the FCC should act to see that the interference temperature returns to the economically efficient level. The Commission can do this by tightening the Part 15 restrictions on interference sources and by tightening restrictions on out-of-band emissions by licensed transmitters. Because there would a lag, measured in years, between the time the FCC acted to reduce unintentional radiations from sources such as personal computers and the subsequent reduction in interference, the FCC should have in place a method for forecasting interference temperature rises and permitting rational action before harm occurs.[24]

9. About the Author

Charles L. Jackson received his Ph.D. degree in electrical engineering from the Massachusetts Institute of Technology. Dr. Jackson is a member of the IEEE, the AAAS, the American Mathematical Society, and Sigma Xi. He is an adjunct professor of electrical engineering and computer science at the George Washington University, where he has taught graduate courses in mobile communications, wireless networking, and Internet technologies. From 1982 to 1988, he was an adjunct professor at Duke University. He is a member of the Executive Committee of the Public Utilities Research Center of the University of Florida, the U.S. Department of Commerce's Spectrum Planning and Policy Advisory Committee, and the Federal Communications Commission's Technological Advisory Committee. He has written for professional journals and the general press, with articles appearing in publications ranging from *The IEEE Transactions on Computers to Scientific American* to *The St. Petersburg Times*. A longer professional biography is available at http://www.jacksons.net.

I declare under penalty of perjury that the above is true and
correct to the best of my knowledge and belief.

Charles L. Jackson
April 4, 2004

[24] Personal computer users take advantage of both licensed and unlicensed radio modems and these modems require interference-free spectrum to work well. Consequently, computer manufactures have strong incentives to make their devices non-interfering.