# IEEE P802.11
# Wireless LANs

## Comparisons For 3 Frequency Cell vs. 2 Frequency Cell Plans

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## Abstract

**This paper compares the cosite interference susceptibility of 3 frequency cell plans based on proposed signaling similar to that of Raytheon and Harris vs. the 2 frequency cell plan proposed by Micrilor. Specific simple scenarios are constructed for the comparison. The scenarios are chosen to emphasize differences in the approaches. A shadow fading channel model is utilized with log normal statistic.**

## 1.0 INTRODUCTION

This paper examines some bounding cases which illustrate some limitations for 3 frequency cell plans vs. 2 frequency cell plans as relates to current considerations for IEEE 802.11 10 MBPS standardization. 3 frequency cell plans presumably apply to Raytheon, Alantro, Lucent and Harris proposals while a two frequency cell approach is embraced by the Micrilor proposal.

Units, which are free to roam within the cell or to reassociate to new cells, are referred to as stations. A fixed access point occupies the center of the cell. All users within the cell operate on the same frequency on both the forward and reverse links. In all cases the two and three frequency cell planning approaches are compared for same size cells, and the selection of *n*, the path loss coefficient, is presumed such that it is constant over a cluster of cells.

Micrilor has indicated that the processing gain offered is sufficient to justify a 2 frequency cell plan with CDMA. The proposed (claimed) processing gains differentials (compared to Micrilor) are;

| | | |
|---|---:|---:|
| **Harris** | **-3dB** | **11 MBPS** |
| **Lucent** | **-2dB** | **10 MBPS** |
| **Raytheon** | **-3dB** | **11 MBPS** |
| **Alantro** | **+.7dB** | **11 MBPS** |
| **Micrilor** | **0dB** | **10 MBPS** |

In the following sections basic analyses of fundamental cases and topologies are provided given the consideration for a large scale attenuation model with path loss exponents of 3, 4, 5, and log normal distribution of Rx power about the mean with $\sigma = 10dB$. The Harris and Raytheon performance was traded against the Micrilor. This compares the lowest processing gain 3 frequency approaches to the 2 frequency channel approach. It is hoped that this comparison encompasses extremums of claimed performance concerning cell planning trade-off.

In all but one case examined the 3 frequency cell plan out performed the 2 frequency cell plan. The reason that this occurs is that the 3 frequency cell plan always ensures a minimum of *r* (cell radius) separation between fringes of same frequency cells while the 2 frequency cell approach provides virtually no isolation between cells of the same frequency except for that related to processing gain. This lack of spatial separation cannot be virtually recovered by incremental increases in processing gain of only 3dB.

## 2.0 The Model

This paper examines only the large scale attenuation channel anomalies also called shadowing. Shadowing is the term which refers to attenuation caused by obstructions such as walls, equipment, inventory, etc. Sometimes the term shadow fading is used, although, shadowing is more a function of position than time. Thus shadowing is a strong function of the non-time-varying physical parameters of the channel. Cox, and Rappaport, have all shown that the logarithm of the received power for such links tends toward Gaussian distributions for random positioning of the transmitter and receiver.

Hence, the pdf of the received power envelope, dependent on position, is log-normal. For a received signal given by;

$$L(t)R(t)e^{j\omega_c t + j\theta(t)} \qquad \textit{Eq.2.0-1}$$

$L(t)\underline{\Delta}$ log normal envelope

$R(t)\underline{\Delta}$ Rayleigh envelope associated with temporal fluctuations

We define, $U(t) = 10\log_{10} L^2(t)$

so that,
$$p(u) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\left(\frac{\left(u - k\bullet 10\bullet \log_{10} d^n\right)^2}{2\sigma^2}\right)}$$
*Eq. 2.0-2*

$d\,\underline{\Delta}$ distance *Eq. 2.0-3*

$n\,\underline{\Delta}$ path loss exponents usually a function of physical parameters of the link.

Although *L (t)* indicates a function of time, the measurements, used to compile the data are considered to be long term. Usually, measurements are conducted at one location under stable or averaged conditions, then a new receiver location is tried. <u>The important point is that these measurements are intended to characterize power envelope fluctuations according to long term relative positional changes between some test transmitter and receiver pair.</u> Of course, these statistics change from room to room, building to building, etc. Nevertheless, research has revealed some important trends that assist the communications engineer with the task of assigning dynamic range and coverage requirements for transmission through these channels. One of the most important parameters of the shadow fade is the first order moment eluded to above;

$$\bar{u} \propto 10\log_{10} d^n$$
*Eq. 2.0-4*

This is the expected attenuation of the link as a function of distance d. Values of n vary from 1.6 to 6.1 depending on the specific channel, with free space @ *n=2*, (Rappaport and McGillem, Cox, Murray and Norris). The cases where *n<2* represent conditions of constructively interfering multipath from fixed geometry's. The mean value for shadow fading, given by eq. 2.0-4, has varying values of *n* according to certain ranges of *d.* One must be careful in extrapolating results at a few meters range to compare with non-LOS experiments at ranges of 100 M to 500 M. In fact, the relationship of *(n)* and *(d)* are known to vary in a nonlinear fashion. That is, the farther the link travels through a building the larger *n* becomes. This affect is not considered in the subsequent analysis.

This paper provides analysis which relates to the cell radii in meters bounded by the graphs in figure 2.0-1. Typically examples are shown based on average power but some 2 sigma cases are examined as well.

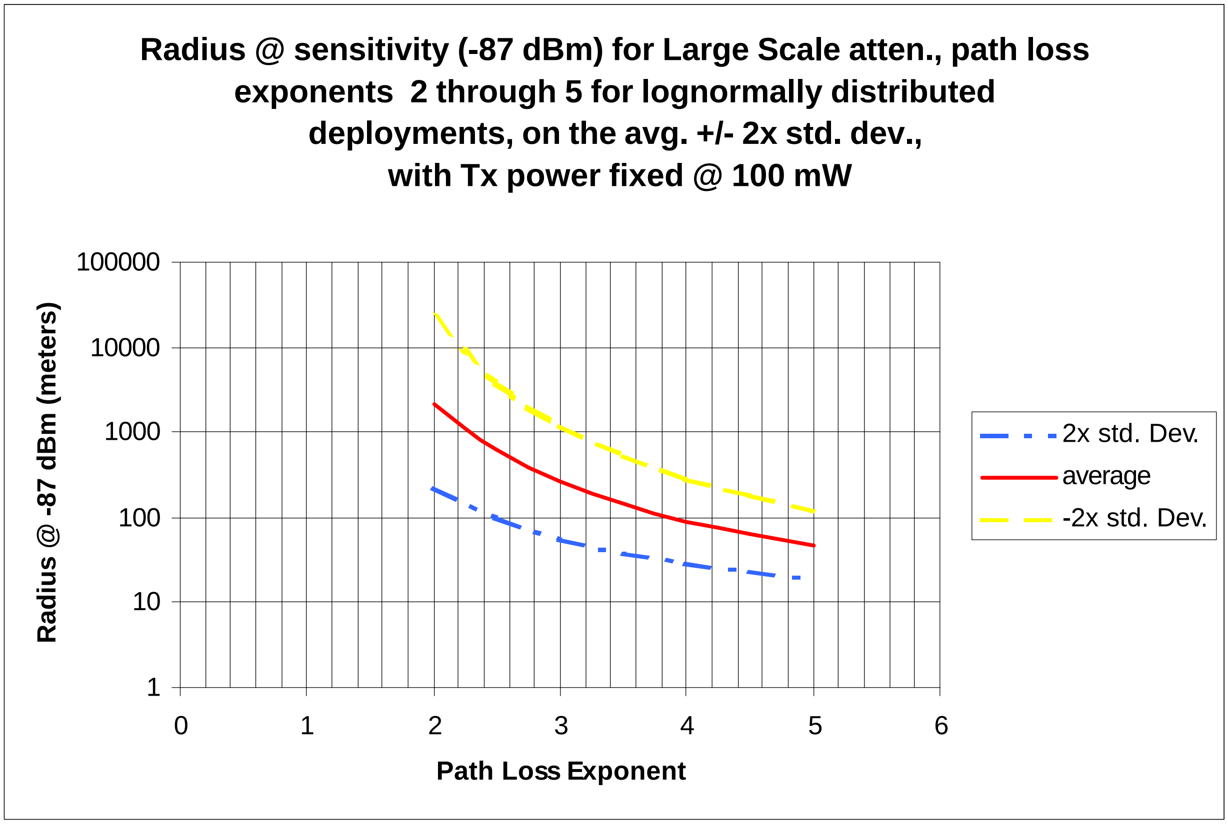
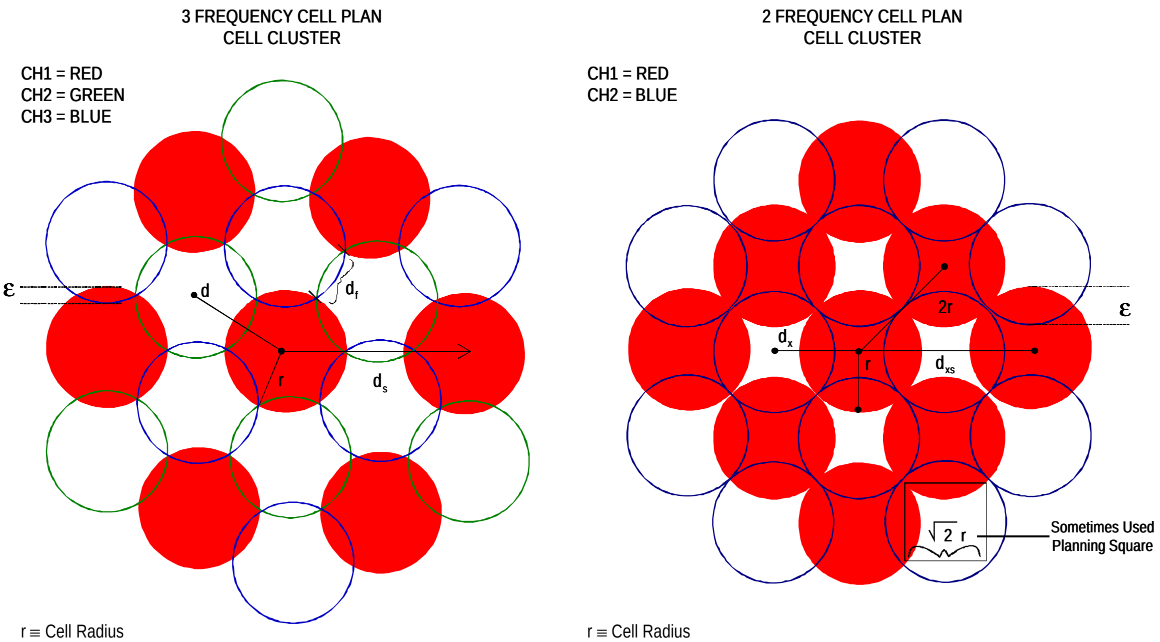


*Figure 2.0-1*

Occasionally, cell clusters are referenced and related to an association of 3 frequency cell plan or 2 frequency cell plan topologies. Figure 2.0-2 illustrates both topologies and some of the significant geometry.



r ≡ Cell Radius

d ≡ Diagonal Distance between Cell Centers 2r(1-ε)

$d_s$ ≡ Distance between Cell Centers of Same Frequency: 3r

$d_f$ ≡ Distance between Same Frequency Cell Fringes: r

ε ≡ Cell Eye Overlap = .268r

ST2700353A.940

r ≡ Cell Radius

$d_x$ ≡ Colateral Distance Between Cell Centers: $\sqrt{2}\ r$

$d_{xs}$ ≡ Colateral Distance Between Cell on Same Frequency: $2\sqrt{2}\ r$

d ≡ Diagonal Distance Between Cell Centers (Same Frequency): 2r

ε ≡ Cell Eye Overlap $\simeq .586r$

*Figure 2.0-2*

A quick observation of the figure illustrates the more dense packing inherent with a 2 frequency approach and the excessive cell overlap that results. The circular cross-sectional view of the cells in figure 2.0-2 is preferred to a hexagonal or square cell formulation because it better illustrates true geometrical spacing and overlaps and relates to spherical coordinate interpretations which are more relevant to the physics of electromagnetic propagation. Of course, it is also realized that cells will possess irregular field intensities at various radius offsets vs. angular position within the cell. Figure 2.0-3 illustrates the irregular fields anticipated at or near cell boundaries. The irregular constant power contours superposed on the cells illustrate this idea (assuming isotropic radiators at the cell center). The contour irregularity arises due to the statistical nature of deployment and the uncertainty of the environment represented by the log normal statistic.

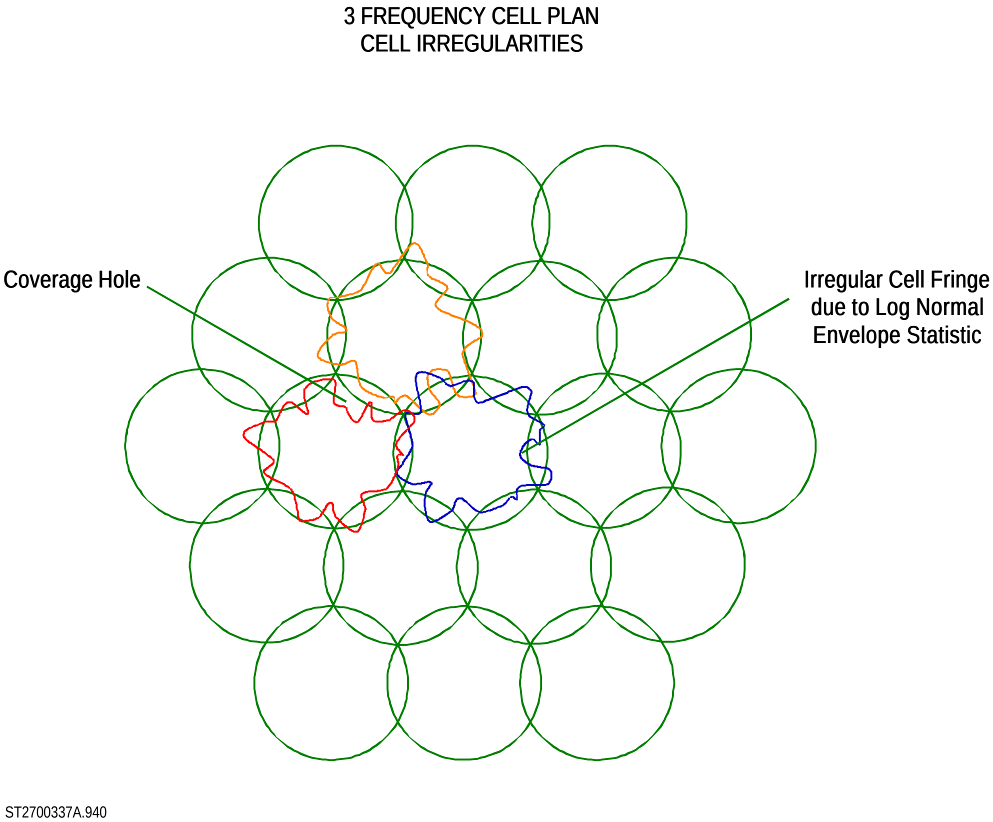


*Figure 2.0-3*

## ▪ 2.1 COMMENTS ON ASSUMPTIONS AND PARAMETERS

Assumptions are the cornerstones of very good and very bad simulations/calculations. Therefore it is reasonable to describe some of the assumptions involved in the subsequent calculations so that the reader can properly apply the results or at the least interpret the significance of the result.

The parameters in part are supplied by proposers either by published information or by measured data or by phone conversation or in some cases all three. The data information supplied was not questioned unless there were ambiguities or unresolved numbers. Otherwise, parameters and assumptions were applied to make calculation easy to understand and limiting cases tractable. To that end the following comments apply;

| | |
|---|---|
| **SCENARIOS:** | **The scenarios were selected as worst case because they were easily visualized and represent some bound in performance and illuminate conceptual differences in approaches.** |
| **TX POWER:** | **.1 W has been suggested by proposers as being a reasonable operating point which trades off economy vs. cost.** |
| **RX LEVEL:** | **It is assumed that each of the vendors can build similar noise figure radios. Advantages in performance due to signaling strategies are otherwise absorbed into these analyses in terms of SIR performance.**<br>**Hence, -87 dBm was selected for comparison purposes. –85 or –80 dBm could just as well be selected because it has been found that the interference considerations dominate most of the concerns. Whether or not the numbers are viewed as S/(I+N) or SIR does not change the trend of the results.** |
| **LOS FACTOR:** | **30λ was selected because it represents roughly the length or breadth of a room or cubicle (approximately 12 feet). Classically, Rappaport used 10λ. STI's experience is that typically the number is less than 30λ for best model fit, but Lucent has suggested even greater values at times. This number is also known as the free space corner distance in the path loss equation. STI varied this parameter and did not find reversal of trends between cell planning based on the two approaches.** |
| **FREQUENCY:** | **2450 MHz was selected simply because it is near the average center frequency of the band.** |
| **PATH LOSS EXPONENTS:** | **3, 4, 5 were selected as being the most representative and encompassing of likely encountered indoor environments. Extensive STI measurement data and the literature at large corroborate this.** |
| **LOG NORMAL ASSUMPTION:** | **STI has verified the log normal assumptions time and again. Likewise, Rappaport, Cox, and others concur. 10 dB σ is sufficient to cover most any circumstance.** |
| **CELL RADIUS:** | **A cell radius designed to the mean statistic is the only practical way of deployment so that any** |

| | |
|---|---|
| | **communication is possible when frequency reuse is based on 2 or 3 frequencies. Cell radius is always adjusted as *n* varies so that receive sensitivity is strongly related to *r*.** |
| **SIR REQUIRED:** | **The lowest claimed processing gain versus the highest claimed is a difference of 3 dB. In addition, Micrilor has indicated a SIR of +2 dB and has at times past measured this number. Harris originally claimed 8 dB for the SIR requirement but has since measured 6 dB, <u>for a single interference case</u>. STI simulated/calculated always allowing a 6 dB advantage for the Micrilor approach (i.e., 8-2).**<br>**Statistics of interferers are assumed as reducing to Gaussian after correlation. STI has verified that single interference cases <u>will not</u> be Gaussian in their behavior and that less SIR is required in such circumstances.** |
| **MULTIPLE INTERFERERS:** | **In cases where multiple cells are involved in calculation or multiple interferers, they add non-coherently. Furthermore, interference between cells is assumed to be asynchronous, or uncoordinated.** |

## ▪ <u>3.0 Mobile Station Co-Interference</u>

Simulations were conducted to compare the jamming probabilities for closet possible mobiles at their respective same frequency cell fringes. For the purposes of comparison the following tables illustrate the key parameters and assumptions of the simulation.

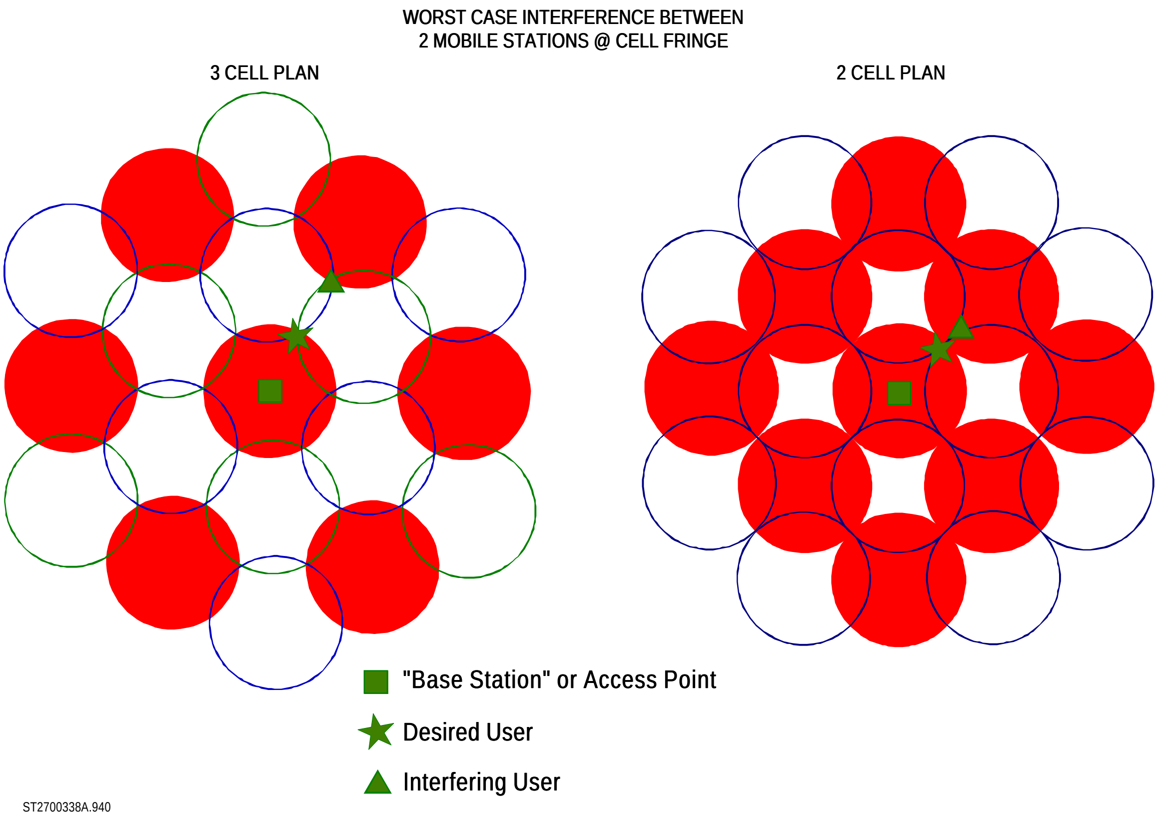


*Figure 3.0-1*

| | |
|---|---|
| **SCENARIO:** | **Consists of station at the cell fringe trying to 'hear' its designated access point while a single station in the closest position of a same frequency cell is radiating. Figure 3.0-1 illustrates the case.** |
| **TRANSMIT POWER:** | **All transmitters are @ .1W** |
| **RX LEVEL:** | **~ -87 dBm** |
| **LOS FACTOR:** | **30λ (free space corner distance) ~ 3.67 meters (12 ft.)** |
| **PATH LOSS EXPONENTS:** | **3, 4, 5** |
| **STANDARD DEVIATION OF PATH LOSS:** | **10 dB** |
| **CELL RADIUS:** | **Based on mean of –87 dBm from n = 3, 4, 5** |
| **2 FREQUENCY CELL SYSTEM:** | **Benchmark required of 0 dB S/I (normalized)** |
| **3 FREQUENCY CELL SYSTEM:** | **Benchmark Required of 6 dB S/I (normalized)** |
| **PER:** | **≤ 10%** |

Figure 3.0-2 illustrates the results via a family of curves.

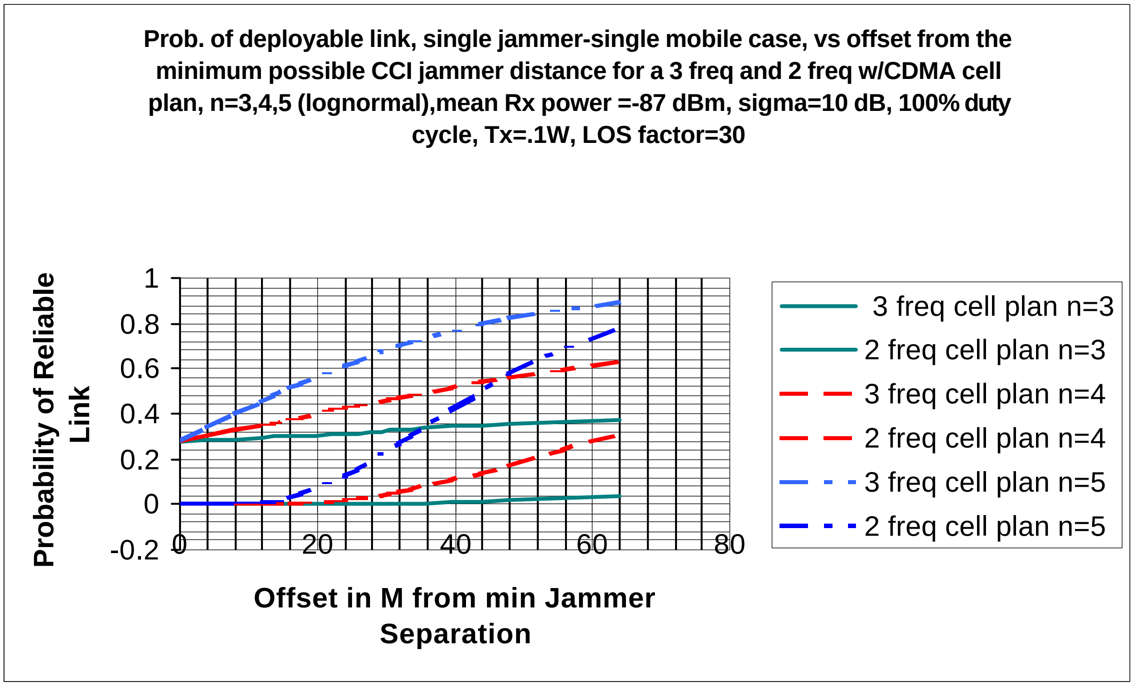


*Figure 3.0-2*

The X axis indicates the offset distance in meters from the cell fringe assigned to the offending interferer while the Y axis corresponds to the probability that an arbitrarily deployed link will operate under the prescribed scenario. The 3 cell approach never drops below .27 in probability because the same frequency cell fringes are never deployed closer than *r*. The three curves converge at the fringe because the cell radius *r* is adjusted appropriately for the consideration of *n* such that –87 dBm is received on the average when an access point transmits to a station at the fringe. Actually, a spatial minimum separation of 30λ was given to the 2 frequency cell plan stations even though the geometries suggest no separation worst case. Furthermore, it is evident that for *n=3* that a significant portion of the adjacent cell users (in the 2 frequency cell case) are in jeopardy because even at 60 meters, probabilities are nil. Neither approach performs well, for *n = 3*.

The above case was run a second time while permitting r to be modified such that it is very small without changing Tx power. That is the constant power contours were increased for the interferences by 20 dB while keeping the Rx level at –87 dBm. Figure 3.0-3 illustrates the result.

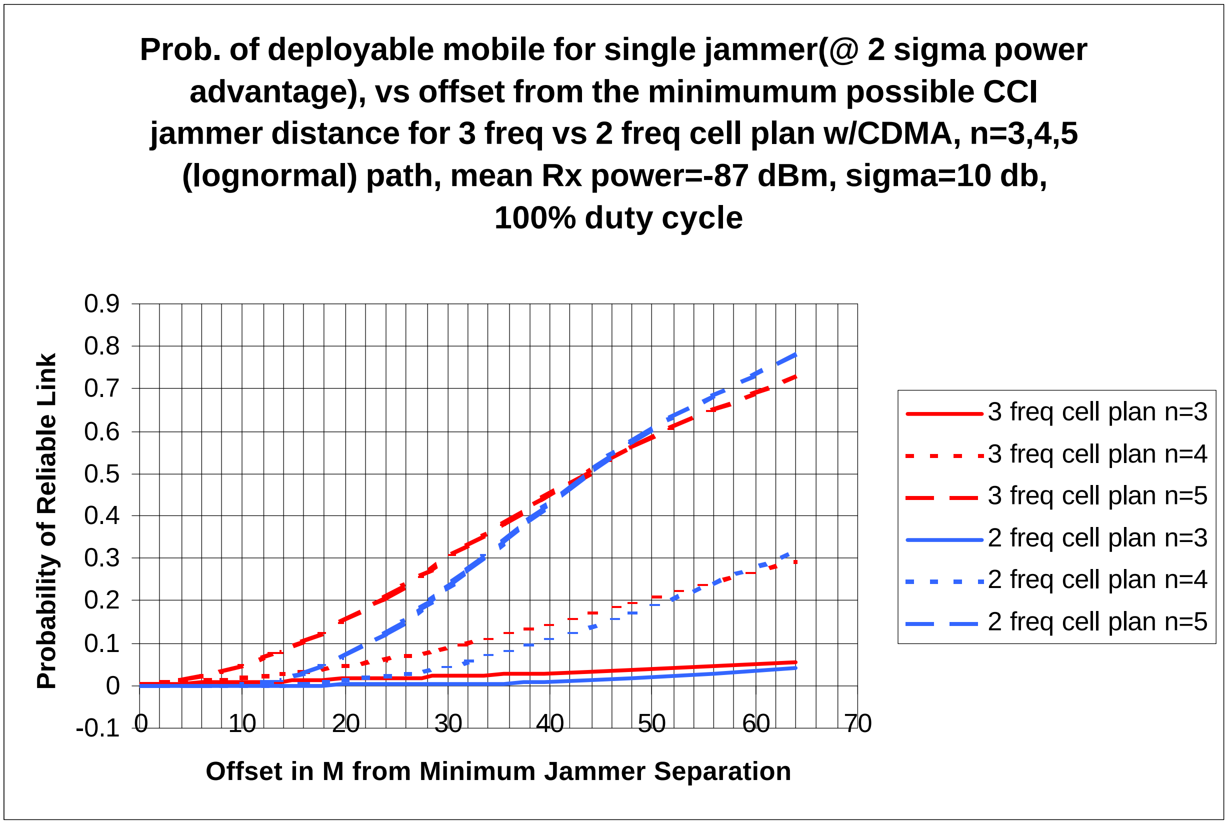

Prob. of deployable mobile for single jammer(@ 2 sigma power advantage), vs offset from the minimumum possible CCI jammer distance for 3 freq vs 2 freq cell plan w/CDMA, n=3,4,5 (lognormal) path, mean Rx power=-87 dBm, sigma=10 db, 100% duty cycle
Probability of Reliable Link
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
10
20
30
40
50
60
70
Offset in M from Minimum Jammer Separation
3 freq cell plan n=3
3 freq cell plan n=4
3 freq cell plan n=5
2 freq cell plan n=3
2 freq cell plan n=4
2 freq cell plan n=5

***Figure 3.0-3***

This design methodology (decreasing r dramatically) is not recommended.  It is included as an example to show that the approaches gain no significant advantage over one another when r decreases.

## 3.1 MULTI-JAMMER SINGLE STATION SCENARIO

A simple extension to the previous case is to provide multiple jammers. Figure 3.1-1 illustrates this extended case.

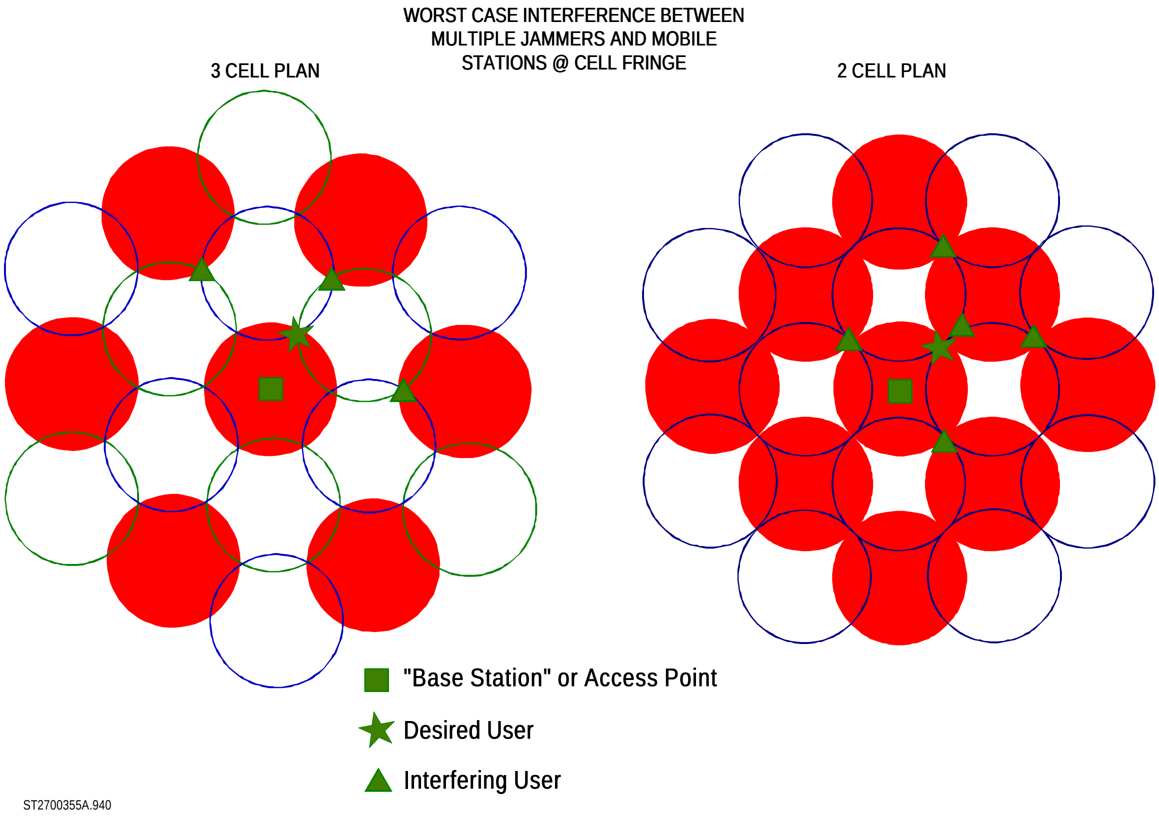


*Figure 3.1-1*

Figure 3.1-2 provides the trade-off curves of interest. The trend is not substantially modified from the previous case because of the fact that the closest interferer dominates the phenomena.

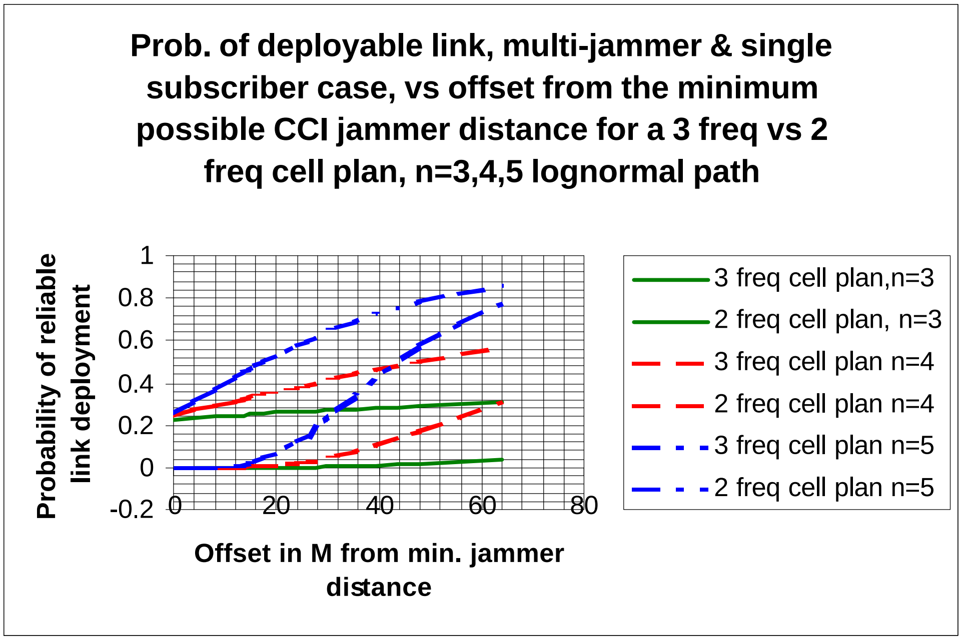


*Figure 3.1-2*

## ▪ 4.0 CASE OF INTERFERENCE BETWEEN MOBILE STATION IN ADJACENT CELL @ THE CELL FRINGE (WORST CASE)

This scenario bears some similarities to the case presented in section 3 except that the physical isolation given to the 3 frequency cell plan approach is traded for ACI isolation. All of the applicable assumptions and parameters remain in tact as presented earlier. The topology for the case is presented in figure 4.0-1 Harris provided lab measured isolation SIR data indicating that a SIR of –22 dB was sufficient to operate at PER < 10%. Therefore the –22 dB figure was used for the purpose of calculation in the 3 frequency cell plan approach.

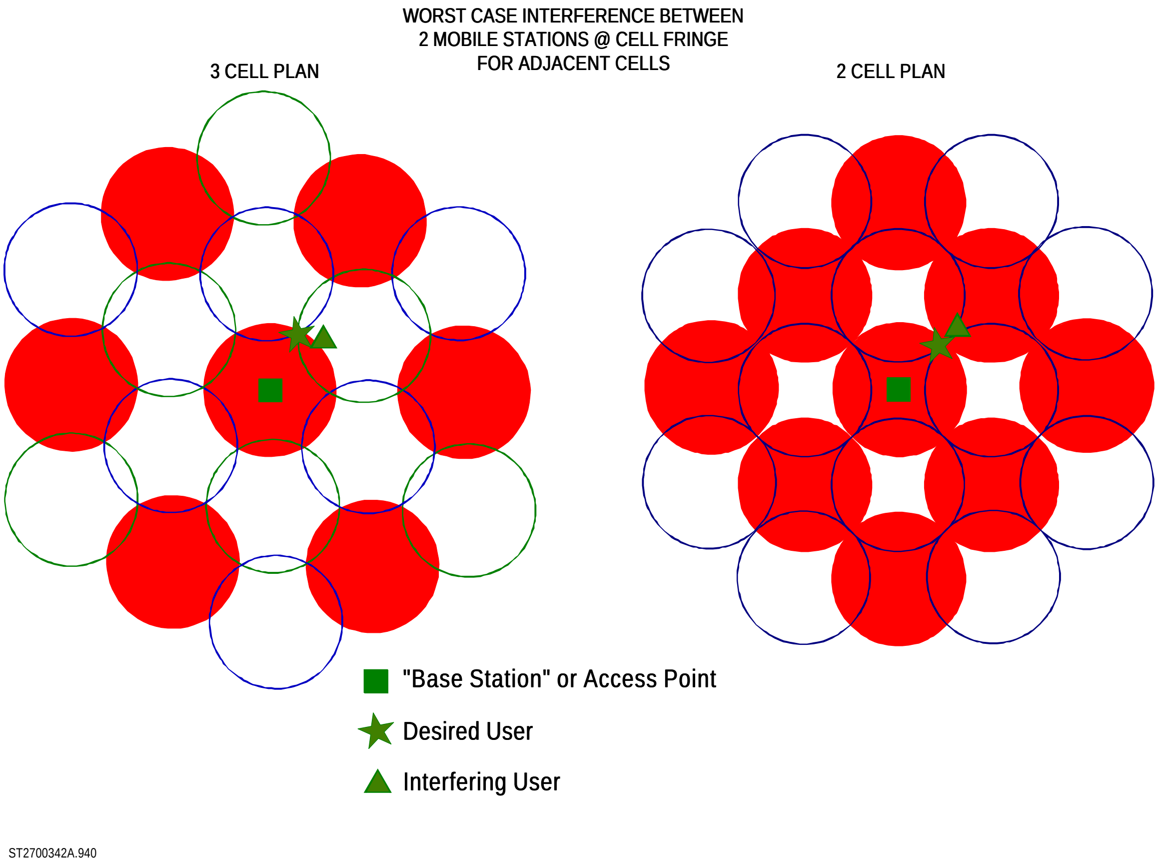


*Figure 4.0-1*

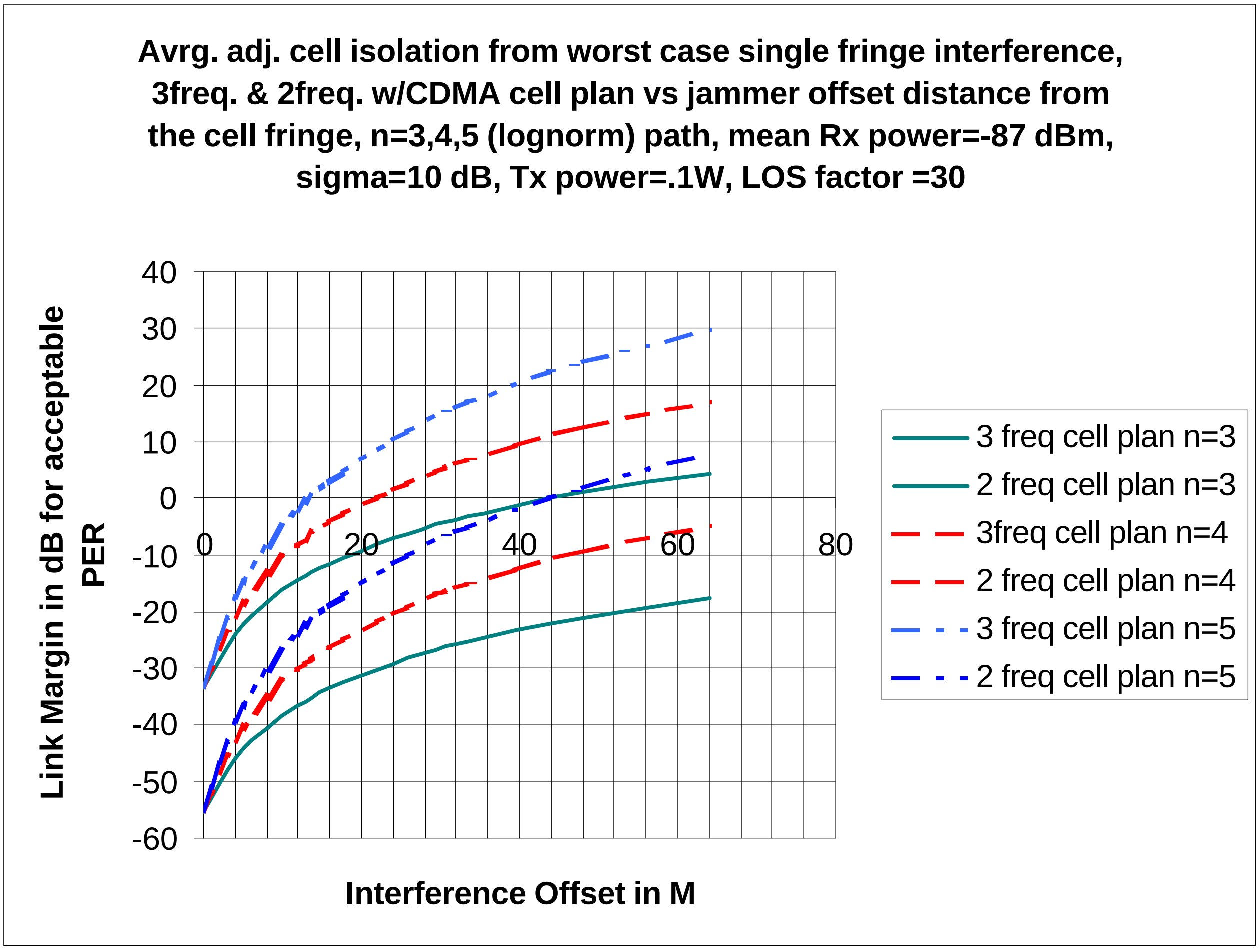

Avrg. adj. cell isolation from worst case single fringe interference, 3freq. & 2freq. w/CDMA cell plan vs jammer offset distance from the cell fringe, n=3,4,5 (lognorm) path, mean Rx power=-87 dBm, sigma=10 dB, Tx power=.1W, LOS factor =30
Link Margin in dB for acceptable PER
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
20
40
60
80
Interference Offset in M
3 freq cell plan n=3
2 freq cell plan n=3
3freq cell plan n=4
2 freq cell plan n=4
3 freq cell plan n=5
2 freq cell plan n=5

*Figure 4.0-2*

Figure 4.0-3 presents the required expected link margin in dB for this case given deployments in arbitrary indoor environments. The case is run for *n = 3, 4, 5* as before and the cell radius *r* is adjusted appropriately for each value of *n*. Both systems suffer dramatically because of the close proximity. As the jammer is moved further away the link margin on the average increases until the link becomes viable. *n=3* cases are bad for both systems but even *n=4* are mediocre. In all cases it appears that the 3 frequency cell approach would be more robust or able to recover better than the 2 frequency cell approach.

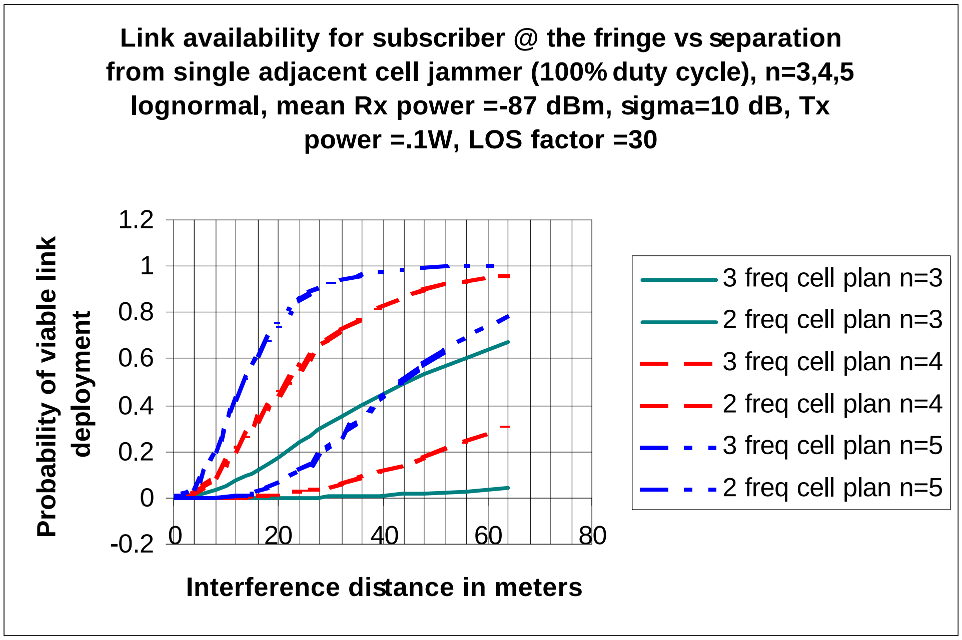


*Figure 4.0-3*

## 5.0 ACCESS POINT GENERATED INTERFERENCE

Another interesting case is illustrated in figure 5.0-1.

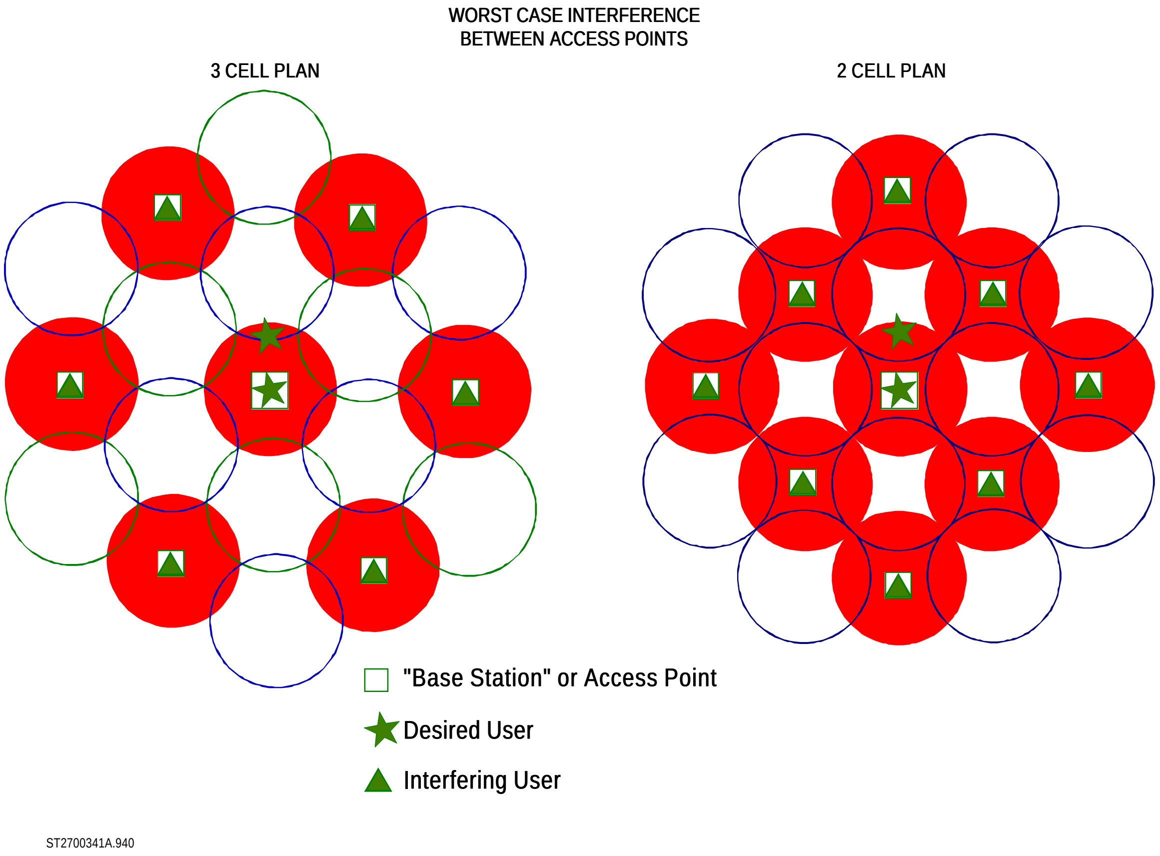


*Figure 5.0-1*

In this case the nearest neighbor same frequency cells from the cluster possess access points which all transmit simultaneously at .1 Watt and interfere with the center cell access point while the center cell access point attempts to process an RF signal from a station at the cell fringe.

The probabilities of interest are illustrated in figure 5.0-2 for two different cell radii. Cell radii designed to operate based on average power yield the reasonable powers. Cell radii designed to be artificially small to encompass 2σ variations in the log normal link attenuation yield the low probabilities.

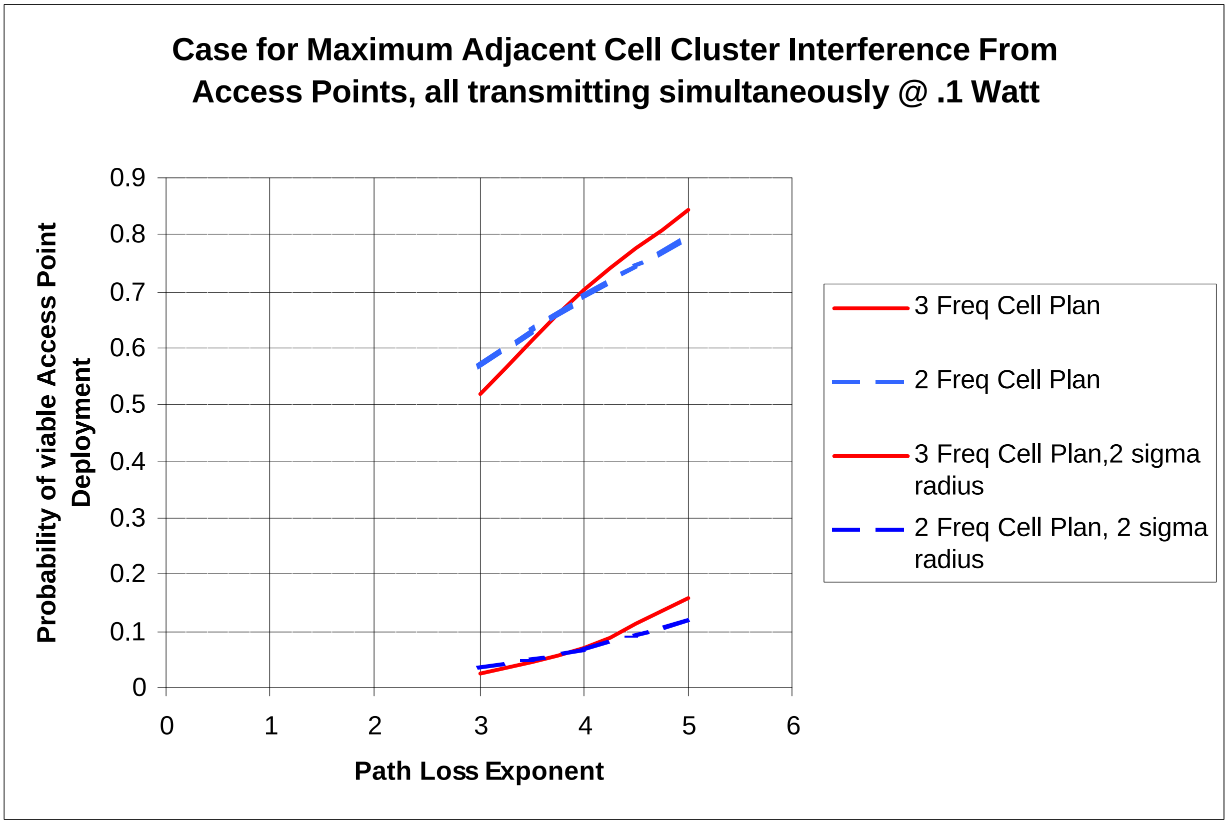

Case for Maximum Adjacent Cell Cluster Interference From Access Points, all transmitting simultaneously @ .1 Watt
Probability of viable Access Point Deployment
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
Path Loss Exponent
3 Freq Cell Plan
2 Freq Cell Plan
3 Freq Cell Plan,2 sigma radius
2 Freq Cell Plan, 2 sigma radius

*Figure 5.0-2*

## ▪ 6.0 JAMMING OF ACCESS POINT FROM ADJACENT CELL STATIONS

Figure 6.0-1 illustrates the topology for another taxing case. Each nearest neighbor adjacent cell is populated with an interferer at its fringe. The center cell access point is attempting to service a station at its maximum cell fringe while the interferers compete. The interference's are located half way deep into the cell overlay eye, ε, which was defined earlier, while the desired station is located at *r*. Hence, the interferences have slight advantages due to the uncertainty at the cellular overlap. Cases were also run for stations located closer. Both systems improved in performance some but the 3 frequency cell plan still significantly out performed the 2 frequency cell plan.

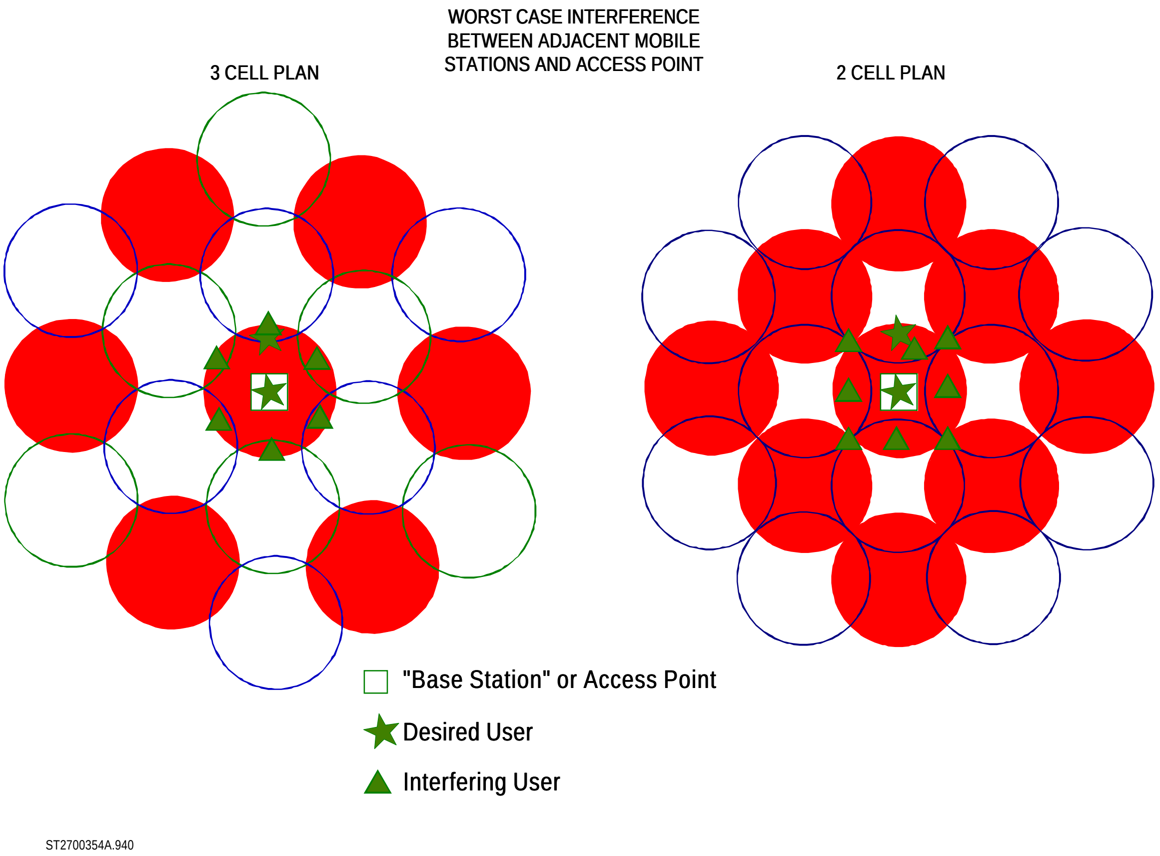


*Figure 6.0-1*

Figure 6.0-2 shows the performance for the indicated case.

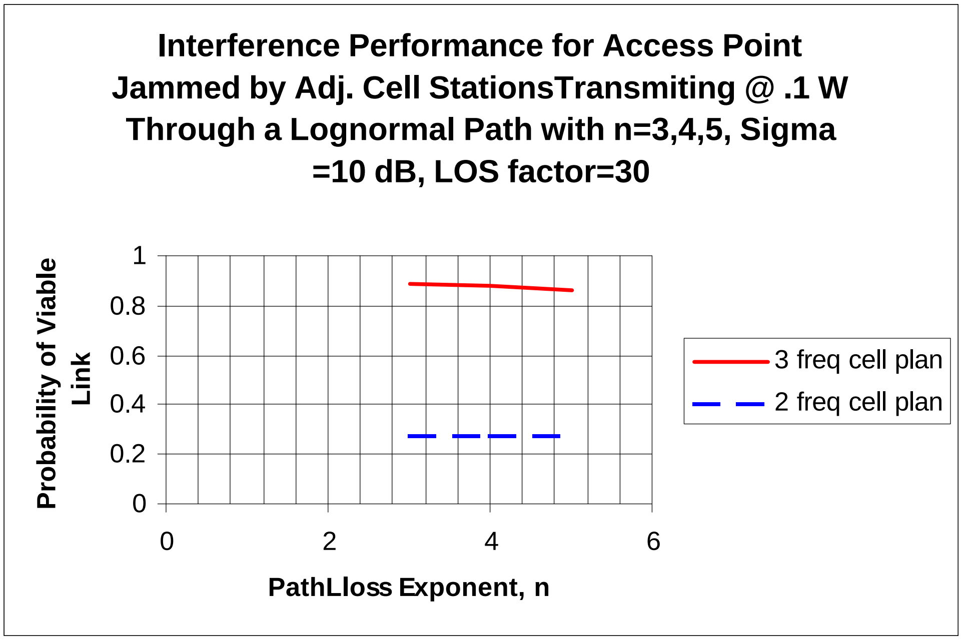


*Figure 6.0-2*

## ▪ 7.0 SIMPLE SINGLE INTERFERENCE LIMIT FOR 2 FREQUENCY CELL VS. 2 FREQUENCY CELL

One simple way of comparing a fundamental concept related to the two planning techniques is by examining the excess distance required by the 3 frequency cell approach to offset the claimed 6 dB advantage offered by the 2 frequency cell approach. This is easily accomplished by calculating the point at which interference path loss from the two cases equate for a single interferer.

$d_2 \underline{\Delta}$ interference range for CDMA approach normalized to 1

$d_3 \underline{\Delta}$ required separation for 3 frequency cell approach to overcome the 2 frequency cell approach with 6 dB advantage

$d_0 \underline{\Delta}$ free space corner distance

$n \underline{\Delta}$ path loss coefficient

$\lambda \underline{\Delta}$ wave length

$\bar{u} \underline{\Delta}$ mean path gain

$$\bar{u}_2 \underline{\Delta} \left(\frac{\lambda}{4\pi d_0}\right)^2 * \left(\frac{d_0}{d_2}\right)^n * \left(\frac{1}{4}\right)$$

6dB advantage of CDMA approach

$$\bar{u}_3 \underline{\Delta} \left(\frac{\lambda}{4\pi d_0}\right)^2 * \left(\frac{d_0}{d_3}\right)^n$$

Equating $\bar{u}$ to $\bar{u}_{CDMA}$ and solving, yields the trivial result;

$$d_3 = (4)^{1/n} \cdot d_1$$

$$d_3/d_2 = (4)^{1/n}$$

$$d_3 = 4^{1/n} \qquad \text{(normalized to } d_2 = 1)$$

$d_3 = 2d_2$, $n=2$
$d_3 = 1.587\ d_2$, $n=3$
$d_3 = 1.41421\ d_2$, $n=4$
$d_3 = 1.319\ d_2$, $n=5$

Examination of figure 7.0-1 and all the cases presented shows that the 3 frequency cell plan always preserves minimum separations for same frequency cell cases, which is greater than or equal to $2d_2$. For same frequency cell interference, $d_2$ varies from essentially 0 up to $r$ (as the interference is moved away from the cell fringe), where $r$ is the maximum practical case to consider. $d_3$ varies from $r$ to $2r$ (as the interference is moved away from the cell fringe). Therefore, this means that for same frequency cell interference cases, only one instance can occur where the CDMA approach operates similar to the 3 frequency cell approach. That scenario is illustrated in figure 7.0-1.

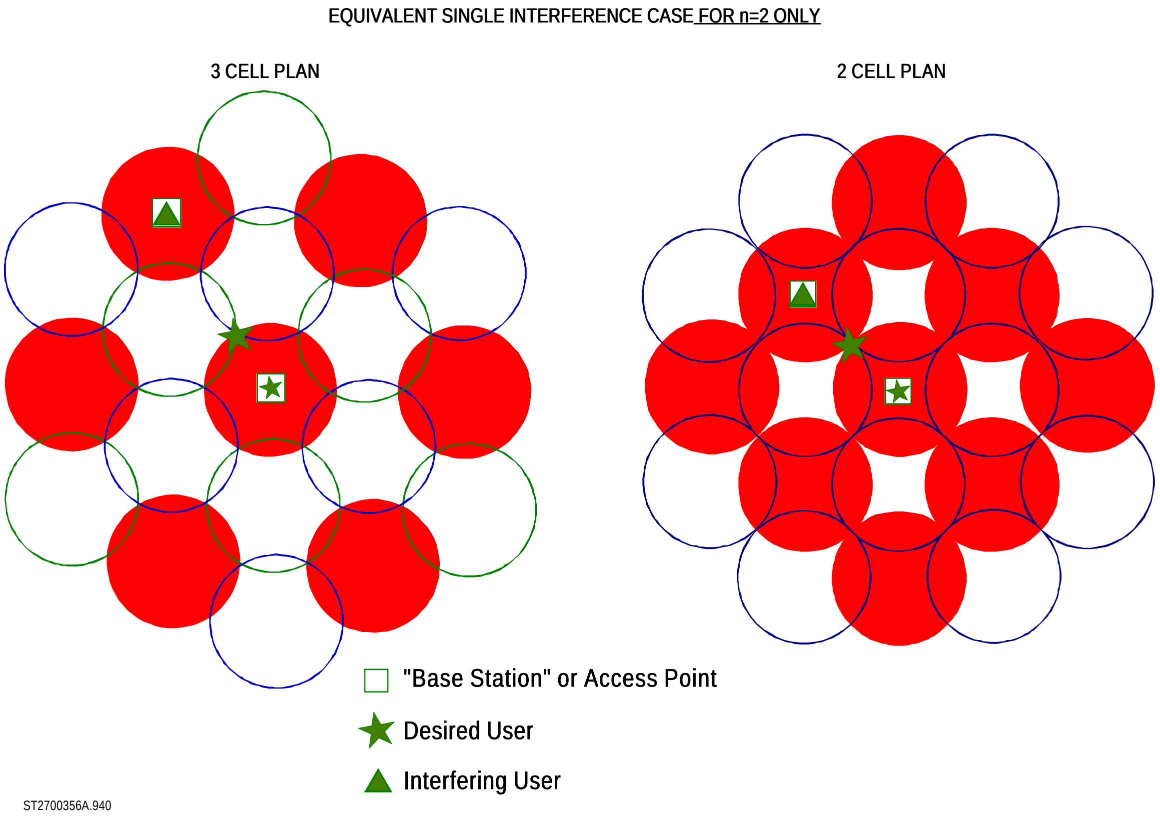


***Figure 7.0-1***

When multiple interferers enter the picture the simple cases degenerate to several alternate topologies which are not simply represented by figure 7.0-1 or the derived equation, but have been addressed in part elsewhere in this paper. The derived equation merely emphasizes the nature of one aspect of the trade between the two plans and that for apples to apples comparisons for single jammed same frequency cell scenarios the 2 frequency plan cannot be comparatively competitive, for $n \geq 2$ .

## ▪ 8.0 SUMMARY

The simple scenarios presented illustrate that (for these cases considered); a 3 frequency cell plan out performs a 2 frequency cell plan, even when CDMA is taken into account. Although a final simulation with pdf's describing emitter probabilities, station locations, and dispersive Rayleigh fade, has not been completed it is believed that the simple examples illustrate attributes and trends which will strongly influence the final model.

It appears that the differential advantage of 3 dB processing gain cannot overcome the geometric or spatial deficits of the compacted cells for the 2 frequency cell plan.

Both plans seem to be on par with one another only in the case of adjacent cell access point interference from the cluster to a centralized cell access point.

The selection of *r* is critical for the comparison of such plans. Plans using radii from the average received power case were compared to radii adjusted for power variations of 2 sigma. Artificially small radii narrow the gap in performance between the 2 cell planning and 3 cell planning concepts because eventually the 3 frequency cell plan begins to lose some of its spatial advantage. The 2 sigma cases could not be deployed for either cell planning case because they perform so poorly and therefore are of academic interest only.

## 9.0 BIBLIOGRAPHY

1. Rappaport, T.S., and McGillem, C.D, 'UHF Fading in Factories'. IEEE Journal on Selected Areas in Communications. Vol 7, No 1, pp 40-48, January 1989.

2. Rummler, W.D, 'Time-and-Frequency-Domain Representation of Multipath Fading on Line-of-Sight Microwave Paths'. The Bell System Technical Journal. Vol 59, No. 5, pp 763-796, May-June-1980.

3. Cox, D.C., Murray, R.R., and Norris, A.W, 'Measurements of 800 MHz Radio Transmission Into Buildings with Metallic Walls'. The Bell System Technical Journal. Vol 62, No 9, pp 2695-2717, November 1983.

4. Arnold, H.W., Murray, R.R., and Cox, D.C., '815 MHz Radio Attenuation Measured within Two Commercial Buildings'. IEEE Transactions on Antennas and Propagation. Vol 37, No 8, pp 800-803, August 1989.

5. Arnold, H.W., Cox, D.C., and Murray, R.R., 'Macroscopic Diversity Performance measured in the 800-Mhz Portable Radio Communications Environment'. IEEE Transactions on Antenna's and Propagation. Vol 36, No 2, pp 277-281, February 1988.

6. Rappaport, T.S., and McGillem, C.D., 'UHF Fading in Factories'. IEEE Journal on Selected Areas in Communications. Vol 7, No 1, pp 40-48. January 1989.

Cox, D.C., Murray, R.R., and Norris, A.W. '800 MHz Attenuation Measured in and Around Suburban Houses'. AT&T Bell Laboratories Technical Journal. Vol 63, No 6, pp 921-954, July-August 1984.