Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
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

COMMENTS OF LUCENT TECHNOLOGIES INC.

Introduction

Lucent Technologies Inc. ("Lucent") hereby submits its comments in response to the Commission's Notice of Inquiry and Notice of Proposed Rulemaking, released November 28, 2003, in the above referenced proceeding. Lucent limits its comments to issues raised in the NOI/NPRM and specifically contends that the interference temperature concept should not be used in the CMRS bands.

The Commission seeks input on its proposal to shift the paradigm for interference management from a transmitter focus, typically described in terms of maximum transmitted power and limits on out-of-band emissions to a receiver focus, expressed in a new metric identified as interference temperature (ITemp). The Commission suggests that a receiver focused view of interference management and the associated use of ITemp will provide additional, presently unrealized opportunities for unlicensed devices, and could reduce a licensee's uncertainty relative to the level of interfering RF energy in its assigned band.

As a vendor of commercial mobile radio service (CMRS) infrastructure, Lucent is naturally interested in the environment in which its equipment must operate, and the manner in which that environment is measured, managed, and controlled. Specifically, Lucent is concerned with the possibility that a modification to the current paradigm of interference management, if implemented in the CMRS bands, might create a burden to the operation of CMRS systems deployed by Lucent's carrier customers. In fact, Lucent's investigation and analysis suggests that the introduction of ITemp and the associated proposition that its use will support the operation of unlicensed devices as underlays will indeed be detrimental to CMRS operators.

Unlicensed Underlays Should Not Be Permitted in CMRS Bands

The concept of ITemp is schematically described in Figure 1 of the NOI/NPRM.[1] As clearly represented by this Figure, the use of ITemp will necessarily allow an increase in the noise floor and consequently reduce the coverage of the primary, licensed user. Lucent agrees with

[1]NOI and NPRM, para. 15

this representation and further suggests that the adverse impact on the incumbent, licensed system will be significant. Within the CMRS bands, the current and future deployment of third generation systems – CDMA2000 and UMTS – will further the already widespread use of spread spectrum technology. Although spread spectrum systems include mechanisms to mitigate the effects of internally generated system noise, they are susceptible to degradation caused by noise from external sources.

Spread spectrum systems use complex signal processing to permit the use of multiple users in the same frequency space. For any given user the processing identifies and extracts the signal containing the desired conversation and represents signals from all other conversations as noise. The signal processing further minimizes this residual noise contributed by the multiple users, increasing the desired signal to noise ratio for a given conversation.

Spread spectrum systems also use system based instantaneous power control, which permits the receiving base station to adjust the transmitted power from every mobile terminal to the minimum effective level. This is important because each user competes not only with the natural noise floor of the environment (kTB plus the system noise figure) but also with noise generated by the coding and processing of signals from the other mobile system users. By keeping all competing mobile users at their minimum power level, the internally generated noise is kept to the lowest level possible.

This permits an increase in the total number of users up to the level where the internally generated noise degrades the desired signal to noise ratio, and call quality is adversely impacted. The presence of additional sources of noise, such as that caused by out-of-band energy from interferers in adjacent spectrum, or by external inband sources such as unlicensed devices, necessarily and significantly degrades the signal to noise ratio and negatively impacts the call quality of the victim system, both in range (the coverage area of the cell that can be adequately served by a single base station) and in capacity (the number of simultaneous users or aggregate rate of data transmission that can be achieved in one cell). Restoration of coverage and capacity in the presence of such interference will require action by the victim system's operator. The desire to maintain system capacity would demand the addition of more cell sites in a given area. The only other alternative for the operator of such a victim system is the acceptance of reduced capacity within the existing defined cells.

A Lucent Study

Lucent has investigated the impact of external noise on CDMA systems, specifically by examining the effect on reverse link coverage and capacity. The Lucent study (included as an attachment) explains that call quality at the base station receiver is ideally a function of the propagation path loss, the base station receiver noise floor, and the loading factor (or number of desired active subscribers). The Lucent study also notes that the maximum allowable path loss dictates cell size or coverage and, therefore, the maintenance of a given level of call quality can require a trade off between cell coverage and capacity (loading). Specifically, to maintain call quality when there is an increase in base station receiver noise caused by external interference, it is necessary to reduce the maximum allowable loss and the associated cell coverage, or reduce the loading (number of subscribers) supported by the system. Practically, if it is desired to maintain system capacity, a reduction in cell size is necessary. Similarly, a desire to retain a given cell size will require a reduction in system capacity.

Although a quantitative assessment of the impact of external noise is subject to specific scenarios and system values (e.g., propagation slope, receiver noise figure and sensitivity), the study offers examples that, based upon given assumptions, indicate the impact is significant. The results (which assume a propagation loss of 35 dB/decade) are shown graphically in Figure 1, below.

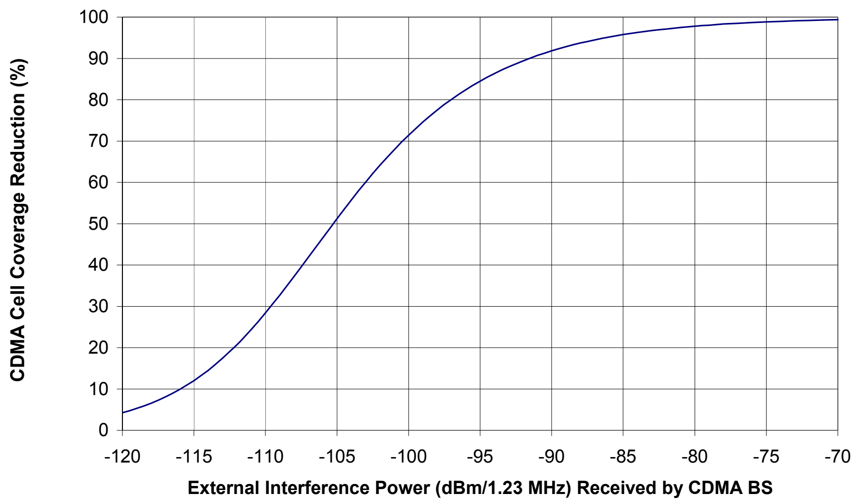

Figure 1 – Effect of Average External Interference Power on CDMA Reverse Link Cell Coverage

As an example, if system capacity is to remain constant, the effect of an external noise power of –109 dBm, equal to the assumed receiver noise floor of –109 dBm, will demand a 30% reduction in cell coverage(relative to the situation where there exists no external interference). If the strategy is to maintain cell size (i.e., coverage), external noise equal to the receiver noise floor of –109 dBm demands a capacity loss of about 80% (Figure 2, below).

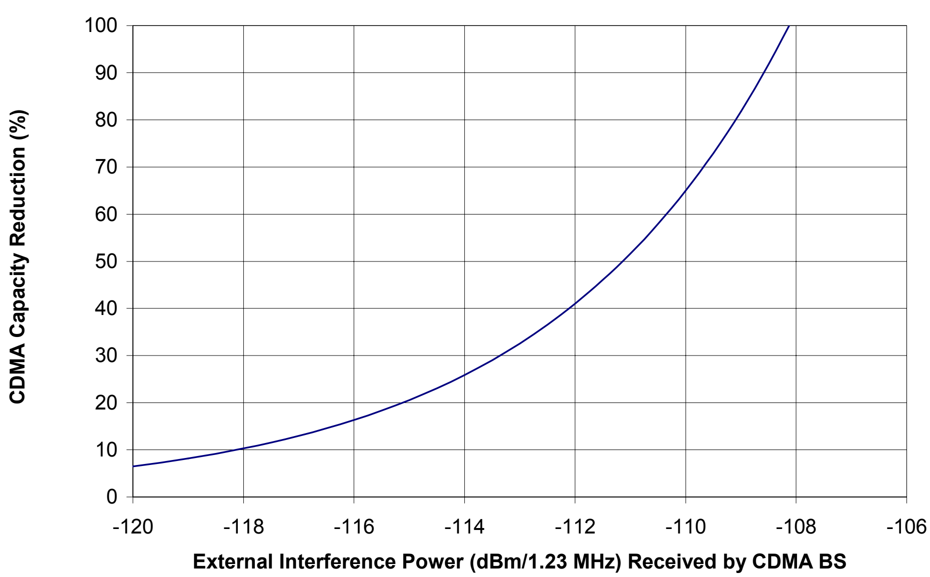

Figure 2

The Commission asks, "whether a modest rise in the noise floor, such as envisioned by the interference temperature concept, would generally not cause harmful interference as defined under our rules."[2] It further notes "harmful interference is defined by our rules as interference that causes serious detrimental effects as opposed to interference that is merely a nuisance or annoyance that can be overcome by appropriate measures."[3]

Cell site design is based upon a link budget that contains a multitude of parameters, including the noise floor. Only minimal levels of external interference are typically considered, perhaps sufficient to raise the noise floor by 0.1 dB. Accordingly, any increase in the noise floor above this minimal level, such as that potentially allowed by the establishment of an ITemp level and caused by the expanded use of unlicensed devices, will, as indicated by the figures above, degrade the coverage and/or capacity of the victim, licensed system. In order to remedy the impact of the additional noise and provide an appropriate level of service for its customers, a carrier would likely increase the number of cell sites. Given the intense price and cost pressures on CMRS operators within their competitive markets, and the large costs associated with the addition of cell site equipment, Lucent suggests that the economic burden associated with the costs of additional cell sites rises well above the level of a "nuisance" and should be considered harmful.

The CMRS Bands Will Not Support Shared Use

Even if the use of ITemp and its associated support of the broad use of unlicensed underlays were permitted in the CMRS band – notwithstanding the degradation in coverage/capacity that could occur – it appears that such an arrangement could not be effectively deployed. The ITemp concept suggests that a rise in the noise floor (up to the ITemp level established for the band and area) would provide "headroom" in which unlicensed devices might operate. Indeed, Figure 1 in the NOI/NPRM clearly represents that the ITemp level – elevated above the original noise floor – would provide new opportunities for spectrum access. However, this very "headroom" is built into the link budget of CMRS spread spectrum systems and is inherently used to effectively provide the required capacity to meet subscriber demand. Accordingly, the "headroom" would rarely, if ever, be available to the underlay devices. Perhaps the only time that an underlay system could possibly have access to spectrum would be at off-peak hours, if and when the CMRS system had little demand.

Moreover, it should also be recognized that system energy is always present on CDMA system forward links. Specifically, pilot signals are continuously transmitted. Accordingly, an unlicensed device seeking to use this frequency space based on the absence of energy would have difficulty finding an opportunity to do so.

[2] NOI and NPRM, para. 27
[3] Id.

Wireless Unlicensed Devices Have Been Successfully Deployed in Dedicated Spectrum

Wireless unlicensed devices have provided valuable services including wireless local area networks (WLANs) that offer high speed access in designated areas. Lucent recognizes the benefit of such services and has developed capabilities that support interoperability between the WLANs and CMRS networks. The significant amount of spectrum allocated for unlicensed use (130 MHz below 3 GHz and 380 MHz in the 5 GHz band) allows unlicensed devices to operate consistent with the mandate of Part 15 that they do not cause interference to any licensed user. Unlicensed devices should continue to operate in such dedicated spectrum; not as underlays in spectrum allocated and assigned to licensed operators.

Technology Used in CMRS Bands is Spectrally Efficient

The highly competitive CMRS market has supported the deployment of increasingly more efficient radio technologies. As shown in the chart below (Figure 3), the spectral efficiency of CMRS technology has increased 30 times relative to that provided by the original analog AMPS systems. Accordingly, the Commission need not look to the use of unlicensed devices as a means to improve the spectral efficiency of the technologies used in the CMRS bands.

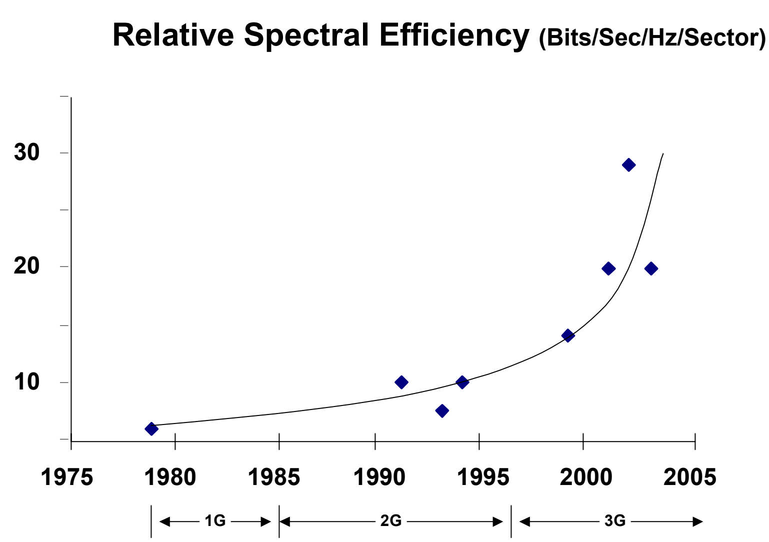

Figure 3

Conclusion

There exists little, if any, opportunity for unlicensed devices to realize untapped opportunities for spectrum access in the CMRS band. Any noise margin or "headroom" envisioned through the use of the Interference Temperature concept would be used by the spread spectrum technologies employed by CMRS operators and would, therefore, be unavailable to unlicensed devices. Moreover, even if unlicensed devices could operate in the CMRS band, the increase in external noise generated by unlicensed underlays is problematic as it would necessarily degrade the incumbent system's coverage and/or capacity. Licensed operators in the CMRS band should not be subject to this additional interference and the resulting need for additional base stations.

Lucent appreciates the Commission's recognition that "it will take a significant period to develop the underlying information, analyses and policy plans needed to fully implement the interference temperature concept across all feasible frequency bands."[4] Lucent would add, however, that considerable effort and time is likely necessary to determine if the concept does, in fact, offer the benefits the Commission envisions, and whether its implementation is practicable.

Respectfully submitted,

Lucent Technologies Inc.

By: /s/ Robert A. Geilich
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April 5, 2004

[4] NOI and NPRM, para. 29

Attachment – Comments of Lucent Technologies Inc. - ET Docket No. 03-237

Lucent Technologies
Bell Labs Innovations

Subject: **Impact of External Interference on CDMA**

1. Introduction

This document discusses the impact of reverse link external (non-system) interference to a CDMA system. General coverage and capacity degradations are considered. The computations underscore the need to adequately clear spectrum of all sources of external interference in order to achieve system performance.

The definitions of *external interference* and *performance degradation* in this context must be offered with care. In network applications, the CDMA Base Station (BS) clearly receives in-band interference from other CDMA mobiles. In our discussions, we reserve the term *external interference* for in-band interference from all possible sources except the operating CDMA system. The term *performance degradation* refers to the performance impact relative to the performance achievable with clean spectrum. These definitions are further expanded, below.

Pre-commercial spectrum sweeps can determine the level of external interference present within the CDMA system. Full spectrum clearance can yield maximal capacity and coverage; however, if spectrum cannot be cleared, the presence of external interference can be compensated for *in design* through sacrifice of capacity and/or coverage. Such design solutions, although valid, are generally not considered acceptable by operators since this strategy implies that scarce, expensive radio spectrum is not being used to its full potential. For example, "noisy" spectrum can be tolerated if cells *in design* are spaced sufficiently close together; alternatively, noisy spectrum may be acceptable at full coverage if the system's design capacity is appropriately reduced.

In the following, we presume full spectrum clearance in design. *The performance degradation as a function of external interference is therefore relative to maximum coverage or maximum capacity*. The results can therefore be interpreted in two ways:

- The values can be used in design planning to trade off the ability to clear radio spectrum against the performance degradation caused by embedded interference. For example, a narrowband interferer at –115 dBm can degrade cell coverage relative to that achieved by clean spectrum by 10%. If this interferer cannot be removed, the network can still achieve full capacity provided that the design coverage is reduced by this amount. Note that, strictly speaking, this interpretation can apply only to steady-state sources of interference, since—by definition—transient sources are difficult to capture or characterize, thus making it impractical to compensate for their impact in design.

- The values can be used to project the performance impact for existing networks *originally deployed with clean spectrum* where new interference sources develop. This interpretation may be more useful for mature markets, where cell site spacing is already well established. Any performance impact on existing networks must be relative to an original (baseline) spectrum present at the time of deployment*; in this interpretation, the impact is relative to a presumed baseline clean spectrum.* Original (baseline) coverage and capacity for the network were therefore at optimal values prior to the introduction of the new interference. The degradation caused by new interference for a network deployed with a baseline spectrum that was already noisy at the time of deployment requires additional (but similar) calculations. If the interference is short-lived, these effects may be more apparent as transient sources of origination failure or dropped calls rather than constant, systematic impacts on coverage or capacity.

The rest of this memorandum is organized as follows: Section 2 addresses the relationship between the average external interference power and the CDMA reverse link coverage. Section 3 discusses the relationship between the average external interference power and the CDMA reverse link capacity. Section 4 provides a summary.

2. Effect on Reverse Link Coverage

In the typical CDMA reverse link budget for RF planning, no margin is allocated for external interference. If the cell layout is designed to the maximum allowable propagation loss dictated by the link budget analysis, the receiver noise rise caused by external interference may result in a reduction in the maximum propagation loss (used to determine the cell radius and cell coverage). In other words, when the CDMA mobile is located at the cell edge, the BS receiver quality target cannot be maintained. Since the maximum path loss in the CDMA link budget is a function of the BS receiver noise floor and loading factor, there exists a penalty tradeoff between the cell coverage and capacity.

In this section, it is assumed that the cell layout is designed to the maximum propagation loss dictated by the reverse link budget and the service objective is to maintain the capacity. In the presence of external interference from non-CDMA systems, the CDMA BS receiver noise floor rises and therefore the reverse link coverage shrinks. It is shown in A.1 that when the number of CDMA users (i.e., capacity) remains the same, the CDMA BS receiver sensitivity degradation (D) (defined as the ratio of the sensitivity ($S_{w/ext}$) with external interference to the sensitivity ($S_{w/o\ ext}$) without external interference) equals the noise rise caused by average external interference power, i.e.,

$$D = \frac{S_{w/\,ext}}{S_{w/\,o\,ext}} = \frac{I_{ext} + FN_oW}{FN_oW} \qquad \textbf{(1)}$$

where N_o is the spectral density of thermal noise, F is the BS receiver noise figure, I_{ext} is the average external interference power (falling into the CDMA carrier bandwidth) received by the CDMA BS antenna connector and W is the system bandwidth. If the propagation loss slope is known, then the receiver sensitivity degradation can be translated into the coverage area reduction. It follows that the CDMA reverse link cell coverage reduction ratio (R_{cov}) due to external interference can be expressed by:

$$R_{\text{cov}} = 1 - \left(\frac{L_{w/\,ext}}{L_{w/\,o\,ext}} \right)^{2/\gamma} = 1 - \left(\frac{S_{w/\,o\,ext}}{S_{w/\,ext}} \right)^{2/\gamma} = 1 - \left(\frac{FN_o W}{I_{ext} + FN_o W} \right)^{2/\gamma} \qquad (2)$$

where L denotes the maximum allowable propagation loss and γ denotes the propagation loss exponent. This equation shows that the penalty in the CDMA reverse link cell coverage (or maximum propagation loss) depends on the CDMA BS receiver noise rise as well as the propagation loss slope, and is independent of the CDMA loading.

As an example, Figure 1 shows the relationship between the CDMA Modcell reverse link coverage loss and the average external interference power when the capacity remains constant and the propagation loss slope is 35 dB/decade. It is observed that an external interference power of –105 dBm/1.23 MHz will cause about 5.5 dB noise rise and 51% cell coverage loss. As the average external interference power is -120 dBm (11 dB below the Modcell receiver noise floor, -109 dBm/1.23 MHz) causing a 0.3 dB noise rise, then the cell coverage reduction becomes about 4%. Service providers can determine a tolerable reverse link external interference power level for spectrum clearance based on the elected acceptable coverage reduction when performing the network deployment study. Note that Figure 1 should be viewed as an example only and not universally applied to all products and scenarios, since the shape of the curve will differ as the noise figure and required receiver sensitivity vary.

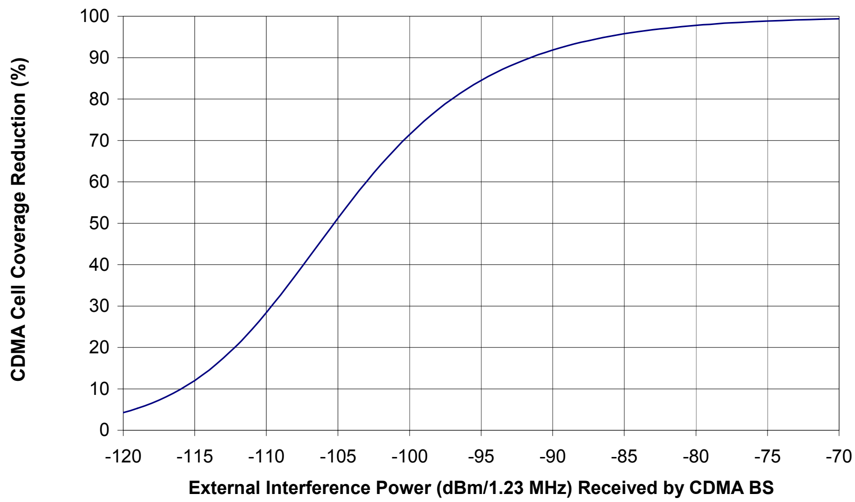

Figure 1: Effect of average external interference power on CDMA reverse link cell coverage

3. Effect on Reverse Link Capacity

In this section, it is assumed that the cell layout is designed to the maximum propagation loss dictated by the reverse link budget and the service objective is to maintain the coverage. In the presence of external interference from non-CDMA systems, the CDMA BS receiver noise floor will be raised and therefore the reverse link capacity will be reduced. It is shown in A.2 that when the receiver sensitivity and cell coverage remain the same and the cell layout is designed to the maximum propagation loss dictated by the reverse link budget, the CDMA reverse link capacity reduction ratio (R_{cap}) due to external interference can be determined by:

$$R_{cap} = 1 - \frac{N_{w/\,ext}}{N_{w/o\ ext}} = \left(\frac{I_{ext} + FN_oW}{FN_oW} - 1\right)\left(\frac{1}{\rho} - 1\right) \qquad (3)$$

where $N_{w/\ ext}$ denotes the CDMA capacity with external interference, $N_{w/o\ ext}$ the CDMA capacity without external interference and ρ denotes the CDMA reverse link loading factor. The above equation indicates that the penalty in CDMA reverse link capacity depends on the CDMA BS loading factor and the receiver noise rise caused by external interference.

As an example, we consider IS-95 EVRC. The typical reverse link budget for the IS-95 EVRC with mobility and voice applications, considers a 3.5 dB CDMA BS receiver interference margin (i.e., the noise rise due to other user interference), which corresponds to a 55% loading. Figure 2 shows the relationship between the IS-95 EVRC reverse link capacity loss and the average external interference power when the CDMA cell coverage remains constant. It is observed that an external interference power of –109 dBm/1.23 MHz will cause about 3 dB noise rise and 82% capacity loss. As the external interference power is -120 dBm causing a 0.3 dB noise rise, then the cell capacity reduction becomes about 6%. Service providers can determine a tolerable reverse link external interference power level based on the elected acceptable capacity reduction when performing the network deployment study.

Note that Figure 2 should be viewed as example only and not universally applied to all products and scenarios, since the result will vary with noise figure and receiver sensitivities.

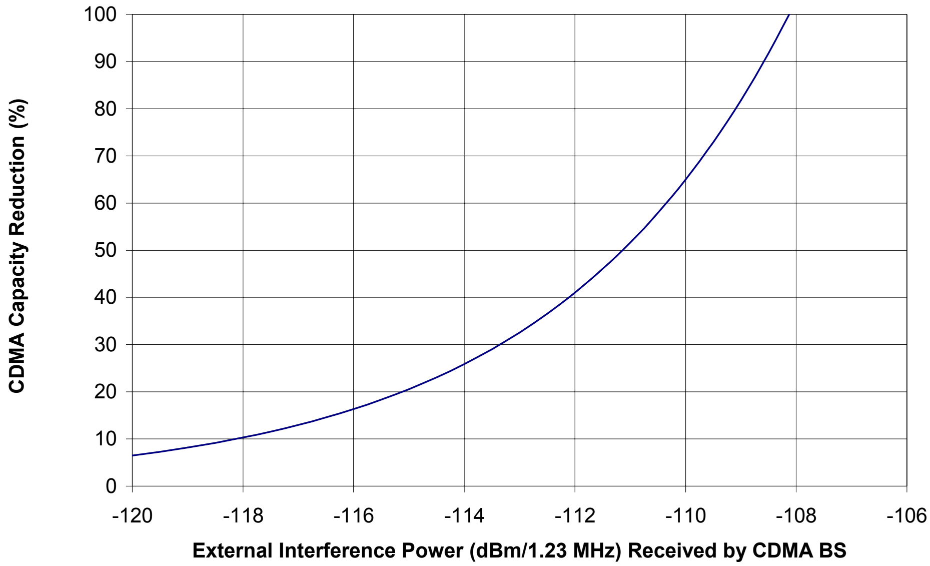

Figure 2

4. Summary

The presence of reverse link external interference will negatively impact the capacity and coverage of CDMA systems. The impact of external interference can be viewed as degrading capacity while maintaining coverage; alternatively, it can be shown that the cell footprint can be maintained if capacity is degraded.

The computed capacity and coverage degradation may be used to assess the impact of external interference that develops *after* deployment; i.e., new interference that develops relative to the baseline condition of the spectrum. Alternatively, the computed capacity and coverage degradation can be used in pre-deployment design planning to compensate for noisy spectrum if clearance is not practical. For example, closely spaced cells can yield full capacity since a coverage penalty can be tolerated. This strategy is generally considered undesirable since it implies that scarce, expensive radio spectrum is not being fully utilized; however, it may be tolerable in areas where cells must be closely spaced regardless of interference conditions in order to address capacity demands.

In all cases, the degradation of performance in the presence of external interference can be significant. Accordingly, it is critical that spectrum be completely cleared in order to fully realize CDMA performance.

Appendix – CDMA Reverse Link Coverage or Capacity versus Noise Rise

In Section A.1, we derive the relationship between the CDMA reverse link cell coverage loss and the BS receiver noise rise (or sensitivity degradation) caused by external interference from non-CDMA systems. In Section A.2, we solve the relationship between CDMA reverse link capacity loss and the BS receiver noise rise caused by external interference.

A.1 CDMA Reverse link Coverage versus Noise Rise

We first consider the equation for receiver Eb/Nt. For simplicity, we make the conservative assumption that the external interference Iext is present uniformly; i.e., within all (as opposed to a single) base station(s). Considering the desired signal, other user interference from the serving cell and other cells, external interference and receiver noise floor, the CDMA base station received Eb/Nt can then be expressed as:

$$\frac{E_b}{N_t} = \frac{S/R}{FN_o + \frac{I_{ext}}{W} + \frac{\alpha(1+\beta)(N-1)S}{W}} = g\frac{S}{FN_oW + I_{ext} + \alpha(1+\beta)(N-1)S} \qquad \text{(A.1)}$$

where Eb is the bit energy, N_t is the spectral density of thermal noise plus interference, N_o is the spectral density of thermal noise, F is the BS receiver noise figure, Iext is external interference from non-CDMA systems, S is the received signal strength, R is the bit rate, α is the voice activity factor, β is the ratio of other sector interference to serving sector interference, N is the number of mobiles in a sector, W is the system bandwidth, and g (= W/R) is the processing gain.

In order for a CDMA call to maintain target quality, the power control algorithm should ensure that the receiver achieves the minimum Eb/Nt requirement:

$$\left(\frac{E_b}{N_t}\right)_{\text{required}} \equiv d \qquad \text{(A.2)}$$

Equation (A.1) can be rewritten to explicitly indicate the number of mobile calls N:

$$N = \frac{g}{\alpha d}\frac{1}{(1+\beta)} + 1 - \frac{1}{\alpha(1+\beta)}\frac{FN_oW + I_{ext}}{S} \qquad \text{(A.3)}$$

In the above equation, the finite limit on capacity can be conveniently reached by letting the signal-to-cell-site noise ratio go to infinity (i.e., by letting the received signal power become unbounded with respect to the cell site noise). This capacity is called the pole point, Nmax, and represents a theoretical maximum that cannot be reached but serves as a useful reference point for the reverse link.

$$N_{\max} = \frac{g}{\alpha d}\frac{1}{(1+\beta)} + 1 \qquad \text{(A.4)}$$

Therefore, the receiver sensitivity (i.e., the minimum desired signal strength) can be obtained by substituting Equation (A.4) into Equation (A.3):

$$S = \frac{FN_o W + I_{ext}}{\alpha(1+\beta)(N_{\max} - N)} = \frac{FN_o W + I_{ext}}{\alpha(1+\beta)N_{\max}(1-\rho)} \quad \text{(A.5)}$$

where ρ = N/Nmax is the reverse link loading factor. When the number of CDMA mobiles (i.e., capacity) remains the same with and without external interference, the sensitivity degradation (D) (defined as the ratio of the CDMA BS receiver sensitivity (S w/ ext) with external interference to the sensitivity (S w/o ext) without external interference) is given by:

$$D = \frac{S_{w/\,ext}}{S_{w/\,o\,ext}} = \frac{I_{ext} + FN_o W}{FN_o W} \quad \text{(A.6)}$$

It is observed that the sensitivity degradation equals the noise rise caused by the external interference, regardless of the CDMA loading. From the link budget point of view, the maximum allowable propagation loss (L) between a CDMA mobile and the serving BS can be determined by:

$$L = \frac{P_{CDMA\_M}}{G_{CDMA\_BS} G_{CDMA\_M} M_{fade} G_{Handoff} S} \quad \text{(A.7)}$$

where PCDMA_M denotes the CDMA mobile transmit power at the antenna connector, GCDMA_BS denotes the CDMA BS antenna minus cable loss, GCDMA_M denotes the CDMA mobile antenna, Mfade denotes the log-normal fade margin and Ghandoff denotes the soft handoff gain. It follows that with external interference, the CDMA reverse link cell coverage reduction ratio (R_{cov}) can be expressed by:

$$R_{\text{cov}} = 1 - \left(\frac{L_{w/\,ext}}{L_{w/\,o\,ext}} \right)^{2/\gamma} = 1 - \left(\frac{S_{w/\,o\,ext}}{S_{w/\,ext}} \right)^{2/\gamma} = 1 - \left(\frac{FN_o W}{I_{ext} + FN_o W} \right)^{2/\gamma}$$

where γ denotes the propagation loss exponent. This equation shows that the penalty in the CDMA reverse link cell coverage (or maximum propagation loss) depends only on the CDMA BS receiver noise rise caused by external interference, and is independent of the CDMA loading.

A.2 – CDMA Reverse link Capacity Loss versus Noise Rise

Equations (A.5) and (A.7) indicate that when the receiver sensitivity and cell coverage remain the same, the relationship between the CDMA capacity (Nw/ ext) with external interference and the capacity (Nw/o ext) without external interference is determined by:

$$\frac{FN_oW + I_{ext}}{N_{max} - N_{w/\,ext}} = \frac{FN_oW}{N_{max} - N_{w/o\,ext}}$$

Rearranging the above equation, we obtain that the CDMA reverse link capacity reduction ratio (R_{cap}) due to external interference:

$$R_{cap} = 1 - \frac{N_{w/\,ext}}{N_{w/o\;ext}} = \left(\frac{I_{ext} + FN_oW}{FN_oW} - 1\right)\left(\frac{N_{max}}{N_{w/o\;ext}} - 1\right) = \left(\frac{I_{ext} + FN_oW}{FN_oW} - 1\right)\left(\frac{1}{\rho} - 1\right)$$

The equation indicates that the penalty in CDMA reverse link capacity depends on the CDMA BS loading factor and the receiver noise rise caused by external interference.