June 17, 2002

Attachment 1
Sprint Reconsideration Petition, ET Docket No. 98-153

Operational Overview of the IS-95 CDMA Downlink

Introduction

Accurate assessment of the impact of ultra-wideband ("UWB") interference on the CDMA (IS-95) PCS downlink requires a clear understanding of how the downlink operates. A number of misconceptions about that operation seem to have influenced the FCC's decision regarding acceptable UWB emission levels in the PCS band (1850-1990 MHz). Those misconceptions include:

- PCS receivers cannot operate at or near the thermal noise floor;
- Indoor UWB emission levels can be greater than outdoor levels in the PCS bands;
- The effect of CDMA other-cell interference was not properly taken into account in the Telcordia Model filed jointly by Sprint and Time Domain;[1]
- Fading of the PCS signal reduces the relative effect of UWB interference;
- Rayleigh fading is the appropriate multipath fading model for CDMA;
- Frame errors observed in the field tests reported jointly by Sprint PCS/Time Domain at relatively high signal levels (e.g., -85 dBm) somehow suggest that these are marginal signal levels with respect to CDMA coverage;[2] and
- Small increases in the effective noise floor (e.g., 1 to 2 dB) do not have significant impact.

These notes describe (mathematically where necessary) relevant aspects of the IS-95 downlink operation. Based on those descriptions, it is shown here that:

1. Because of the spreading gain inherent in the CDMA air interface, the PCS handset in fact has a sensitivity (minimum decodable signal level) on the order of 13 dB below the thermal noise floor of the handset.
2. Considering the design of the entire CDMA system, including the effects of other-cell interference, in-cell interference, and thermal noise, as well as the signal-to-interference plus noise ratio (SINR) requirements for the overhead (common)

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[1] *See* Sprint/Time Domain Ex Parte, ET Docket No. 98-153 (Sept. 12, 2000), Attachment 1, Dr. Jay Padgett, Senior Research Scientist, Telcordia Technologies, *A Model for Calculating the Effect of UWB Interference on a CDMA PCS System* (Sept. 12, 2000)(hereafter, Telcordia Model).

[2] *See* Sprint/Time Domain Ex Parte, ET Docket No. 98-153 (Sept. 12, 2000), Attachment 2, Dr. Jay Padgett, Senior Research Scientist, Telcordia Technologies, *Summary of Testing Performed by Sprint PCS and Time Domain to Characterize the Effect of Ultra Wideband (UWB) Devices on an IS-95 PCS System* (Sept. 12, 2000)(hereafter, Sprint/Time Domain Test Results)

channels, a total received power from each base station that is near the thermal noise floor at the cell edge is a logical design.

3. For a given impact (e.g., *x* percent coverage reduction due to a UWB transmitter *d* meters from the PCS handset), the emission levels for indoor UWB devices need to be at least 5 dB below the emission levels for outdoor UWB devices.
4. Other-cell interference was properly taken into account in the Telcordia model.
5. The effect of a given UWB interference level on coverage reduction is the same, whether or not fading is explicitly taken into account.
6. With IS-95 CDMA, fading statistics are normally much less severe than indicated by the Rayleigh model, due to the use of multipath diversity, implemented in the RAKE receiver, typically using maximal ratio combining.
7. Frame errors are expected to occur even at high signal levels, because of the way in which the IS-95 downlink power control operates. A frame error is typically used as the trigger for a power increase. Power is reduced a small amount for each error-free frame. When a frame error occurs, power is increased (typically by 1 dB). Therefore, even in a static situation (no fading or change in path loss or interference), frame errors will occur on a regular basis.
8. Even fairly small increases in the effective noise floor can significantly degrade PCS network coverage.

SINR and Minimum Signal Levels

Points Addressed

In its Comments, Sprint documented for the FCC the impacts of UWB interference (*e.g.*, loss of network capacity/coverage, increased call blocking) for a "fair signal (-90 dBm RSSI) PCS handset" and a "weaker signal (-100 dBm RSSI) PCS handset."[3] Time Domain in response questioned the notion that "CDMA signal levels below –95 dBm are sufficiently reliable in constitute a useful coverage area":

> If the received signal is at the minimum sensitivity of the handset of –105 dBm, then, there is no margin for a Rayleigh fade. . . . Rayleigh fades and other sources of noise are sufficiently common that the threshold for evaluation should be at a minimum –95 dBm.[4]

In response, Sprint advised the FCC that its link budgets often include a receive sensitivity for the handset of –105 dBm, and that it would incur "enormous costs if, as Time Domain suggests, Sprint PCS must redesign its networks to –95 dBm to allow for UWB interference."[5]

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3 *See* Sprint Supplemental Comments, ET Docket No. 98-153, at 4-5 (Oct. 2, 2002).

4 Time Domain Reply Comments, ET Docket No. 98-153, at 40-41 (Oct. 27, 2000)(emphasis in original).

5 Sprint Ex Parte, ET Docket No. 98-153, at 6 (Feb. 21, 2001).

The FCC Staff agreed with Time Domain's position on this issue:

> Further, the staff does not agree with Sprint that its PCS system is designed to work at a thermal noise level of –105 dBm. Such a level provides no margin for fading or from noise from other sources, *e.g.*, harmonic emissions from microwave stations and from television broadcast stations, multipath effects, and noise from other PCS stations.[6]

In making this statement concerning Sprint's network design, however, Staff acknowledged that it does "not have any data regarding the actual signal levels employed in PCS systems."[7]

This section provides background on the minimum received signal level for a PCS handset, which is shown to be on the order of 13 dB below the thermal noise floor, thereby providing adequate margin for variations in signal power and interference (for which downlink transmit power control compensates). The analysis shows that a CDMA handset in the PCS band can operate with a desired signal level of less than –111 dBm.

Analysis

If E_b is the received energy per bit on a particular uplink channel, and N_0 and I_0 are the power spectral density (watts/Hz) of the thermal noise and total interference, respectively, then the signal to interference plus noise ratio (SINR) is $E_b/(N_0 + I_0)$, which must meet or exceed some threshold for the channel to meet its frame error rate (FER) objective. That is,

$$\frac{E_b}{N_0 + I_0} \geq \left(\frac{E_b}{N_0 + I_0} \right)_{\min}, \tag{1}$$

where the threshold in general depends on a number of factors, including the multipath delay spread (which determines the RAKE diversity combining gain), interleaving depth, fade rate, type of channel coding, and the target FER.

If the intermediate-frequency (IF) channel bandwidth is W Hz and the data rate is R bps, the "spreading gain" or "processing gain" is W/R. Letting C represent the received carrier (desired signal) power, and N and I represent the noise and interference power, respectively, at the receiver, the relationships $E_b = C/R$, $N = WN_0$, and $I = WI_0$ lead to the identity:

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6 FCC Staff Report, *Potential Interference to PCS from UWB Transmitters Based on Analyses from Qualcomm Incorporated*, ET Docket No. 98-153, at 4, dated February 14, 2002, filed May 3, 2002 (hereafter, FCC PCS/UWB Staff Report).

7 *Id*. at 6.

$$\frac{E_b}{N_0 + I_0} = \frac{W}{R}\frac{C}{N+I}\,. \qquad (2)$$

Defining the "jamming margin" as

$$M = \frac{W/R}{\left[E_b/(N_0 + I_0)\right]_{\min}} \qquad (3)$$

and combining (1) and (2) gives the requirement:

$$\frac{C}{N+I} \geq \frac{1}{M}\,. \qquad (4)$$

For IS-95, $W = 1.25\ \text{MHz}$, and for rate set 2, $R = 14.4\ \text{kb/s}$ for a traffic channel. The spreading gain is therefore $W/R = 86.8$, or about 19.4 dB. With $\left[E_b/(N_0 + I_0)\right]_{\min} = 6.2\ \text{dB}$, the jamming margin is about 13.2 dB. This means that a traffic channel can operate with a received (desired) signal power that is 13.2 dB below the noise floor (thermal noise plus interference). The thermal noise floor for a PCS handset is:

$$N = -174 + 10\log\left(1.25\times10^6\right) + F \quad \text{dBm} \qquad (5)$$

where F is the handset noise figure in dB. For example, with an 8-dB noise figure, $N = -105$ dBm, and the handset sensitivity in the presence of only thermal noise is about –118.2 dBm.

Discussion

As is discussed in more detail below, the handset receives in-cell and other-cell interference, which add to the thermal noise and results in a noise plus interference level on the order of –98 dBm. Even so, the handset could still operate with a desired signal level of less than –111 dBm, which is still 6 dB below the thermal noise floor. The downlink power control will manage the power allocated to a particular handset based on the interference it receives and variation of the path loss to the handset due to fading. These factors are discussed in more detail below.

Downlink Power Allocation

Points Addressed

This section explains how the downlink allocates its total transmit power among the different CDMA channels (codes). This section does not in itself address any specific points but is necessary background to understand the overall operation of the CDMA system and to support discussion of specific points in subsequent sections.

Analysis

For each IS-95 sector, all downlink channels are code-division multiplexed onto the same RF carrier and transmitted simultaneously by the base station. This includes the overhead channels (pilot, sync, and paging), and multiple traffic channels. The total power transmitted by the base station is divided (allocated) among these channels. The power allocated to each traffic channel is updated once per frame; the power control algorithm is described in a later section.

The power allocation is managed to meet the SINR requirement for each channel. If $P_{rx,j}$ is the total downlink power received from the base station by the j^{th} handset, the desired signal power received by that handset is

$$C_j = a_j P_{rx,j} \tag{6}$$

where a_j represents the fractional power allocation to the j^{th} handset. Thus, if P_{tx} is the total downlink transmit power, then $a_j P_{tx}$ is the transmit power allocated to the j^{th} handset.

The power allocation must be set such that (4) is satisfied, where N is the thermal noise, and the interference I is the sum of in-cell interference, other-cell interference, and interference from other external sources such as UWB devices.

In-cell interference is due to power transmitted by the base station to support the overhead channels and other traffic channels. While all codes transmitted by a given base station are orthogonal, the orthogonality at the receiver is compromised by multipath and there will be some in-cell interference. This effect is represented by a "non-orthogonality factor" F_{no} ($0 \le F_{no} \le 1$). The total in-cell power allocated to other channels that is received by the j^{th} handset is $P_{rx,j}(1 - a_j)$, and the total effective in-cell interference is $F_{no} P_{rx,j}(1 - a_j)$. If perfect orthogonality is preserved over the propagation channel, then $F_{no} = 0$ and there is no in-cell interference. For system-level calculations, a typical value of F_{no} that is used is on the order of 0.5.

Other-cell interference is due to downlink signals from other sector base station transmitters. Its most significant effect occurs near the outer periphery of the cell, in outdoor situations. Other-cell interference is discussed in more detail below.

Accounting for noise plus these sources of interference as well as UWB interference gives the total SINR for the j^{th} handset as

$$\left(\frac{E_b}{N_0 + I_0}\right)_j = \frac{W}{R}\frac{a_j P_{rx,j}}{N + F_{no}(1-a_j)P_{rx,j} + I_{oc,j} + I_{uwb,j}} \qquad (7)$$

where $I_{oc,j}$ and $I_{uwb,j}$ are the other-cell interference and UWB interference received by the j^{th} handset, respectively. The minimum power allocation for the j^{th} handset is therefore

$$a_j \geq \frac{1}{M + F_{no}}\left(\frac{N}{P_{rx,j}} + F_{no} + \frac{I_{oc,j} + I_{uwb,j}}{P_{rx,j}}\right) \qquad (8)$$

For speech, $M >> F_{no}$, so the required power allocation is closely approximated as

$$a_j \cong \frac{1}{M}\left(\frac{N}{P_{rx,j}} + F_{no} + \frac{I_{oc,j} + I_{uwb,j}}{P_{rx,j}}\right) \qquad (9)$$

Discussion

This section has provided the basic downlink power allocation model needed to understand the effect of UWB interference on the CDMA system. The relationships developed here will be used in the following sections. These are the same relationships that were used in the Telcordia Model.

Received Downlink Power and Other-Cell Interference

Points Addressed

The *UWB Order* stated that:

> XSI [XtremeSpectrum, Inc.] noted that the Sprint model . . . did [not] provide an allowance for interference from other base stations although this effect is shown to be significant, resulting in as much as a 5 dB rise in the effective noise floor.[8]

XSI seems to have misunderstood the Telcordia Model and the assumed operating conditions. In fact, the Annex to the Model provides a detailed discussion of other-cell interference (OCI) and the effect of indoor operation on it. As noted on page 3 of that Attachment 1, and shown in Figure A-7 of the Annex, the impact of OCI for in-building operation is minimal and can be ignored:

[8] *UWB Order* at ¶ 158.

> For analysis of in-building performance, outer-cell interference is not a significant factor and can be ignored for even a modest amount of building loss (e.g., 10 dB).

This section quantifies the OCI for outdoor operation, and a subsequent section quantifies its impact on a PCS handset operating indoors. The model summarized here is the same as that used in the Telcordia Model.

Analysis

Both the total downlink (in-cell) power $P_{rx,j}$ and the other-cell interference $I_{oc,j}$ depend on the location of the j^{th} handset in its cell or sector. The median path loss between a base station and a handset a distance d from the base can be modeled as $L = d^{g}/k$, where k is a constant that depends on frequency, the propagation environment, and antenna gains and elevations, and g is the path loss exponent, which is normally between 3 and 4 for the mobile/portable environment. Therefore,

$$P_{rx,j} = P_{tx}/L = kP_{tx}d_j^{-g} \tag{10}$$

This same model applies individually to each of the other-cell base stations. The other-cell interference received by the handset depends not only on the distance of the handset from its base station but (weakly) on its azimuth angle q. Figure 1 shows the geometry used to compute the other cell interference. A hexagonal arrangement of base stations is assumed, and the cell radius is denoted by r.

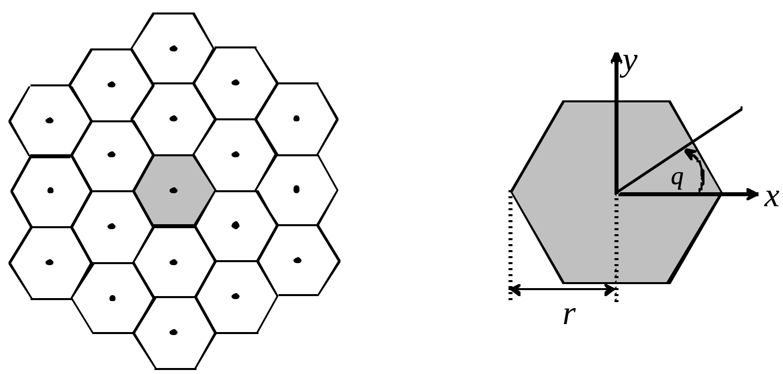

Figure 1: Geometry for calculating other-cell interference

Figure 2 shows I_{oc}/P_{rx} as a function of d/r for $q = 0$, assuming that the handset is outdoors. Indoor operation and its effect on other-cell interference is discussed later.

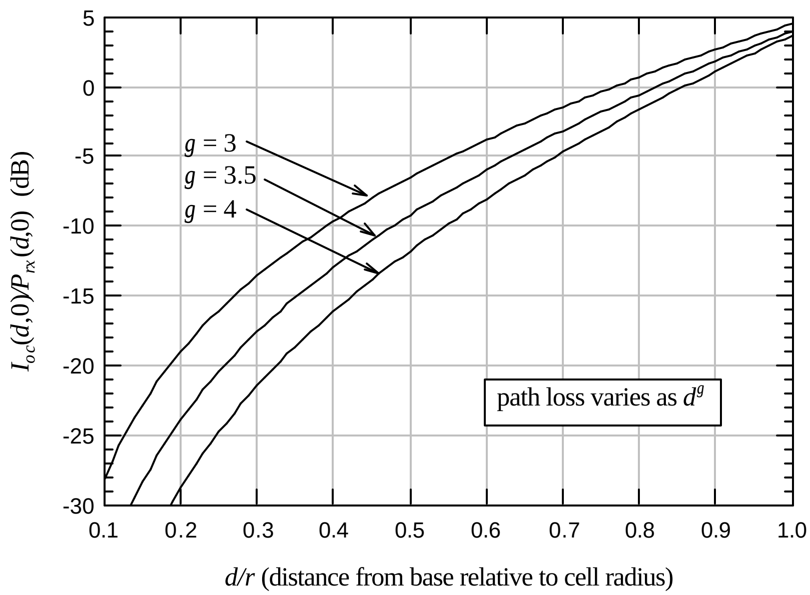

Figure 2: Ratio of I_{oc} to in-cell received power (outdoor operation, $q = 0$)

Discussion

As can be seen from Figure 2, the largest impact of OCI occurs at the cell edge. At that point, the OCI is about 4 dB above the desired signal power for $g = 3.5$, for example. That ratio will be maintained if the transmit power of all base stations is increased or reduced. Contrary to XSI's contention, the impact of OCI, as quantified by Figure 2, was taken into account in the Telcordia Model, with an allowance for a 10-dB building loss, the effect of which is explained in a later section.

It should be noted that PCS signal level limits at service area borders apply not just to the power from a single cell, but to the total power from all cells. The FCC UWB/PCS Staff Report states:

> 47 C.F.R. § 24.236 states that the median field strength at any location on the border of the PCS service area shall not exceed 47 dBμV/m. As this is the signal level established in the rules as what is necessary to prevent unintended operation in an adjacent site belonging to a different licensee, it appears reasonable that PCS systems are designed to operate at this signal level or higher. For a 50 ohm system, this emission level is equivalent to a received signal level of –96 dBm over the 1.25 MHz PCS bandwidth.[9]

The FCC Staff does not explain why it thinks it is reasonable for a PCS operator to use the maximum allowed power at the cell edge, and this assumption is not apparent (*e.g.*, why use power unnecessarily, especially when higher power risk interference with adjacent PCS systems). In any event ,

[9] *FCC UWB/PCS Staff Report* at p. 6.

the above analysis make clear that the sum of the in-cell received power and the OCI, which is subject to this limit, will be higher than the received power from a single cell.

Downlink Overhead Channels and Minimum Signal Levels

Points Addressed

As noted above, the FCC PCS/UWB Staff Report concluded that it was unreasonable to assume that a CDMA system operates at the thermal noise floor. This section addresses that point by considering the power allocation to the overhead channels (pilot, sync, paging), which unlike traffic channels, must always cover the entire cell. The SINR for these channels at the cell edge therefore must be adequate for a handset to decode them. It is shown that this objective can be met with a total received signal power at the cell edge, from each base station, at or near the thermal noise floor and that raising the cell-edge power above this level (by increasing the maximum base station transmit power) provides little benefit in terms of the power available for the traffic channels.

Analysis

The power allocations for the downlink overhead channels must also satisfy (9), except that the received power must be that at the cell edge (denoted $P_{\min}$), since the overhead channels must cover the entire cell. Without the UWB interference, the power allocation requirement for the k^{th} overhead channel is:

$$a_k = \frac{1}{M_k + F_{no}} \left(\frac{N}{P_{\min}} + F_{no} + \frac{I_{oc\max}}{P_{\min}} \right) \tag{11}$$

where M_k is the jamming margin for the k^{th} overhead channel and $I_{oc\max}$ is the other-cell interference at the cell edge. Letting

$$U_{\max} = \frac{N}{P_{\min}} + F_{no} + \frac{I_{oc\max}}{P_{\min}}, \tag{12}$$

it is clear that

$$\begin{aligned} a_{pilot}\left(M_{pilot} + F_{no}\right) &= U_{\max} \\ a_{sync}\left(M_{sync} + F_{no}\right) &= U_{\max} \\ a_{page}\left(M_{page} + F_{no}\right) &= U_{\max} \end{aligned} \tag{13}$$

where a_{pilot}, a_{sync}, and a_{page} are the power allocations and M_{pilot}, M_{sync}, and M_{page} are the jamming margins for the pilot, sync, and paging channels, respectively.

If there are K_{page} paging channels, the minimum total power allocation for the overhead channels to meet their SINR requirements at the cell edge is

$$\begin{aligned} a_{oh} &= a_{pilot} + a_{sync} + K_{page} a_{page} \\ &= U_{\max}\left(\frac{1}{M_{pilot}+F_{no}} + \frac{1}{M_{sync}+F_{no}} + \frac{K_{page}}{M_{page}+F_{no}}\right). \end{aligned} \quad (14)$$

Table 1 shows the minimum SINR, the spreading gain W/R, and the jamming margin M for the pilot sync and paging channels. With these values and a single paging channel,

$$\frac{1}{M_{pilot}+F_{no}} + \frac{1}{M_{sync}+F_{no}} + \frac{1}{M_{page}+F_{no}} \cong 0.045 \quad (15)$$

Because of the relatively high jamming margins for the overhead channels, this result in insensitive to the value of F_{no}.

Table 1: Assumed parameters for the forward link channels.

	$SINR_{\min}$	W/R	M
pilot	–16 dB	0 dB	16 dB
sync	6	30	24
paging	6	24	18

Figure 3 shows a_{oh} vs. $P_{\min}/N$ for $g = 3.5$. As can be seen, the necessary overhead allocation is not very sensitive to F_{no}, and in any event, the overhead allocation should be calculated assuming the worst case ($F_{no} = 1$). Since the curves are fairly flat for $P_{\min}/N > 0\,\text{dB}$, this suggests that from the perspective of power available for traffic channels, $P_{\min}/N \approx 0\,\text{dB}$ would be a reasonable design choice; that is the total in-cell received power at the cell edge is roughly equal to the thermal noise floor of the PCS handset. The total overhead channel power allocation requirement in that case is on the order of 20% ($a_{oh} \approx 0.2$).

A tradeoff is evident from these curves. On one hand, it is desirable to minimize the power allocation required for the overhead channels, since the total power allocation available for traffic channels is $1 - a_{oh}$ (the sum of all the power allocations is 1). On the other hand, increasing $P_{\min}$ requires either (1) making the cells smaller; or (2) increasing the base station power output, which requires changing the transmit power amplifiers. Neither of these is practical.

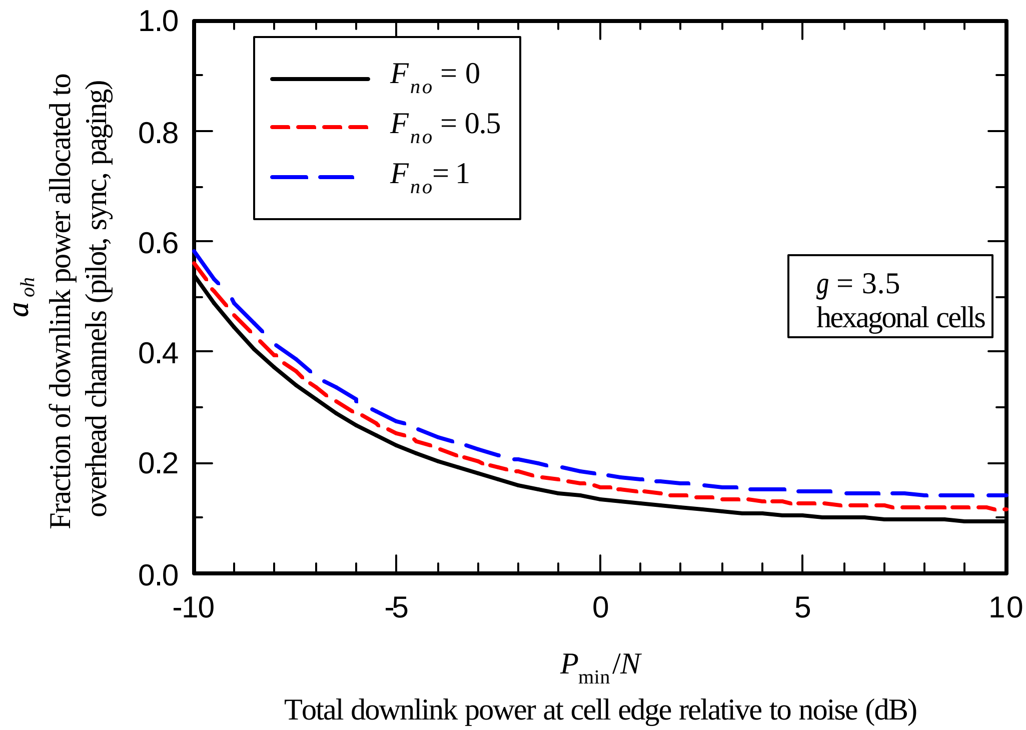

Figure 3: Total overhead channel power allocation requirement vs. $P_{\min}/N$

Discussion

From a system design perspective, there is little benefit to increasing the cell-edge power significantly above the thermal noise floor. For example, if the cell edge power is 1 dB above the thermal noise floor (–104 dBm for a noise floor of –105 dBm), then with $F_{no} = 0.5$, the required overhead channel power allocation is about 14.8%. Increasing the cell-edge power by 5 dB reduces the required overhead channel power allocation to about 12.3%. Since the power allocations (overhead plus traffic) must sum to 1, this has the effect of increasing the power allocation available to traffic channels from 85.2% to 87.7%, an increase of less than 3%. This is not a good engineering tradeoff; unnecessary power increases complicate such factors as power amplifier design and suppression of spurious emissions.

The FCC Staff Report states that it is "not reasonable to design a communications system at or near the thermal noise floor of the receiver."[10] In fact, the analysis shows that it is quite reasonable, and in fact consistent with sound design practice, to operate a CDMA system with a cell-edge power at or near the handset thermal noise floor. The analysis accounted for in-cell interference, OCI, and thermal noise.

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[10] FCC PCS/UWB Staff Report at 5.

Indoor vs. Outdoor Operation

Points Addressed

The *UWB Order* specifies indoor UWB emission levels in the PCS bands that are higher than those allowed for outdoor devices. In fact, the levels for indoor UWB devices should be lower than those for outdoor devices, because, as is shown here, indoor PCS handsets are more sensitive to external interference than are outdoor handsets due to building penetration loss. The analysis presented here shows the coverage loss experienced by a PCS handset due to UWB interference vs. the distance between the PCS handset and the UWB transmitter. For a given coverage loss and a given distance, the indoor emission limits must be at least 5 to 6 dB lower than the outdoor limits.

Analysis

Figure 4 shows the other-cell interference power vs. the received in-cell power, assuming the received power at the cell boundary is –104 dBm, and assuming that the handset is operating outdoors, for $q = 0$. Figure 5 shows $(I_{oc} + N)/N$ vs. P_{rx}. As can be seen, $(I_{oc} + N)/N \cong 6.4\,\text{dB}$ at the cell edge.

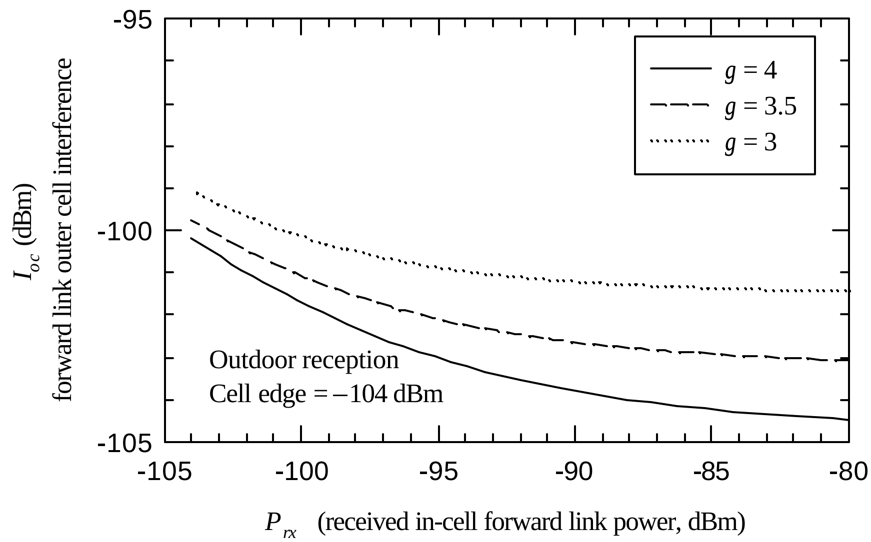

Figure 4: Other-cell interference vs. in-cell received power (from the Telcordia model, Fig. A-1).

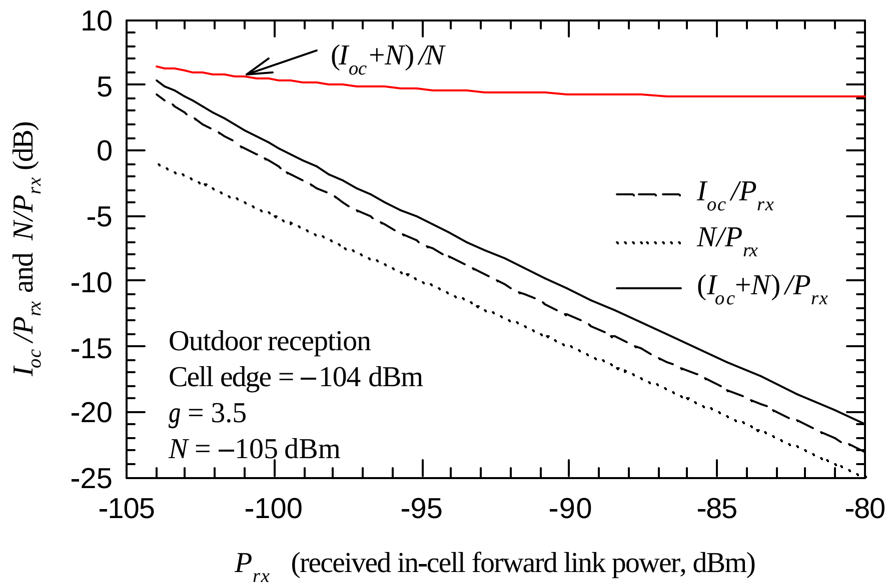

Figure 5 (from the Telcordia model, Fig. A-3).

If the handset is inside a building, both the desired signal and the OCI will be reduced by the building penetration loss. Figure 6 shows the same quantities as Figure 5, except a 10-dB building loss has been assumed, as in the Telcordia model. In this case, $(I_{oc} + N)/N$ is about 0.75 dB for $P_{rx} = N$.

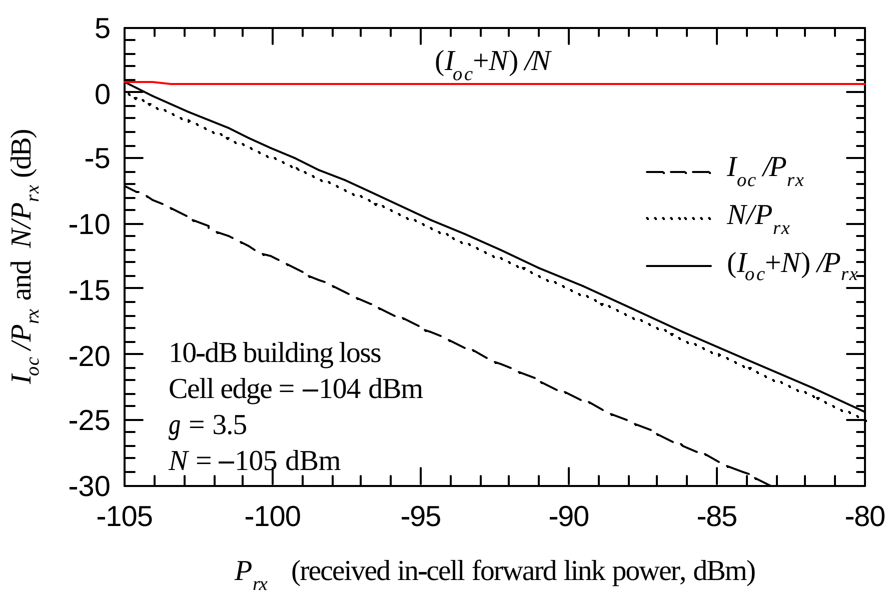

Figure 6: In-building reception (from the Telcordia model, Fig. A-7).

Because of the building loss, the IS-95 downlink is somewhat more sensitive to external interference with indoor handsets than outdoor handsets. To see this, (9) can be written as:

$$Ma - F_{no} = \frac{N + I_{oc}/L_{bldg} + I_{uwb}}{P_{rx}/L_{bldg}} \qquad (16)$$

where L_{bldg} is the building penetration loss, and I_{oc} and P_{rx} are the OCI and desired signal levels, respectively, that would be received by the handset without the building loss. Therefore,

$$\frac{P_{rx}}{L_{bldg}} = \frac{N + I_{oc}/L_{bldg} + I_{uwb}}{Ma - F_{no}} \qquad (17)$$

Without the UWB interference, the required received desired signal power for a power allocation of a is

$$\frac{P_{rx0}}{L_{bldg}} = \frac{N + I_{oc}/L_{bldg}}{Ma - F_{no}} \qquad (18)$$

and the ratio of the required power with the interference to the required power without it is

$$\frac{P_{rx}}{P_{rx0}} = \frac{N + I_{oc}/L_{bldg} + I_{uwb}}{N + I_{oc}/L_{bldg}} = 1 + \frac{I_{uwb}}{N + I_{oc}/L_{bldg}} \qquad (19)$$

Assuming path loss varies as d^{g}, the coverage area available to a handset suffering UWB interference at a level I_{uwb} is therefore

$$\frac{A_{w/uwb}}{A_{no\ uwb}} = \left(\frac{P_{rx}}{P_{rx0}}\right)^{-2/g} = \left(1 + \frac{I_{uwb}}{N + I_{oc}/L_{bldg}}\right)^{-2/g} \qquad (20)$$

If the UWB device radiates a power level of Φ_{uwb} dBm/MHz, then the power received by a PCS handset a distance *d* meters from the UWB transmitter, assuming free-space path loss, is

$$I_{uwb} = \Phi_{uwb} + 1 - 38 - 20\log d + G_{HS} \qquad (21)$$

where G_{HS} is the PCS handset antenna gain, assumed 0 dBi in the following examples. The 1 dB is added in (21) to account for the difference between the 1 MHz reference bandwidth for the UWB emission limit and the 1.25 MHz bandwidth of the IS-95 channel. The free-space path loss at 1 meter is 38 dB.

Figure 7 shows the IS-95 PCS coverage area reduction vs. the distance *d* between the UWB transmitter and the PCS handset, assuming the FCC UWB outdoor emission limit of –63 dBm/MHz. As can be seen, the effect is more severe for indoor handsets. A 9-dB building loss was assumed for the indoor case because this is the level the FCC used in the *UWB Order* for the GPS band.[11]

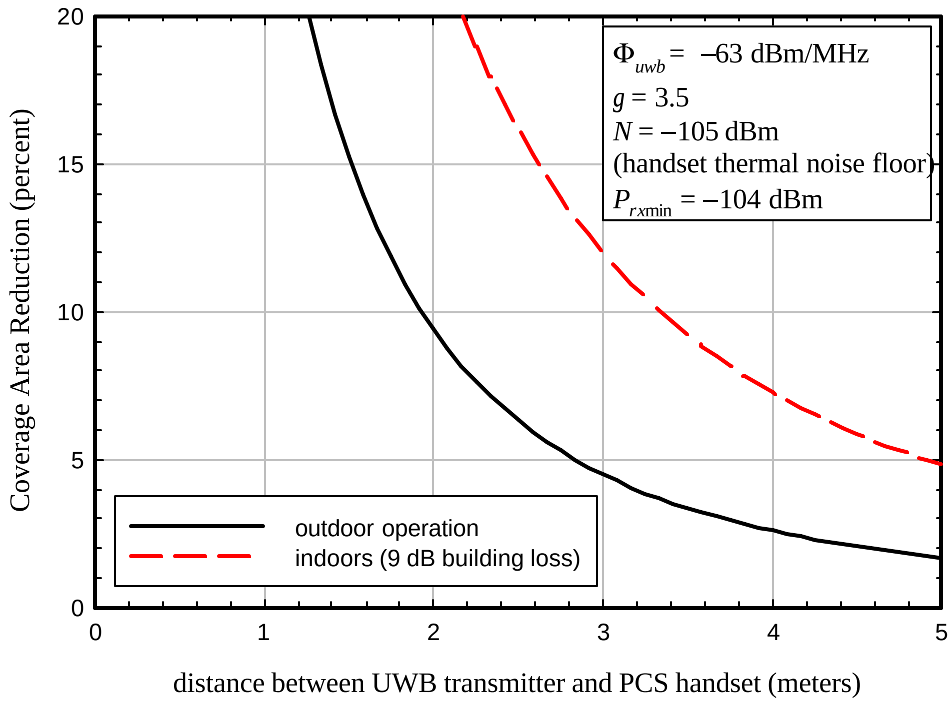

Figure 7: IS-95 PCS coverage area reduction due to UWB interference at the FCC outdoor limit.

Figure 8 shows the effect on the indoor PCS handset of reducing the UWB emissions in the PCS band to –68 dBm/MHz. At that level, the effect is comparable to that of a –63 dBm/MHz UWB device on an outdoor handset.

[11] *See UWB Order* at ¶ 97. The NTIA Study upon which the FCC based its building loss attenuation suggests that a somewhat higher attenuation factor is appropriate for the PCS band. Moreover, commercial operators often use even higher attenuation factors in practice to preserve the level of service quality that customers have come to expect. However, regardless of the specific factor used, UWB emissions levels should be more stringent indoors than outdoors.

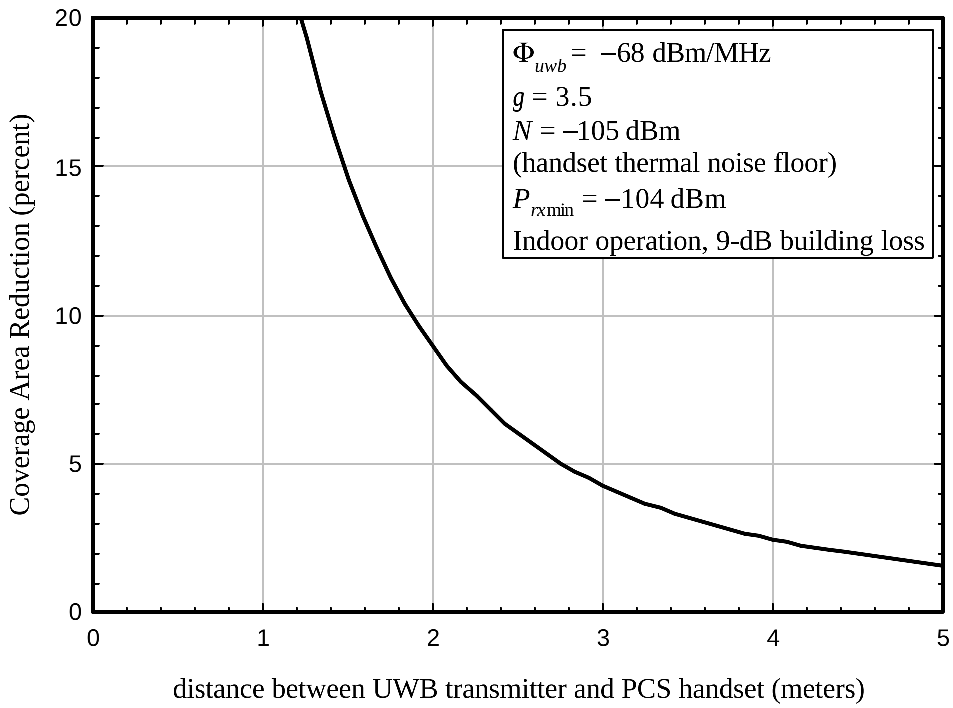

Figure 8: Effect of reduced UWB emission limit for indoor operation

If $P_{rx\min} = -100$ dBm instead of –104 dBm, the effect on coverage is shown in Figure 9. As would be expected, the effect of the UWB interference is reduced due to the stronger PCS downlink power. However, the other-cell interference has also increased by 4 dB and is therefore stronger relative to thermal noise than in the –104 dBm case. This means that there is a greater difference between the indoor and outdoor cases. Instead of a 5-dB difference, the indoor UWB level must now be reduced by 6.5 dB for parity with the outdoor impact, as shown in Figure 10, which shows the indoor PCS coverage impact with a UWB emission limit of –69.5 dBm/MHz and a –100 dBm minimum PCS signal level.

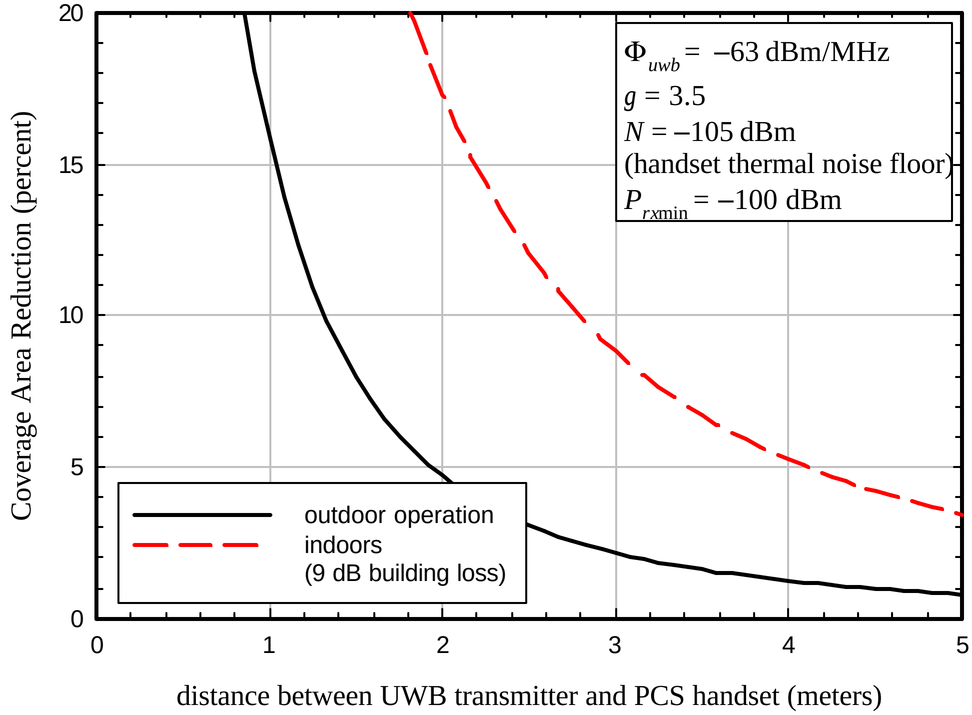

Figure 9: Coverage reduction if the cell-edge signal level is –100 dBm.

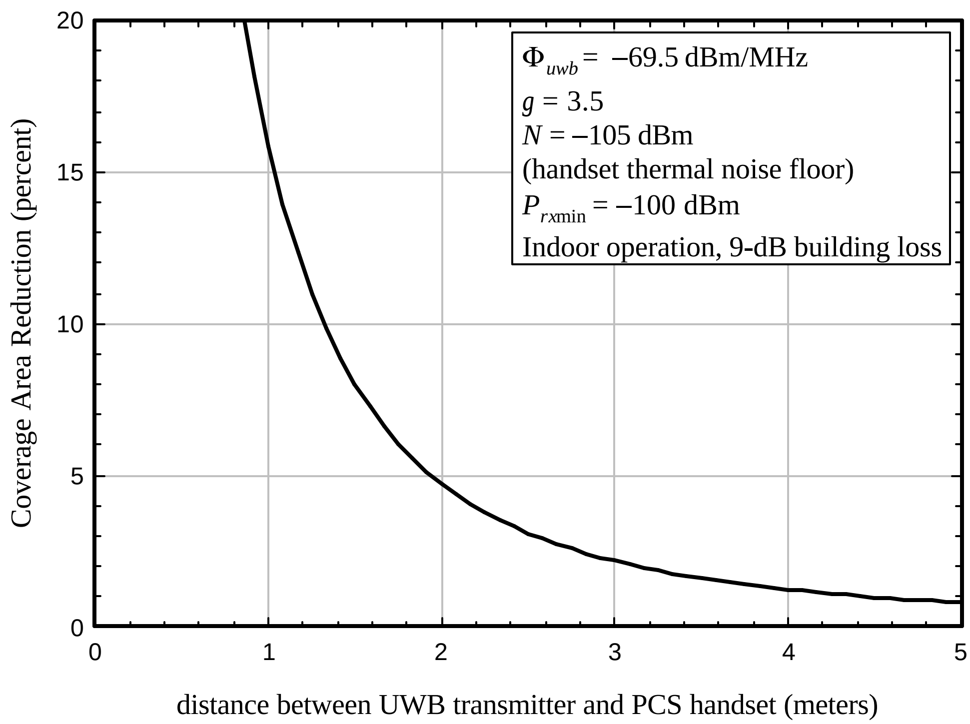

Figure 10: Indoor PCS coverage impact with –100 dBm cell edge signal and –69.5 dBm/MHz UWB emission limit

In general, the ratio of indoor to outdoor UWB emission limits, for the same PCS coverage reduction, is given by:

$$\frac{\Phi_{uwb,in}}{\Phi_{uwb,out}} = \frac{N + K_{oc} P_{rx\min} / L_{bldg}}{N + K_{oc} P_{rx\min}} \tag{22}$$

where $K_{oc} = I_{oc\max} / P_{rx\min}$, the ratio of the OCI to the total in-cell received power at the cell edge. In the examples used here, for $g = 3.5$, $K_{oc} = 4\,\text{dB}$. As $P_{rx\min}$ is increased, the OCI term becomes more dominant compared to thermal noise, and the effect of the building loss becomes more significant.

Overall, what is clear from this analysis is that indoor UWB levels should be lower than outdoor levels, for comparable impact on the coverage of the PCS downlink.

Discussion

The *UWB Order* specifies an outdoor UWB emission limit in the PCS band of –63.3 dBm/MHz and an indoor limit of –53.3 dBm/MHz. From the calculations given here, the outdoor limit will cause a network coverage reduction of about 4% if the UWB device is 3 meters from the PCS handset. Assuming the accuracy of the –63.3 dBm/MHz outdoor emissions level and for a 4% reduction at 3 meters indoors, the indoor UWB emission limit would need to be –68.3 dBm/MHz to about –70 dBm, depending on the value of the PCS minimum signal level ($P_{rx\min}$) used to establish the protection limits.

Fading

Points Addressed

The *UWB Order* notes that:

> XSI stated that it is important to note that the anechoic chamber eliminated all external RF noise and any potential interference due to other CDMA cells or multi-path which it says are the most important factors in understanding potential interference for a PCS network.[12]

The *Order* also states:

> XSI concluded that the live testing by Sprint PCS showed that effects such as interference, noise, and Rayleigh fading were severe enough to mask any effects predicted by the analytical model . . . [13]

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[12] *UWB Order* at ¶ 158.

[13] *Id.*

Analysis

These statements summarize two misconceptions that seem to have influenced the FCC's decisions. First, although multipath fading is indeed a factor in real-world operation of any mobile radio system, it does not "mask" any interference that effectively raises the noise floor. If the desired signal must be X dB with respect to the noise floor (X can be negative in the CDMA case), and some margin Y dB must be allowed for fading, then the average received signal level must be $X+Y$ dB relative to the noise floor (the exact value of the margin will depend on the fading statistics). The average received signal level therefore must be $N+X+Y$ dBm. If the noise floor is raised by some amount Δ dB due to UWB interference, then the average received signal level must be $N+\Delta+X+Y$ dBm. The effective noise floor increase therefore translates directly to an increase in the required receive signal power, whether the desired signal is fading or not. The supposition that fading somehow "masks" the effect of external interference is therefore incorrect.

The second misconception is that Rayleigh fading statistics are appropriate for CDMA systems. In fact, CDMA handset receivers use multi-branch RAKE receivers, which coherently combine different multipath clusters as diversity branches to dramatically reduce the variations due to fading. The effect is illustrated by comparing Figure 11 and Figure 12. Figure 11 shows a Rayeigh faded signal for a frequency of 1.9 GHz and a speed of 2 mph vs. the frame count (20 milliseconds per frame for IS-95).

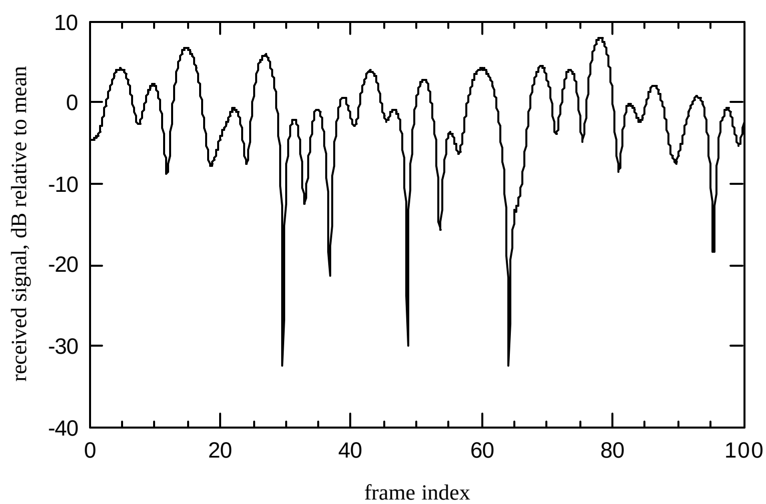

Figure 11: Rayleigh-faded PCS signal for a speed of 2 mph

Figure 12 shows the output of a 3-branch maximal ratio combiner (3-branch MRC is typically used in IS-95 handsets), where each branch is tracking an independently Rayleigh-faded signal. Equal average power was assumed for all three branches. As can be seen, the variation in the signal power is dramatically reduced.

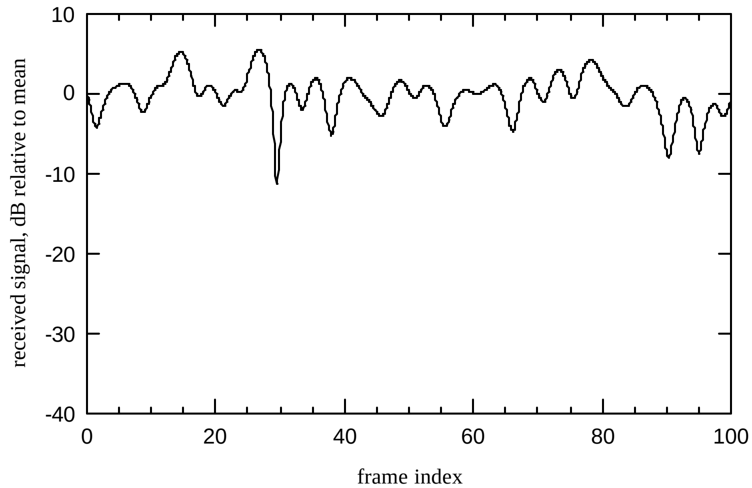

Figure 12: Output of 3-branch maximal ratio combiner, 3 independent Rayleigh paths

Discussion

It is clear from the simple analysis above that fade margin and external interference as additive effects; fading does not serve to "mask" the effect of UWB interference or make it less significant. Further, if the required average signal power is increased due to fading, then the effect can be viewed as a reduction in the jamming margin *M*, but the coverage area reduction derived above is independent of *M*, so the results in Figures 7-10 apply for faded as well as non-faded PCS signals. It is also clear that with CDMA, the effects of fading on the required signal power are not nearly as severe as would be suggested by considering a pure Rayleigh model, due to the effect of the RAKE receiver and the multipath diversity that it provides.

Power Control

Points Addressed

The *UWB Order* states that:

> According to TDC [Time Domain Corporation], the model developed by Telcordia predicted that in an anechoic chamber IS-95 cellphones should not experience frame error rates greater than 2 percent at received signal levels as low as –105 dBm; however, in the open field the FER would jump momentarily to as much as 8 percent even when the received signal was as great as –85 dBm. TDC adds that extrapolation from testing suggests that the impact of the UWB emission on PCS might be observable when the PCS signal is marginal, at –95 dBm, and the UWB devices is continually transmitting and within 1.5 meters.[14]

[14] *UWB Order* at ¶ 157.

These statements suggest that frames error rates are somehow indicative of a marginal signal level condition. This is not the case for CDMA systems.

Analysis

The IS-95 downlink power control operates as follows. Each frame includes a checksum that is used by the handset to determine whether there are any bit errors in the received frame. If so, a frame error is declared and the base station increases the downlink power allocation to the handset by a step (e.g., 1 dB) on the next frame. If there is no frame error, then the power is reduced by a small increment (e.g., 0.02 dB). The reductions continue, one per frame, until another frame error occurs. Thus, even in a static situation (no fading, and constant interference) and a strong received signal level, two things will be observed: (1) the transmitted downlink power allocated to the traffic channel will constantly vary; and (2) frame errors will occur regularly. If there is fading, obviously there will be more variation in the downlink traffic channel power. There may also be an occasional burst of high frame error rates, because a number of frames may be required for the power control to adjust to the fade (a 6-dB fade would require 1-dB increases in 6 successive frames). It is therefore normal to observe frame errors in the IS-95 downlink, even at strong signal levels. The presence of frame errors has no significance other than to indicate that power control is operating as expected.

Discussion

The observation that frame errors occurred at strong signal levels has no relevance to determining what constitutes a "marginal" IS-95 signal level, and no relevance to analysis of UWB interference effects on IS-95 PCS systems.

Noise Floor Increases

Points Addresed

The FCC PCS/UWB Staff Report discusses at several points the use of effective noise floor increases as measures of the impact of UWB interference on PCS systems. In particular, statements in that Report include:

> The staff's primary concern with Qualcomm's analysis, after correction of its calculation on propagation loss, is that Qualcomm based its definition of harmful interference on any emission greater than 6 dB below the thermal noise floor of a PCS receiver. While such an analysis can determine if a signal will increase the receiver noise floor in situations where no RF background noise exists, this is not indicative of harmful interference in a communications system.[15]

> For a radiocommunications service, such as PCS, harmful interference is defined as interference that seriously degrades, obstructs, or repeatedly interrupts. . . . [T]he staff sees no basis for protection of PCS receivers from a signal level that increases the thermal noise floor of the receiver by

[15] FCC PCS/UWB Staff Report at p. 4.

1 dB, *i.e.*, from an emission that is 6 dB below the PCS receiver thermal noise floor.[16]

Analysis

To address these statements, it is useful to express the results of Figure 7 in terms of both the received UWB interference relative to thermal noise (I_{uwb}/N), and also the effective increase in the noise floor, which is $(I_{uwb}+N)/N$, shown in Figure 13 and Figure 14, respectively. As can be seen, even received UWB interference levels several dB below the thermal noise floor (assumed –105 dBm) cause a significant coverage degradation.

The FCC PCS/UWB Staff Report in fact alludes to this effect, stating: "A higher receiver noise figure simply means that the PCS mobile unit needs to be closer to the base station or that the base station needs to operate at a higher power than would be required if the mobile receiver had a lower noise figure."[17]

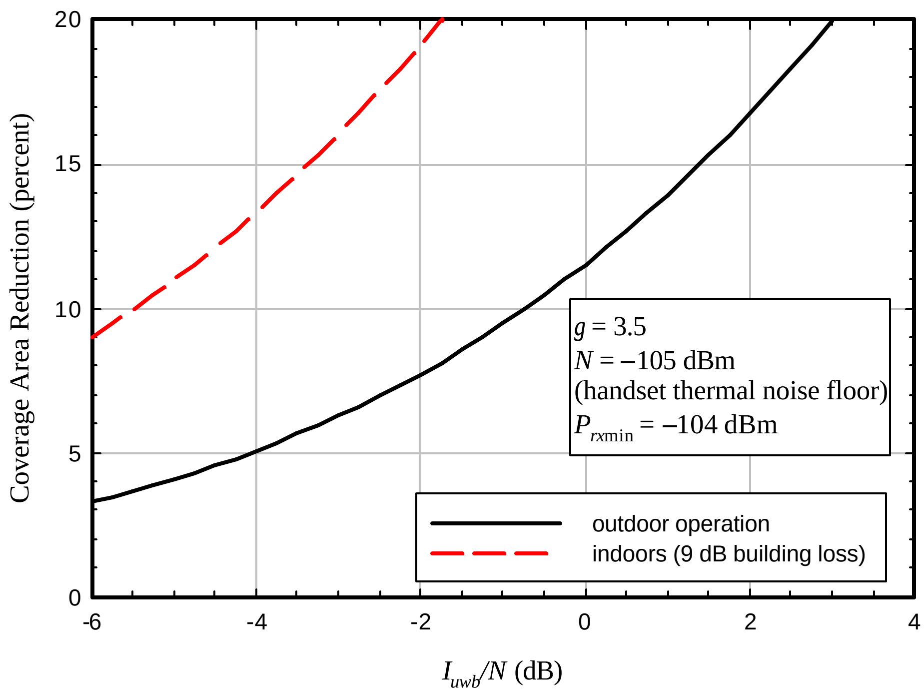

Figure 13: Coverage area reduction vs. received UWB interference power relative to the thermal noise floor of the PCS handset

[16] *Id*.

[17] *Id*. at 5.

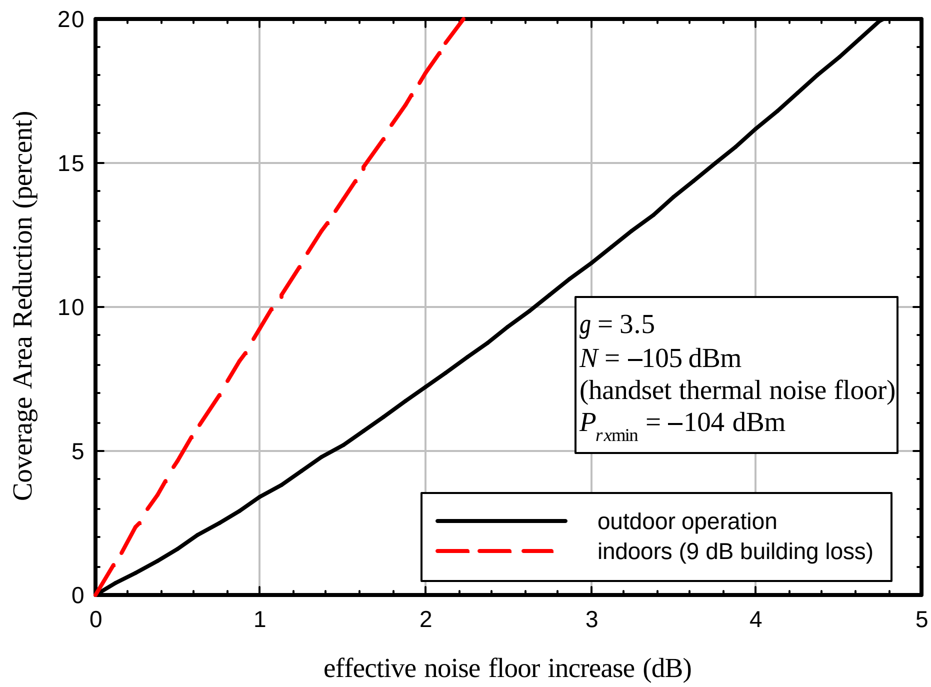

Figure 14: Coverage area reduction vs. effective increase in thermal noise floor due to UWB interference

Discussion

Although there is no definition provided for "serious degradation," it is clear from the above results that even a 1-dB effective noise floor increase will cause a non-negligible coverage degradation for outdoor handsets, and a significant (about 9%) coverage degradation for indoor PCS handsets. Also, Figure 13 clearly shows a difference of nearly 5 dB in the sensitivity of indoor handsets to UWB interference, compared to outdoor handsets.

The Staff is correct that a noise floor increase dictates that either the handset must move closer to the base station, or the base station power must be raised. The first remedy is equivalent to stating that the noise floor increase has reduced coverage (otherwise the handset would not need to move), which agrees with the analysis presented here. The second remedy (increased downlink power) is impractical. Higher power linear amplifiers for CDMA systems generally are not available from manufacturers, and even if they were, there would be significant implications on cost as well as engineering aspects such as cooling.