Spread Spectrum Is Good—But it Does Not Obsolete *NBC v. U.S.*!

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I. INTRODUCTION

This short Article addresses a popular misconception—that new technologies such as spread spectrum have eliminated the problem of radio interference. That is false. Spread spectrum is a great technology, but it does not eliminate the problem of interference. Similarly, although some have asserted otherwise, signals below the noise floor can create interference.

We first show that a number of authors have embraced these misconceptions in works addressing public policy—unfortunately, we are not attacking a strawman. Simplifying these authors' views somewhat, they argue technology has eliminated the problem of interference; therefore, the legal rationale for radio regulation under the Communications Act of 1934, affirmed in the 1943 *NBC* case,[1] must be reconsidered. On such reconsideration, the First Amendment trumps an obsolete theory of interference; therefore, the fundamental structure of the Communications Act of 1934 is invalid.

We then provide a nonrigorous (no equations!) explanation of the nature of interference created by spread spectrum signals or by signals below the noise floor. We also offer a few pointers to the technical literature for those who wish to understand these issues in more depth.

II. PURPOSE AND APOLOGY

Scientific discoveries and technologies sometimes gain a cachet out of proportion to their value. Their names become buzzwords—and they are called on to explain problems far beyond their reach. Google the phrase *chaos theory* together with the word *politics* or Google the terms *quantum* and *finance*, and you will find a host of articles and Web pages that stretch the fabric of science far beyond its elastic limit.[2] Some authors merely use the science as simile, but others claim that the relevant science supports their analysis of politics, finance, or movie criticism.

A recent example of this phenomenon has occurred in telecommunications policy discussions in which analysts claim that new

1. NBC v. United States, 319 U.S. 190 (1943).

2. We note that such overreaching papers are sometimes written by engineers. Back when information theory was a hot new topic, a famous editorial by Peter Elias lamented the repeated appearance of the generic paper *Information Theory, Photosynthesis, and Religion*, which "discusses the surprisingly close relationship between the vocabulary and conceptual framework of information theory and that of psychology (or genetics, or linguistics, or psychiatry, or business organization)" and suggested that the authors "give up larceny for a life of honest toil." Peter Elias, *Two Famous Papers,* 4 IRE TRANSACTIONS ON INFO. THEORY 99, 99 (1958).

technology has solved the problems of radio interference.[3] Such claims have appeared in both the popular press and in academic journals.[4] The purpose of this Article is to examine two such claims and to match those claims with what we understand to be the capabilities of the technology. It is not our purpose here to engage in a discussion of spectrum policy—we (the Authors, collectively and individually) may agree with some of the policies advanced by these authors and disagree with others—rather, our purpose is to examine assertions regarding technology and to put those assertions into perspective.[5]

These technological claims are then used as the basis for arguing that the policy goals and legal basis of the Communications Act of 1934 are no longer valid.[6] For example, Benkler and Lessig state:

> If the engineers are right—if the efficiency of an architecture of spread-spectrum wireless technology were even roughly equivalent to the architecture of allocated spectrum—then much of the present broadcasting architecture would be rendered unconstitutional. If shared spectrum is possible, in other words, then the First Amendment would mean that allocated spectrum—whether licensed or auctioned—must go.[7]

The Communications Act of 1934[8] incorporates large parts of the Radio Act of 1927[9] and, albeit amended many times, still governs use of the radio spectrum in the United States. The Supreme Court upheld the constitutionality of the Communications Act in *NBC*.[10] Justice Frankfurter,

3. Succinctly stated, interference occurs when one radio transmission impairs the reception of a second transmission. Properly defining *interference* and *harmful interference* can be a difficult task—one as rooted in economics and tort law as engineering. For the purposes of this Article, we assume that the reader will follow Justice Stewart's approach to definitional issues and supply the definition he or she finds appropriate. *Cf.* Jacobellis v. Ohio, 378 U.S. 184, 197 (1963) (Stewart, J., concurring) (noting that despite the near impossible task of defining "hard-core pornography" he "[knew] it when [he] [saw] it"). For a discussion of interference, *see generally* R. Paul Margie, *Can You Hear Me Now?,* 2003 STAN. TECH. L. REV. 5, http://stlr.stanford.edu/STLR/Articles/03_STLR_5/article_pdf.pdf.

4. *See infra* Parts III.A and III.B.

5. Although we argue that some policy recommendations are based on reasoning from faulty premises, we acknowledge that those recommendations may, nonetheless, be valid.

6. Of course, there are attacks on the viability of NBC based on theories other than spread spectrum is like a magic pixie dust. *See, e.g.*, Stuart Benjamin, *The Logic of Scarcity: Idle Spectrum as a First Amendment Violation,* 52 DUKE L.J. 1 (2002).

7. Yochai Benkler & Lawrence Lessig, *Net Gains: Will Technology Make CBS Unconstitutional?*,THE NEW REPUBLIC, Dec. 14, 1998 at 12, 14.

8. Communications Act of 1934, ch. 652, 48 Stat. 1064 (1934) (codified as amended in various sections of 47 U.S.C.).

9. Radio Act of 1927, ch. 169, 44 Stat. 1162 (1927), repealed by Communications Act of 1934, ch. 652, § 602(a), 48 Stat. 1064, 1102 (1934).

10. 319 U.S. 190.

writing for the majority, upheld the challenged regulations and noted that interference justified regulation,"[u]nlike other modes of expression, radio inherently is not available to all. That is its unique characteristic, and that is why, unlike other modes of expression, it is subject to governmental regulation. Because it cannot be used by all, some who wish to use it must be denied."[11] In dissent, Justice Murphy agreed with Justice Frankfurter on interference as the justification for regulation, "[o]wing to its physical characteristics radio, unlike the other methods of conveying information, must be regulated and rationed by the government. Otherwise there would be chaos, and radio's usefulness would be largely destroyed."[12]

Both the majority and the dissent in *NBC* accepted interference as the justification for regulation—that was not in debate. But, if spread spectrum eliminates interference, then that predicate is wrong.

We note that we hold in high regard many of the authors whose works are considered below and, if it were possible, would omit their names from our analysis. Unfortunately, it is hard to cite an article properly without using the author's name.

We use the following approach. We state a proposition and follow that proposition with quotations from multiple sources showing how individual authors have expressed and accepted that proposition. We then analyze that proposition from the point of view of communications engineering. Our analysis is intended to be accessible—not mathematical. There are no equations, and mathematical jargon has been relegated to the footnotes.

III. ANALYSIS

A. *Assertion One: Spread Spectrum Eliminates Interference*

This assertion appears in various forms in many publications. Below are several instances of this assertion.

- CDMA [a spread spectrum technology] modulation schemes *allow you to use spectrum without interfering* with others.[13]

- A variety of techniques, some dating back to the 1940s, allow two or more transmitters to coexist on the same frequency. The best-known

11. *Id*. at 226.
12. *Id.* at 228 (Murphy, J., dissenting).
13. George Gilder, *Telecosm: "Auctioning the Airwaves*," FORBES ASAP, Apr. 11, 1994, at 99, 112 (emphasis added).

of these is spread-spectrum. . . . The practical consequence is that no government regulator or property owner need decide which signal is entitled to use the frequency; *both of them can use it simultaneously*.[14]

- [N]ew technological developments, such as spread spectrum and ultra-wideband radio, make it possible for many users to use the same broad swath of spectrum simultaneously *without interference*.[15]

- The spread spectrum transmissions of multiple users occupy the same frequency band, but are treated by each other as manageable noise, *not as interference* that causes degradation of reception.[16]

- But the most important implication of spread spectrum technology for regulatory purposes is that it allows many users to use the same band of frequencies simultaneously. Because every signal is noise-like, the signal of each user is, to all the others, just part of the background noise. Th*e receiver ignores all signals but the one chosen for reception*, and "receives"—translates into humanly intelligible form—only those noise-like transmissions that carry the intended signal.[17]

- Using a variety of strategies, mostly known as spread spectrum, researchers in wireless technology have begun to demonstrate the viability of systems that allow many users to share the same slice of spectrum *without interfering* with one another.[18]

- *The problem of interference*, as real and serious as it was, like the problem of recouping the non-zero marginal cost of the book, *went away*.[19]

- With spread spectrum, a transmission is disassembled and sent out

14. Kevin Werbach, *Supercommons: Toward a Unified Theory of Communications*, 82 TEX. L. REV. 863, 874 (2004) (emphasis added).

15. Stuart Buck, *Replacing Spectrum Auctions with a Spectrum Commons*, 2002 STAN. TECH. L. REV. 2, ¶ 6, http://stlr.stanford.edu/STLR/Articles/02_STLR_2/article_pdf.pdf (emphasis added).

16. Yochai Benkler, *Overcoming Agoraphobia: Building the Commons of the Digitally Networked Environment*, 11 HARV. J.L. & TECH. 287, 324 (1997) (emphasis added).

17. *Id.* at 396 (emphasis added).

18. Benkler & Lessig, *supra* note 7, at 14 (emphasis added).

19. Eben Moglen, Freeing the Mind: Free Software and the Death of Proprietary Culture, Keynote Address at the University of Maine Law School's Fourth Annual Technology and Law Conference, 13 (June 29, 2003), http://moglen.law.columbia.edu/publications/maine-speech.pdf (emphasis added).

over a variety of frequencies, *without causing interference* to whatever else might be operating within those frequencies, and is reassembled on the other end . . . .[20]

- *With spread spectrum technologies, spectrum would not need to be allocated*, in the sense of giving one person an exclusive right to the detriment of all others. With spread spectrum, broad swaths of the radio spectrum could be available for any to use, so long as they were using an approved broadcasting device. Spectrum would become a commons, and its use would be limited to those who had the proper, or licensed, equipment.[21]

These quotations came from *Forbes*, *Columbia Journalism Review*, *The New Republic*, three law review articles, and speeches by the authors. Those authors include professors at Stanford, New York University, Columbia, and the University of Pennsylvania. Another author is a practicing attorney who was a member of the *Harvard Law Review* and clerked for two federal circuit court judges.

Unfortunately, the fundamental assertion is incorrect. Actually, spread spectrum does not eliminate interference; rather, it changes the nature of interference.

Aquinas regarded arguments based on authority as the weakest form of proof.[22] Nevertheless, arguments regarding spread spectrum put forth by engineering experts would seem to carry more weight than those of the legal experts cited above. The reader can judge whether our contention that spread spectrum does not eliminate interference carries any weight. Others with substantial credentials support that same view. Consider Professor Andrew Viterbi, the Presidential Chair Professor in the Electrical Engineering Department at the University of Southern California and a member of both the National Academy of Engineering and the National Academy of Science. Viterbi explains the effect of spread spectrum on interference, saying: "[T]he main thrust of spread spectrum CDMA is to render the interference from all users and all cells, sharing the same spectrum, as benign as possible."[23]

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20. Jesse Sunenblick, *Into the Great Wide Open*, COLUM. JOURNALISM REV. Mar.–Apr. 2005, at 44, 46 (emphasis added).

21. Lawrence Lessig, Code and the Commons, Keynote Address at Fordham Law School: Media Convergence, 7 (Feb. 9, 1999), http://www.lessig.org/content/articles/works/Fordham.pdf (emphasis added).

22. "Nam, locus ab auctoritate est infirmissimus." THOMAS AQUINAS, SUMMA THEOLOGIAE, I^{a} Q. 1, 8, *available at* http://www.corpusthomisticum.org/sth1001.html.

23. Andrew J. Viterbi, *The Orthogonal-Random Waveform Dichotomy for Digital*

Professor James Spilker, Jr., Consulting Professor in the Electrical Engineering and Aeronautics and Astronautics Departments at Stanford University and a member of the National Academy of Engineering, summarizes spread spectrum well, saying:

> It is often desired to provide a method by which multiple signals can simultaneously access exactly the same frequency channel with minimal interference between them. Spread spectrum signaling has the capability to provide a form of multiple access signaling called code division multiple access (CDMA) *wherein multiple signals can be transmitted in exactly the same frequency channel with limited interference between users, if the total number of user signals M is not too large*.[24]

Let us back up a little, provide some background, and explain why spread spectrum does not eliminate interference. Spread spectrum is the name for a class of methods for impressing or modulating information on radio signals.[25] Spread spectrum has many advantages over earlier methods for transmitting information over radio such as AM and FM. A key advantage is that in many circumstances it is better at resisting interference than systems using most other radio modulation technologies. Depending on the circumstances, spread spectrum transmissions may generate either more or less interference to other communications systems than would modulation methods such as AM or FM.

An example may illustrate some of these properties. Consider a simplified world of radio communications in which there is a block of spectrum divided into ten radio channels. The radio channels are used for one-way communications from multiple groups of climbers communicating with their base camps in the valley below as illustrated in Figure 1. This example is constructed to remove some technical complications—e.g., all the transmitters are roughly equidistant from all the receivers. One can think of these radio channels as being 25 kHz blocks of spectrum. Communication using multiple individual frequency channels is defined as Frequency-Division Multiplexing ("FDM"),[26] and the process of accessing

Mobile Personal Communications, IEEE PERS. COMM., First Qtr. 1994, at 18.

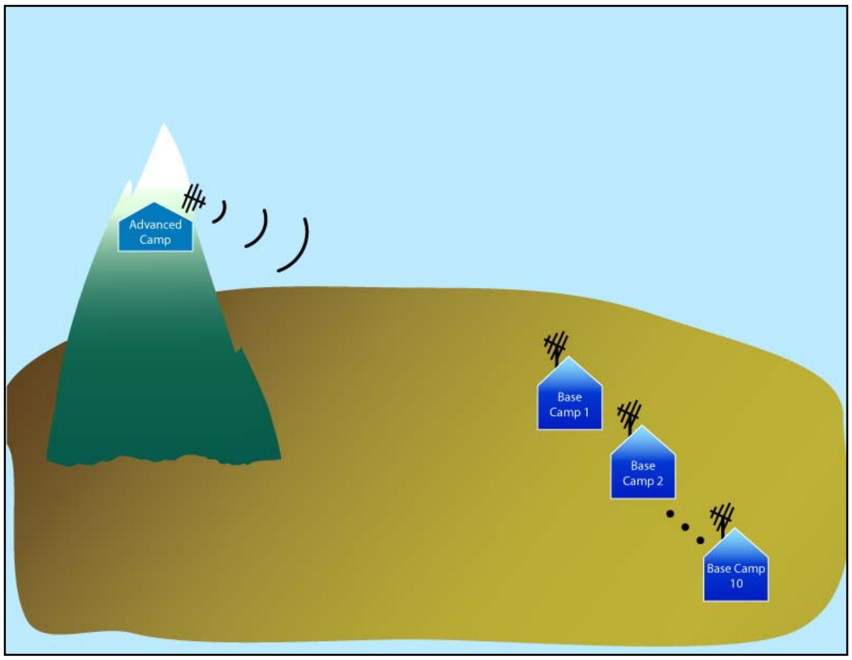
24. 1 GLOBAL POSITIONING SYSTEM: THEORY AND APPLICATIONS 62 (Bradford W. Parkinson & James J. Spilker Jr., eds., 1996).

25. For an older, but still excellent, introduction to spread spectrum see Raymond L. Pickholtz, Donald L. Schilling & Laurence B. Milstein, *Theory of Spread-Spectrum Communications—A Tutorial*, 30 IEEE TRANS. ON COMM. 855 (1982), http://mail.com.nthu.edu.tw/~jmwu/com5195/Schilling-DSSS-tutorial.pdf.

26. ATIS Committee T1A1, ATIS Telecom Dictionary, frequency-division multiplexing (FDM)), http://www.atis.org/tg2k/ (scroll to frequency-division multiplexing (FDM), http://www.networkdictionary.com/telecom/fdm.php (last visited Mar. 23, 2006).

these channels is called Frequency-Division Multiple Access ("FDMA").[27] An ideal frequency division multiplex system would permit a user to operate on any one of the ten channels without causing interference to users on the other nine channels. But, if two users tried to use a specific channel at the same time, the receivers in the valley would not be able to separate one signal from the other and interference would result.[28]

Figure 1: The Hypothetical Communications World



27. ATIS Committee T1A1, ATIS Telecom Dictionary, frequency-division multiple access (FDMA), http://www.atis.org/tg2k/ (scroll to frequency-division multiple access (FDMA)), http://www.networkdictionary.com/telecom/fdm.php (last visited Mar. 23, 2006).

28. Recall that this is an idealized system. In the real world, the use of adjacent FDM channels often causes interference because real-world receivers cannot perfectly reject signals in adjacent channels.

Figure 2: Ten Separate Frequency Division Channels

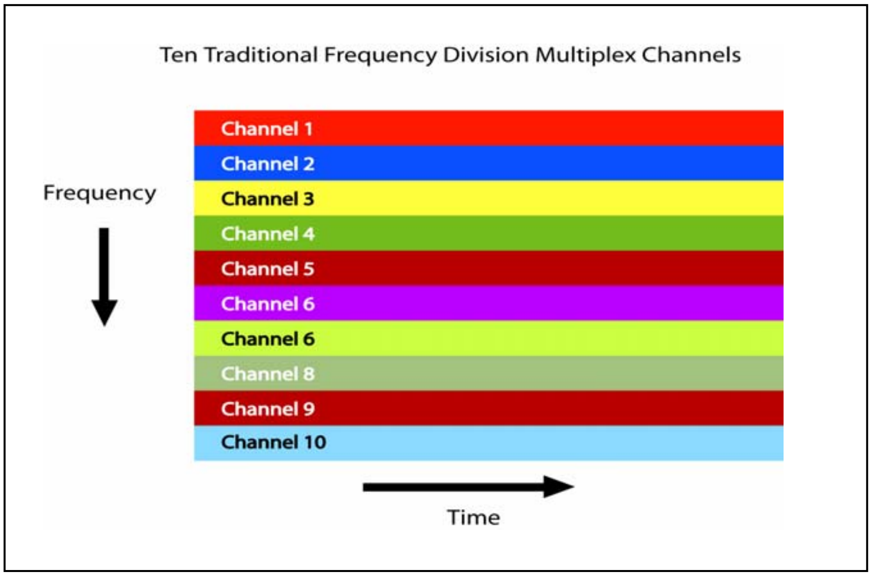


Figure 2 shows the ten channels as a region or range of frequencies devoted to one use over time. Channel 1 is shown by the bar across the top of the figure.

In this technology, signals are not spread—rather, each signal occupies just the bandwidth it needs. Interference is a purely zero-one affair. If two users try to transmit on the same channel at the same time, each receives interference that makes the channel unusable. If two users transmit on different channels at the same time, there is no interference.

Figure 3 illustrates a hypothetical spread spectrum signal corresponding to the Channel 1 signal of the Figure 2 above. The intense signal that filled Channel 1 is now a weaker signal that covers all ten channels. The transmitted energy is scattered in both time and frequency in what appears to be a random fashion in accordance with what is called a spreading code. The process of multiplexing many signals on the same block of radio spectrum by using separate spreading codes for each user is called Code-Division Multiple Access ("CDMA").

Figure 3: A Representation of a Spread Spectrum Signal

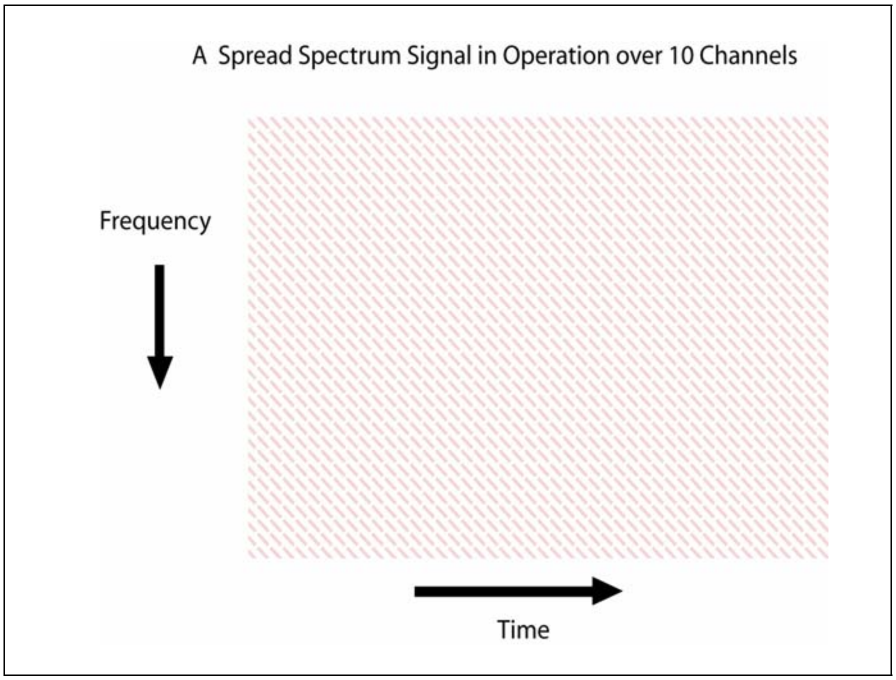


Figure 4 illustrates a different spread spectrum signal occupying all ten channels.

Figure 4: Representation of a Second Spread Spectrum Signal

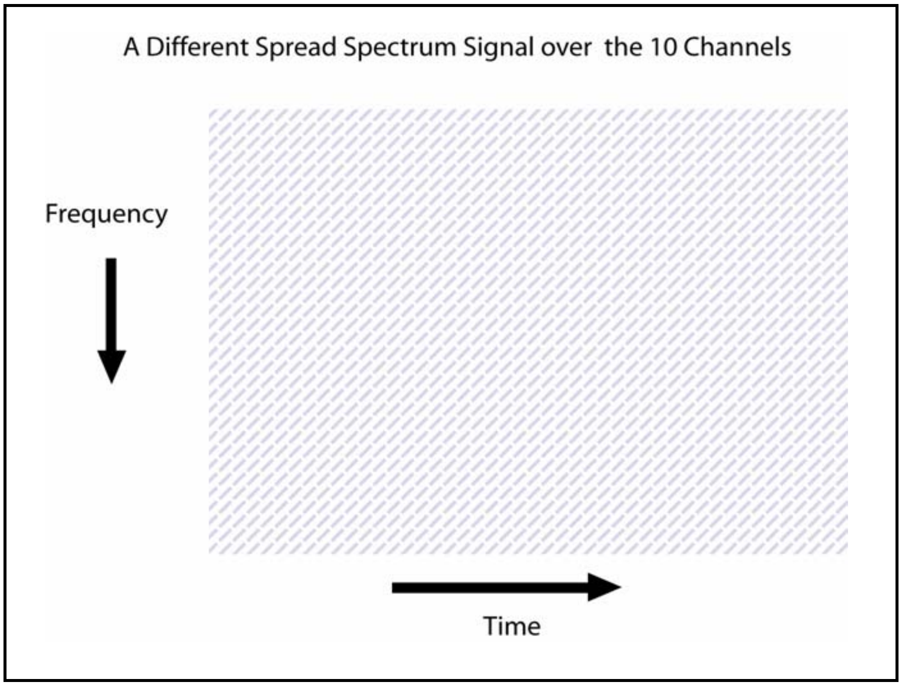
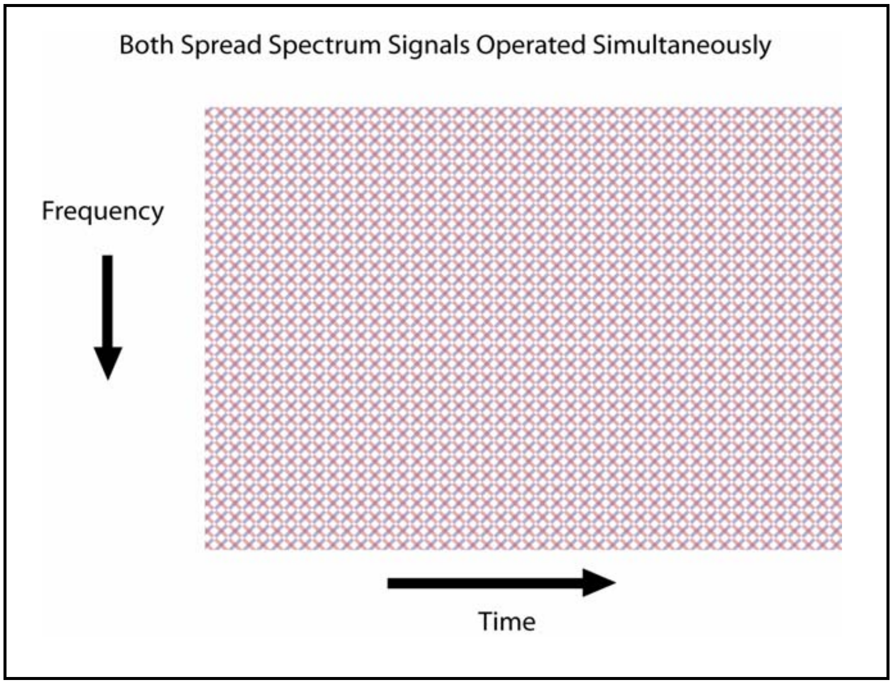


Figure 5 illustrates the operation of both spread spectrum signals simultaneously.

Figure 5: Representation of Two Spread Spectrum Signals



Those signals overlap in time and space. If one examines any small range of frequencies over a short period of time, one will find parts of both spread spectrum signals. However, the proper receiver can distinguish one spread spectrum signal from the other *sufficiently well*, making effective communication possible. Unlike the case with the earlier frequency-division channels, the receiver for one spread spectrum signal responds slightly to the other spread spectrum signal.[29] So, a spread spectrum system such as this could work acceptably if two or three users were operating.

29. Two caveats should be added here. First, recall that the perfect rejection of the adjacent channel signals in FDMA depended upon an ideal system. However, even in an ideal CDMA system, a receiver for one spreading code will respond (slightly) to a signal sent with a different spreading code. Second, there are some CDMA systems in which a receiver can perfectly separate two signals—such CDMA signals are as separate as the ten frequency-division multiplex channels considered above. But, there is no free lunch. If there is space for only ten frequency-division channels, there will be space for only ten perfectly separate CDMA signals with the same capacity. The sampling theorem shows that a waveform of bandwidth W and duration T has only 2WT degrees of freedom. A system that uses ten orthogonal wideband spread spectrum signals puts one tenth of these degrees of freedom into each spreading code. *See* JOHN G. PROAKIS, DIGITAL COMMUNICATIONS 160–68 (4th ed. 2001).

But, each additional user would increase the interference to all other active users. At some point, perhaps at about four to six users, interference would become so great that all users would lose service.

At this point, the nonengineering reader is probably willing to throw up his or her hands and ask, "What is the point of all this? You started with an ideal system that had no interference and replaced it with a system that has inescapable interference and supports fewer communications than were possible before!" The answer is that the utility of spread spectrum depends on the problem one is trying to solve. Assume that there are twenty groups of climbers on the mountain—more climbers than channels. Assume also that the climbers cannot coordinate channel use with one another or determine when another climbing party is using a channel, and only need to send requests back to their base camp occasionally—an average of two minutes per hour for each party. In the world with ten channels with zero-one interference, a climbing party would have to pick one of the ten channels, transmit their message, and hope that no other party was using that channel. In the spread spectrum world, there is an alternative solution. Each of the twenty climbing parties could be given a different spreading code and would use their individual code when transmitting. As long as no more than four or five climbing parties transmit at the same time, the mutual interference is low and all the messages are received. But, under these assumptions it is highly unlikely that more than four climbing parties will choose to transmit at the same time. This spread spectrum system provides efficient distributed access to a range of frequencies.[30] In the real world with pools of thousands of channels and millions of occasional users, the benefits of such distributed access would be even greater.

Of course, this example is an oversimplification—real-world applications include many other factors. One important factor is distance separation. In this example, the climbing parties were all roughly equidistant from the base camps. But, if one user were substantially closer to the base camps than were the others, that user's signal would be substantially stronger—consequently that user's signal would create more interference to other users. In a situation in which such near-far problems

30. A rough calculation shows that in this example interference is approximately 100 times less likely with the CDMA system than with the traditional FDMA channels. This example parallels the data link in the Global Positioning System ("GPS") navigational satellite system in which each satellite uses a different spreading code to transmit its signal. The GPS data link works well with a dozen satellites in view by a receiver at any one time. But, the data link would fail if there were 200 satellites in view—mutual interference would overwhelm the desired signals. An excellent explanation of the GPS signaling system is the two-volume text (roughly 1400 pages) edited by Parkinson and Spikler. GLOBAL POSITIONING SYSTEM, *supra* note 24.

abound, the older separate channel system may be a preferable technology.[31]

In some circumstances, spread spectrum systems can share radio channels with older technologies without receiving or causing harmful interference. But, such sharing does not happen automatically. Rather, one must analyze the systems involved, calculate the performance impairments, and determine the highest power level at which the spread spectrum system can operate without creating unacceptable impairments. In 1991, Schilling and his coauthors provided an example of such a calculation and measurements.[32] They showed that a personal radio service, similar to today's Personal Communications Service ("PCS") that used wideband

31. Real-world FDMA systems also suffer from this near-far problem—though usually not as severely as do CDMA systems. FDMA may be considered as an *orthogonal* multiple access technique for stationary communications so that, in theory, there is no interference (cross correlation is zero). The same can be said with orthogonal, direct sequence spread spectrum (e.g., Walsh codes) CDMA when there is no multipath (echoes or ghosts on the radio path). Multipath will deorthogonalize Walsh (or other orthogonal sequences), and Doppler spread will deorthogonalize FDMA signals. Doppler spread occurs when transmitters and receivers move relative to one another thereby shifting the received frequency slightly from the transmitted frequency. The two schemes are mathematical duals—by dual we refer to mathematical systems with symmetries that permit substituting one variable for another. *See* the discussion in the reference by Viterbi, *supra* note 23. For a discussion of time-frequency dualities, see Phillip Bello, *Time-frequency duality*, 10 IEEE TRANS. ON INF. THEORY 18–33 (1964). That is why, for highly time dispersive (e.g., multipath) channels with little or no Doppler spread, Orthogonal Frequency Division Multiplexing ("OFDM") performs well (the new IEEE 802.11g wireless Local Access Network ("LAN") standard takes advantage of this property). The tradeoff is that narrow subbands make multipath effects and InterSymbol Interference ("ISI") negligible. But, if the subbands are too narrow, Doppler spread deorthogonalizes the subbands and you get the dual of ISI—adjacent channel interference. Some respectable people now assert that they can get substantial capacity increases using coded OFDM. When one looks at it this way, there is both mutual Multiple Access Interference ("MAI") and Gaussian noise. Traditional thinking was that we want to eliminate MAI by first othogonalizing and then working just above the noise floor (strictly speaking, at the lowest ratio of energy-per-bit to the noise density [E_b/N_o] as allowed by coding) in each "channel." This is the case in FDMA—a subdivision of spectrum so that each user gets a piece of "private" spectrum, if only for the allocation period. First generation IS-95 CDMA took a different philosophy by operating at the lowest $Eb/(N_o+M*I_o)$, where I_o is the MAI power density per user and M is the number of active, equally power-controlled users. As M gets large, N_o is no longer the floor; so first-generation CDMA is best thought of as an *interference-sharing* scheme. For larger spreading, I_o is reduced and you can allow more users—but you need more bandwidth to accommodate the increased spreading. CDMA also easily takes advantage of voice activity and actually uses the multipath to improve the Signal-to-Noise Ratio ("SNR") by diversity combining. Modern, 3G CDMA (e.g., cdma2000) uses more sophisticated coding but also allows for interference cancellation, i.e., MAI or Multi-User Detection ("MUD"), or space-time coding, each of which reduces the effective I_o.

32. Donald L. Schilling et al., *Broadband CDMA for Personal Communications Systems*, IEEE COMM. MAG., Nov. 1991, at 86–93.

spread spectrum could share spectrum with the microwave radio systems that were then in the 2 GHz band.[33] But this showing was conditional on the spread spectrum handsets not transmitting at powers above one thousandth of a watt and the acceptance of the authors' definition of impairment.[34] Alternatively, one could say that they showed that a personal radio service with handset power above one thousandth of a watt would create interference. They also calculated total system capacity (the number of mobile units that could be supported in a given region) taking into account the mutual interference of each mobile unit with all the others.[35] The system had a finite system capacity—albeit a capacity about three times larger than the capacity calculated for nonspread spectrum designs.

There is also substantial empirical evidence of interference to spread spectrum signals. One example is the strong protest that users of the GPS satellite signal (a spread spectrum system) raised against interference to the GPS signal from proposed Ultra Wideband ("UWB") systems.[36] Another example is the purchase of additional spectrum by the wireless carriers that use spread spectrum.[37] Relatedly, those wireless carriers using spread spectrum require their equipment suppliers to reduce the interference one handset generates to nearby handsets to a level a million times lower than that permitted by the Federal Communications Commission ("FCC").[38] It is hard to understand why these firms would spend money to reduce interfering signals unless those signals were harmful.

CDMA has built into it extensive capabilities for managing the power of signals transmitted from handsets so that those signals will all arrive at

33. *Id*. at 86, 87, 92 n.5.

34. *Id*. at 92.

35. *Id*. at 90, 92.

36. *See* DAVID S. ANDERSON ET AL., U.S. DEP'T OF COMMERCE, ASSESSMENT OF COMPATIBILITY BETWEEN ULTRAWIDEBAND (UWB) SYSTEMS AND GLOBAL POSITIONING SYSTEMS (GPS) (2001), http://www.ntia.doc.gov/osmhome/reports/uwbgps/NTIASP_01_45.pdf. *See also* Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, *First Report and Order*, 17 F.C.C.R. 7435 (2002), http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf.

37. *See, e.g.*, *Verizon Wireless Buys All NextWave for USD 3B*, MOBILE MONDAY, Nov. 5, 2004, http://www.mobilemonday.net/mm/story.php?id=3893.

38. *See* 3rd Generation Partnership Project 2, Recommended Minimum Performance Standards for cdma2000 Spread Spectrum Mobile Stations Release B, 3-113 (Dec. 13, 2002), http://www.3gpp2.org/public_html/specs/cs0011-B_V1.0.pdf (setting the industry limit of -76 dBm on such emissions); *see also* 47 C.F.R. § 24.238(a) (2004) (limiting the existing PCS bands to -13 dBm). The CFR requires out-of-band emissions to be attenuated below the transmitting power by a factor of 43 + 10 log(P). This is analogous to a speed limit sign that stated "slow down by (your current speed) – 35 miles/hour" So, if you are going 40 mph, you would slow down by 5 MPH (40 – 35) to 35 miles/hour. *See id*. The 63 dBm difference between the FCC permitted level and the industry standard is a factor of two million.

the cell tower at the same strength—thereby avoiding the near-far problem discussed earlier. If spread spectrum really eliminated interference, these capabilities would be unnecessary.

The unlicensed community is pressing for the release of more spectrum for unlicensed applications.[39] However, were interference not a problem, the current several hundred MHz of spectrum available for unlicensed systems would be sufficient to carry more data than any person would need.[40]

Spread spectrum is a great technology. When used in personal wireless systems, such as cellular and PCS, it increases capacity by a factor of two to ten over the earlier Time Division Multiple Access ("TDMA") and FDMA technologies.[41] Used in the GPS system, it permits the efficient sharing of the satellite-to-earth radio channel.[42] Manufacturers and service providers have converged on the use of spread spectrum for third-generation wireless systems.[43] But, as good as spread spectrum is, it is not good enough to make the problem of interference go away.

B. Assertion Two: Signals Below the Noise Floor Are Harmless

- Spectrum below the noise floor is therefore not scarce, at least from the perspective of high-power systems above it, because these systems ignore radiation at that level.[44]

- For example, low-power UWB would be covered by this easement, to the extent that it operates under the noise floor and creates no

39. *See Broadcast to Broadband: Completing the Digital Television Transition Can Jumpstart Affordable Wireless Broadband: Hearing Before the S. Comm. on Commerce, Science, & Transportation*, 109th Cong. (2005) (testimony of Michael Calabrese, Vice President and Director, Wireless Future Program, New America Foundation), http://www.newamerica.net/Download_Docs/pdfs/Doc_File_2460_1.pdf. In his testimony, Mr. Calabrese states, "we also strongly recommend that roughly one-third (20 MHz) of the TV band spectrum reallocated for wireless services be reserved for shared, unlicensed wireless broadband . . . ." *Id.*

40. *Cf. The Future of Spectrum Policy and the FCC Spectrum Policy Task Force Report*: *Hearing Before the S. Comm. on Commerce, Science, & Transportation*, 108th Cong. (2003) (tesimony of Michael Calabrese, Director, Spectrum Policy Program, New America Foundation), http://www.newamerica.net/Download_Docs/pdfs/Pub_File_1165_1.pdf (noting the abundance of spectrum available to the public when regulations eliminate interference).

41. *See* CDMA Development Group, Technology, 2G - cdmaOne, http://www.cdg.org/technology/2g.asp (last visited Mar. 23, 2006).

42. *See* 1 Global Positioning System, *supra* note 24.

43. *See* CDMA Development Group, Technology, 3G-CDMA2000, http://www.cdg.org/technology/3g.asp (last visited Mar. 23, 2006).

44. Werbach, *supra* note 14, at 960.

> interference.[45] An underlay easement would allow secondary unlicensed users to share licensed spectrum as long as they remain below the noise floor established by the license.[46]

The radio noise floor is the level of unavoidable radio static in the environment.[47] Such noise arises from different causes in different regions of the spectrum. In the AM band, the primary source of radio noise is either distant lightning (for someone on a rural road far from town) or nearby electrical equipment (for someone in town).[48] In the cellular and PCS bands, noise comes from the thermal microwave radiation in the environment, electronic equipment such as personal computers, and the out-of-band emissions of radio transmitters.[49] Satellite TV receivers see primarily the thermal microwave radiation from space—and because space is cold—this noise is lower than the noise seen by PCS receivers.[50]

When an external source adds noise to the environment, the total noise rises. Adding noise to the environment might be analogized to pouring more water in a bathtub—the level of the water in the bathtub rises. In contrast, if one pours more water into a river, the level of the water in the river stays the same.[51] Figure 6, taken from a presentation given by Kevin Werbach, illustrates this fallacy.[52] It shows a desired signal, the noise floor, and a signal below the noise floor (an underlay signal). As illustrated, there appears to be no problem.

45. Gerald Faulhaber, The Question of Spectrum: Technology, Management, and Regime Change 11 (2005) (paper presented at the Economics, Technology, and Policy of Unlicensed Spectrum Conference, Michigan State University), http://quello.msu.edu/conferences/spectrum/papers/faulhaber.pdf (last visited Feb. 28, 2006). UWB radios spread their signals out over an enormous range of frequencies with little energy in any small range of frequencies.

46. William Lehr, *Dedicated Lower-Frequency Unlicensed Spectrum: The Economic Case for Dedicated Unlicensed Spectrum Below 3 GHz* 18 (New Am. Found., Spectrum Series Working Paper No. 9, 2004), *available at* http://www.newamerica.net/Download_Docs/pdfs/Doc_File_1548_1.pdf.

47. *See* Rudholf F. Graf, Modern Dictionary of Electronics 505 (7th ed. 1999).

48. A. D. Spaulding & R. T. Disney, U.S. Dep't of Commerce, Man-Made Radio Noise: Part I: Estimates for Business, Residential, and Rural Areas 10–11 (1974), *available at* http://www.its.bldrdoc.gov/pub/ot/ot-74-38/Ch1-3.pdf.

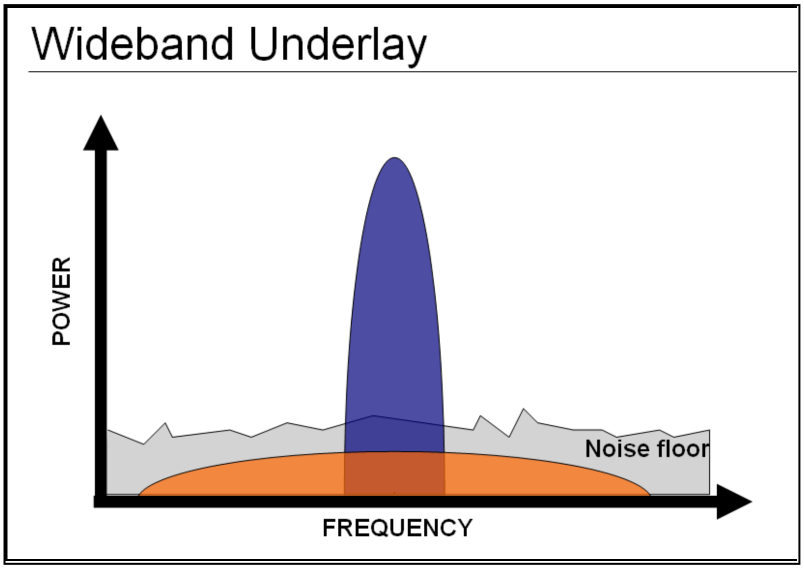
49. *Id.*

50. *See* GARY D. GORDON & WALTER L. MORGAN, PRINCIPLES OF COMMUNICATIONS SATELLITES 202–04, 220–21 (1993).

51. We ignore the transient rise in the river level while the added water works its way downstream.

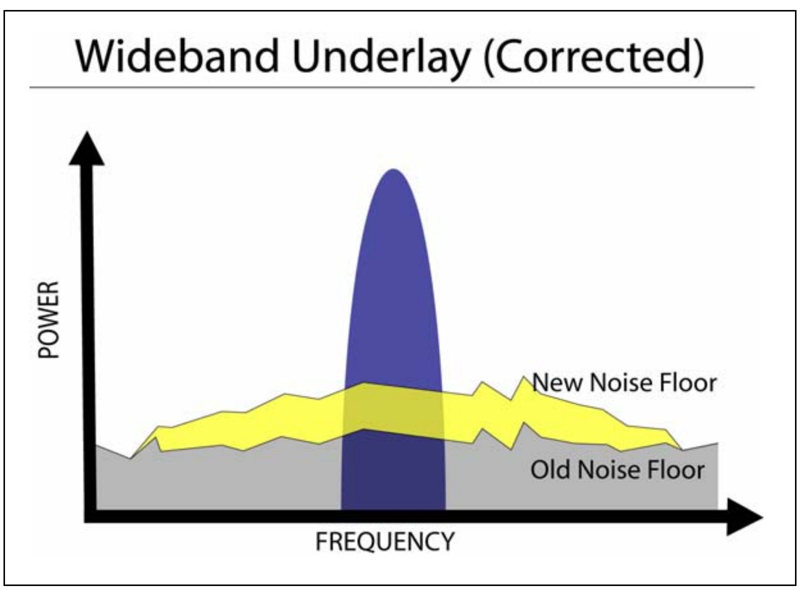
52. Kevin Werbach, The Open Spectrum Revolution, Presentation to the Wireless Future Conference 9 (Mar. 23, 2004), http://werbach.com/docs/wireless_future.ppt.

Figure 6: Illustration of Underlay Signal



However, the drawing does not represent the physics observed in the real world. The proper illustration is shown in Figure 7.

Figure 7: Proper Illustration of Underlay Effects



The contrast is clear. In Werbach's diagram, the added noise or interference does not affect the total noise. In the revised diagram, the added noise or interference increases the total noise. That is how real-world systems work—akin to more water in a tub, not to more water in a river. An interfering signal reduces the margin against noise and interference.

This issue is not merely theoretical. Some modern radio systems can operate at signal levels sufficiently low that added noise or interference—even if below the noise floor—will noticeably degrade the performance of these systems.[53] For example, Superconductor Technologies sells cryogenically-cooled ultra-low noise amplifiers for use in cellular and PCS systems.[54] These amplifiers increase cell coverage by permitting the base station to hear signals that are too weak to hear with more conventional gear. Noise or interference at half the level of the noise floor would impair systems using such receivers.

IV. CONCLUSION

Radio interference remains a genuine problem—and neither using spread spectrum nor keeping the potentially interfering signal below the noise floor eliminates interference. We have tried to explain why interference remains a problem. We have also pointed to the behavior of spectrum users—users who could save billions if spread spectrum truly eliminated interference—as further evidence that our point is correct.

Although our purpose in this paper is to throw cold water on some unjustifiably optimistic views of radio technology, we conclude by noting that there is substantial cause for optimism regarding future use of the radio spectrum. Emerging technologies, such as Multiple-Input Multiple-Output ("MIMO") and Multi-User Detection ("MUD"), will expand spectrum capacity several times over. Unfortunately, these technologies cannot be used in every radio application, and they may impose costs such as shorter battery life or higher prices. Technology has not eliminated interference, but the future for wireless communications is bright.[55]

53. A short calculation shows why this is so. The Superconductor Technologies' SuperLink Rx 1900 has a noise figure of 1 dB. Thus, in an environment with an external noise temperature of 290 K, use of this device yields a system with total noise temperature of 365 K (1 dB higher). Adding noise power at a level of one half the noise floor (140 K) increases system noise temperature to 505 K. Thus, noise well below the noise floor increases system noise temperature by a factor of 505/365 = 1.38 or 1.4 dB. Such a 1.4 dB increase in noise will degrade the performance of modern wireless systems or will require compensating adjustments, such as a 38% increase in transmitted power.

54. *See* Superconductor Technologies Datasheet for SuperLink Rx 1900, http://www.suptech.com/pdf/SuperLinkRx1900_web.pdf (last visited Mar. 23, 2006).

55. Technically speaking and in the interests of completeness, we note that MUD works by eliminating interference. Unfortunately, it can only eliminate some kinds of interference and, even then, is not perfect.

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