Appendix B

An Analysis of the Interference Effects of Illegal Airborne Cellular Telephone Calls

AirCell Proprietary Information

An Analysis of the Interference Effects of Illegal Airborne Cellular Telephone Calls

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0.0 Executive Summary

Anyone familiar with the concepts of RF propagation would immediately recognize that illegal airborne calls using the AMPS system may interfere with the legitimate calls being made by AMPS customers. Data concerning the frequency of such calls were gathered by AirCell, Inc.[5] demonstrates that such calls occur on a remarkable percentage of private flights. Using the results of AirCell's two surveys leads to the conclusion that about 15% of all flights by private aircraft[1] initiate illegal airborne calls[2].

It is not practical or even legal to gather data on the signals that emanate from aircraft calls, so a controlled experiment to assess the effects of the interference from illegal airborne calls would appear to be infeasible. This document endeavors to study the situation by simulating the effects of such calls on the serving cellular system.

The analysis in this paper relied on simulating the propagation effects associated with illegal airborne cellular calls. Simulation can never match the fidelity of reality, but cellular propagation is itself a very well-studied and documented field, so that a simulation, carefully crafted, can certainly capture the situation quite accurately.

The simulation used for the present analysis considered both rural cells (times-12 reuse with omnidirectional antennas) and urban cells (times-7 reuse with 120° sectored antennas). The ubiquitous Lee propagation model was used to characterize the signals from the simulated ground-based legitimate AMPS callers, and a modified Lee model was used for the illegal airborne calls, with the primary modification being in terms of path loss as a function of distance being modified to free-space loss.

The simulation effectively "flew" aircraft over a cellular system, with the interference levels caused by the illegal call being determined at one-second intervals as the aircraft moved. The specific effects of both horizontal and vertical antenna patterns were accurately modeled in the simulation, and the usual AMPS mechanisms for reverse-link power control and handoff were also implemented. The simulation results were based on 1000 overflights, with altitudes, directions, speeds, and call lengths being varied pseudorandomly, and the net outputs were probability densities of the interference levels measured (i.e. computed) in the first tier of cells cochannel to the serving cell.

The interference levels by themselves are meaningless; they must be used to determine an S/I (signal-to-interference) ratio for legitimate ground-based AMPS subscribers sharing the channel with an illegal airborne call. The expected signal levels associated with AMPS calls on the ground can be computed to a considerable accuracy in closed-form, and so the probability of any particular S/I for a ground-based AMPS call affected by illegal airborne interference can be obtained. In the body of this document, Figures 7 through 15 show the probability densities of signal and interference separately, and

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[1] Excluding rental aircraft and pilots flying less than 100 hours per year

[2] For the purposes of this study, an illegal airborne call is one made using a 600 mw handheld phone predominantly vertically polarized.

Figure 16 shows the very severe effects on S/I that occur when illegal airborne calls are active on the same channel.

Of course, not all cells cochannel to the cell serving the illegal airborne call will be equally affected by interference: since the aircraft is in motion, it is typically flying toward three of the first-tier cochannel cells, and away from the remaining three. In this study, the interference from an illegal airborne call was aggregated for all six first-tier cochannel cells, and that aggregate was used to characterize interference in the three most-affected cells. Of course, the aggregate interference under-represents interference in the three poorer cells, so the results of this study are conservative.

Once the probability of any S/I ratio can be determined, we must decide what S/I levels actually would cause deleterious effects to legitimate AMPS subscribers. For this study, we set three S/I levels of interest:

17 dB S/I as the minimum at which a call will not be degraded,

10 dB S/I as a level below which the user will probably terminate the call, and

6 dB S/I as the level below which the base station receiver will drop the call.

Note that Figure 16 shows that, for an urban subscriber sharing a channel with an illegal airborne call,

24 out of 25 calls are below the the S/I ratio of 17 dB, therefore are degraded,

9 out of 10 calls are below the S/I ratio of 10 dB, and will be dropped[3].

If we assume then that three cochannel cells are affected by the S/I ratios shown in Figure 16, then anywhere from 0 to 3 legitimate callers might receive seriously degraded service while an illegal airborne call is in progress. The probabilities of various numbers of callers being simultaneously active can be computed, and we can conclude (as is demonstrated in Section 5) that

an illegal cellular call placed over an urban area during the period from 7 A.M. to 7 P.M. will on average interfere seriously with 1.45 legitimate AMPS calls, causing termination of 94% of the affected calls.

The situation is worse with busy hour loading, specifically,

for each illegal airborne cellular call which is placed over an urban cell system at busy hour, 1.7 legitimate AMPS calls will be degraded or ended, and of those two categories, 16 out of 17 of the degraded calls will be degraded to the level that they must be terminated.

[3] If the ambient interference in the cellular system had been included, these values would have been even worse

Returning to the data gathered concerning the frequency of illegal airborne calls (see Section 2), we can expect that in the area of concentrated illegal activity, where 510 illegal airborne calls per day are occurring, there would be on average

740 calls per day which are seriously degraded,

of which

695 will be terminated.

Of course, calls in cellular systems drop for other reasons as well, but this number of *additional* calls being dropped, even in a large system, would normally only be associated with a very badly balanced system. Thus the effects of the illegal calls is about equivalent, in a large urban area, of constantly operating a cellular system which is in a serious state of imbalance. In fact, illegal airborne calls, which are no doubt almost never detectable in the system, may be responsible for a substantial portion of many AMPS providers' maintenance budget, not to mention customer complaints and churn.

But an illegal airborne call can actually also have deleterious effects on idle cohannels, because many AMPS systems routinely monitor channels for serious interference, and deallocate the channel if such interference is found. Thus an idle AMPS channel cochannel to an illegal airborne call may be deallocated, and will not normally return to service without human intervention. The specific length of time during which such a channel may remain out-of-service probably varies widely by system, but if we assume that such an event occurs in busy hour, and that the channel is not reallocated for an hour, then the cell at busy hour is handling its design load (assumed 1% blocking) with fewer channels than would be called for. In the urban system, this will drive blocking up, thereby affecting service to more customers.

Accounting for channel deallocations, together with the effects of illegal calls on legitimate ground calls, we can conclude that in a system where channels may be deallocated due to interference,

a single illegal airborne call will adversely affect an average of 3.95 customers, either by seriously degrading their call (usually causing termination), or preventing access to the system in the first place.

From the results of the analyses done in this paper, it is obvious that cellular providers can be very substantially affected by illegal airborne calls, and really have no means whatsoever to even detect this activity and thereby press action against such transgressors.

Cellular providers should therefore welcome the AirCell, Inc. product, which provides a legal means to provide pilots and their passengers the capacity to make cellular calls which effectively visits no interference on their systems.

1.0 Introduction

The basic principle making cellular telephony possible is frequency reuse. In a given locale, each channel allocated to a cellular provider can be used many times, provided it is reused in cells which are adequately separated from each other. A cellular provider will normally subdivide the available RF channels into a number of subsets, and assign the same set of channels to cells at adequate distance from each other. Cells using the same frequency subset are called *cochannel* cells, and the most common assignment schemes for the US AMPS cellular system are a seven-cell reuse pattern in urban areas, and a 12-cell reuse pattern in rural areas[4]. In the seven-cell configuration, each cell is normally subdivided into three separate 120° sectors, with each sector transmitting/receiving via a directional antenna and using a separate frequency subset. Cells in the twelve-cell configuration normally transmit using an omnidirectional antenna serving the entire cell.

The separation between cochannel cells is based on well-known propagation principles for land mobile signals, and must such that a telephone in use in one cell will not interfere noticeably with use of the same channel in a nearby cochannel cell. Fortunately, signal propagation from land-based mobile transmitters attenuates quite rapidly due to the low antenna height of the mobile, and to the obstructions (foliage, buildings, etc.) that are in the vicinity of a mobile telephone. The various empirical models of RF propagation for land mobile signals in the AMPS band (800 – 900 MHz all specify that mobile signals attenuate with distance approximately as the inverse fourth power of the distance.

However, if a mobile telephone is raised to a great height, its transmitted signal strength decays much more slowly with distance, and can be described as attenuating approximately as the inverse square of the distance. Figure 1 shows a case in which a mobile telephone in an aircraft is being served by a cell, but is propagating substantial signal energy to nearby cochannel cells. This is the reason that use of mobile telephones from aircraft is illegal. The purpose of this paper is to explore in careful quantitative terms just how severe these interference effects might be in US AMPS cellular systems.

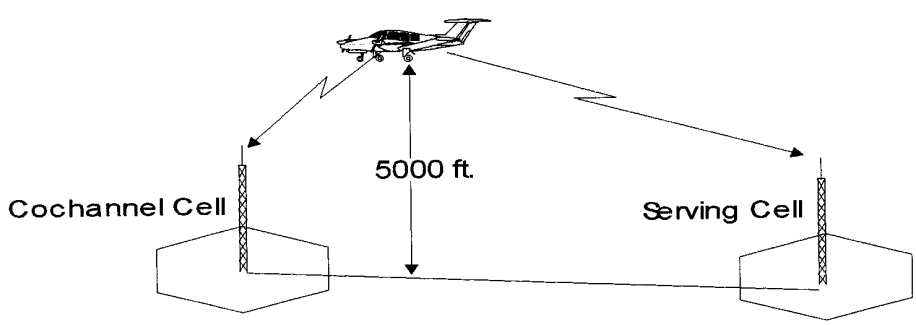

Figure 1 – Geometry of Illegal Airborne Mobile Calls

[4] Some rural operators use the K = 7 pattern, and would experience approximately the same illegal call consequences as urban systems.

2.0 The Reason for Concern

AirCell[5] has conducted extensive interviews with private pilots concerning the extent of illegal cellular telephone use during flights of private aircraft. Pilots were surveyed at the Colorado Air Show (Jefferson County Airport, Broomfield, Colorado) on 31 May and 1 June, 1997. These interviews purposely excluded pilots who rent their aircraft, or who flew less than 100 hours per year. With the pilot sample so delimited, AirCell found that *illegal cellular phone calls were made on 12 % of flights.*

A similar survey was conducted by AirCell at the National Business Aviation Association, in Dallas, Texas, in October 1997. The same restrictions were applied in this case, excluding pilots who rent aircraft or fly less than 100 hours per year. In this case, pilots admitted that *illegal cellular calls were originated on 17% of all flights.* Since there is some difference in these two results, let us assume that illegal calls originate in 15% of all qualifying flights. The actual proportion is probably higher due to sampling error caused by some pilots not responding to the survey.

In some large metropolitan areas, a very substantial number of such flights are in the air each day, and so in fact the potential exists for a considerable number of instances of interference to the cellular infrastructure from such flights. AirCell has data indicating the number of noncommercial, noncommuter IFR flights per day overflying its own cells of approximately 160 miles diameter. These data indicate the extent of noncommercial IFR activity (comprising 1/3 of all noncommercial flight activity) in these areas. In the busiest flight corridors, there are approximately 1700 such flights daily, and the median value is about 190 flights. Assuming that half of all non-IFR flights qualify as nonrental aircraft flown by pilots who fly more than 100 hours per year, we would double the numbers of IFR flights per day as flights to which the survey results apply. Thus we could expect 15% of 3400 flights, or 510 flights per day, as originating illegal cellular calls in the busiest flight corridors, and 15% of 380 flights per day, or 57 flights per day in a 160 mile diameter cell representing the median flight activity.

In what way would such illegal calls affect the normal cellular operations on the ground? First, if call originating from an aircraft is transmitting on a channel which is simultaneously in use on the ground in a nearby cochannel cell (see Figure 1), then the signal level from the illegal airborne call may easily arrive at the base station antenna of the cochannel cell at a level *higher* than the signal from the mobile on the ground which is the legitimate user of the frequency. This would normally prevent the base station receiver from demodulating any acceptable signal on that channel, and so the call from the legitimate mobile on the ground would be dropped. In fact, if the signal level of the illegal airborne call is less than 6 dB below the ground mobile signal, FM demodulation would become impossible, and the call would be dropped by the system. If the illegal airborne signal level was between 10 and 6 dB below the ground mobile signal, the call quality would be very poor, and the legitimate user of the ground-based mobile would probably terminate the call. From 17 dB to 10 dB below the ground mobile signal, the

[5] Via a survey created and conducted by Billig & Associates, a professional polling organization.

ground mobile call would be seriously degraded, since AMPS systems normally consider 17 dB to be the minimum level of signal-to-interference for acceptable call quality.

Because signals from illegal airborne calls attenuate so slowly with distance, a single illegal airborne call may simultaneously affect several legitimate cellular calls at once. Figure 2 shows how this occurs: an aircraft establishes an illegal call while over a particular cell, and then flies outbound from that cell. The signal received from the aircraft by the base station will remain very strong even after the aircraft has traveled a very substantial distance from the cell, and if the call lasts even a few minutes, the aircraft will very likely be closer to several cells cochannel to the host cell, while the host cell is still maintaining the illegal call. In this case, the illegal signal transmitted by the aircraft can cause injurious interference in several cochannel cells at once.

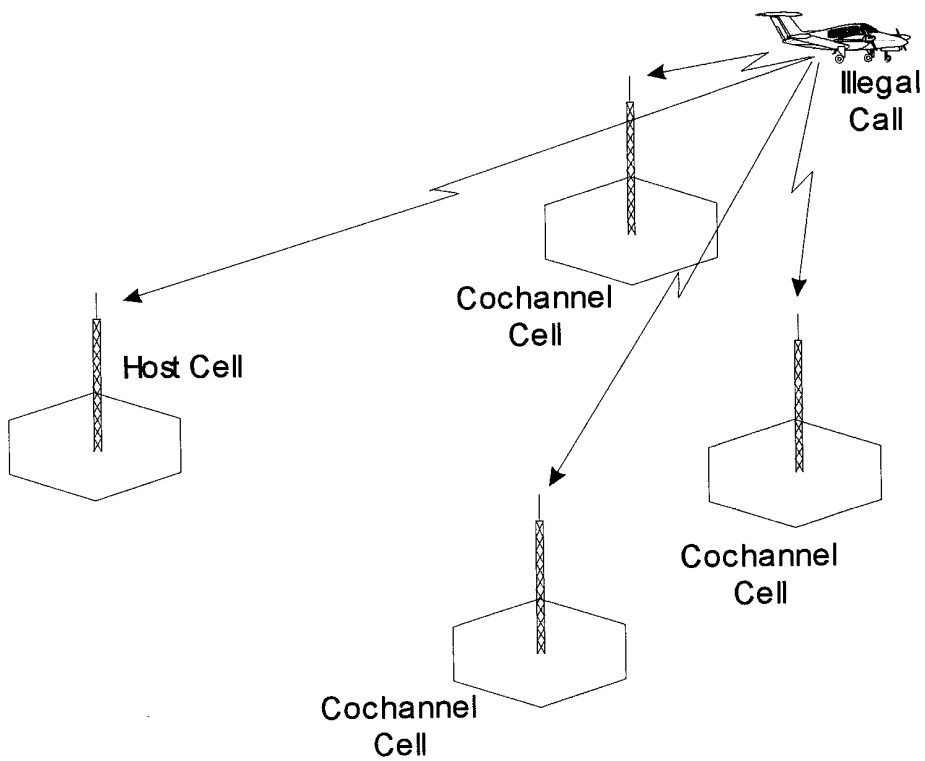

Figure 2 – An Illegal Calling Aircraft Affecting Several Cochannel Cells

Of course, in order for interference to occur, the same channel in use by the aircraft must be in use in at least one of the affected cochannel cells. This is in fact quite likely at busy hour, when most channels are usually in use, and so a single illegal airborne call might easily cause several legitimate cellular calls to be dropped or terminated by the callers.

The purpose of this document is to quantify the apparent affects of illegal airborne cellular calls on cellular systems. Since it is not possible to legitimately collect data from illegal airborne cellular calls, this study uses a careful simulation of aircraft flight over a cellular system, and determines the statistical characteristics of the signals from illegal

airborne calls. These characteristics can be compared to the statistical description of signal levels from legitimate cellular calls in the system. Note that the comparisons to be made will be for the uplink signals (i.e., those transmitted by the mobile unit, whether airborne or ground-based). The next section will elucidate the important quantitative factors entering into this analysis.

3.0 Analysis of Illegal Airborne Cellular Signals

Since signal strength data for illegal airborne cellular calls cannot be legitimately collected, this study relies on a very careful simulation of illegal airborne call activity in order to ascertain the deleterious effects of such calls on cellular operations. Entering into this simulation are several major factors, as described in the subsections below.

3.1 Signal Propagation

There are a number of very well-accepted signal propagation models for cellular systems, with the propagation model of William C. Y. Lee[6] being the most commonly used for the terrain and topography conditions of the United States. This model establishes somewhat different propagation conditions for dense urban, urban, suburban, and rural areas, and has been well-validated for many areas of the United States.

Basically, the Lee model characterizes the attenuation of signal power as a function of distance, and uses standard adjustments for antenna gains, transmit power, antenna heights, etc. Given particular antennas and transmit powers, the attenuation as a function of distance is characterized in terms of a log-log relationship characterizing path loss (in dB) in terms of the logarithm of the path length. This relationship may be approximately represented by the equation

$$L = M(D)\log(d) + b(D) + G \qquad (1)$$

where L = signal attenuation in dB,
$M(D)$ = a slope factor, dependent the demographics (D = urban, suburban, etc.),
d = distance signal has traveled from the transmit antenna,
$b(D)$ = the signal attenuation at a distance of 1 mile from the transmitter,
G = the combined effects of antenna gains and heights, transmit power, etc.

The form of Equation 1 as shown here emphasizes the linear characterization of the Lee propagation model in terms of the logarithm of distance d. The slope factor M(D) is generally in the neighborhood of 40, although it varies as a function of the demographic type of the area. The intercept b(D) indicates what signal level is expected (relative to a reference situation) at a distance of 1 mile from the transmitter.

[6] See Mobile Communications Design Fundamentals, Second Edition, Wiley Series in Telecommunications, 1993, pp.61 - 67

Lee's model deals with ordinary cellular propagation from antennas near the ground, and with the signal propagating near the ground. There is understandably no direct data for illegal airborne cellular calls using the AMPS frequency band, so we must extrapolate somewhat from cellular propagation facts and free-space propagation facts to obtain a suitable equation for propagation of cellular signals from aircraft. For this study, the signals for airborne propagation are derived from a modification of Lee's equation, with the factor M(D) being modified to 20, to reflect free space propagation (i.e., signal attenuates as the inverse of distance squared). The one-mile intercepts used by Lee are based on actual measurements taken one mile from the transmit antennas, in the various demographic conditions. For an illegal airborne call, we assume a one-mile intercept as would be the case for rural conditions, but with attenuation at the free-space rate. This gives a one mile intercept of about –28 dB instead of –48 dB, as used for ground-based cellular propagation. A flat earth is assumed, because all geometries studied are well within line-of-sight.

The final variation used to characterize illegal airborne cellular propagation relates to transmit antenna height. Lee's model awards a substantial gain to antenna height, of 20 dB per decade. Thus an antenna 100 feet above the ground should provide 20 dB more gain than one ten feet above the ground. This effect may be valid up to some altitude above all surrounding obstructions, but would not apply linearly at virtually any altitude, so in this paper, a signal propagated from an aircraft at any altitude is assumed to be propagating from an antenna on a 200 foot tall tower[7]. This is probably conservative, so we will be underestimating the effects of illegal airborne cellular calls on the underlying cellular infrastructure.

Finally, we may need to be concerned with line-of-sight considerations in determining to what distance the effects of an illegal airborne call might propagate. In fact, the range of altitudes used in this simulation, from 3000 feet upward to 15000 feet, assures that the first ring of cochannel cells around a host cell will always be well above the horizon, and this analysis has not dealt with more distant tiers of cochannel cells. Thus line-of-sight *per se* is not important within the scope of the analysis.

Summarizing the above, our airborne signal propagation model is a variant of the Lee model, with

(1) free space loss M(D) (see Equation 1) of 20 dB per decade substituted for the usual loss of 40 dB per decade,
(2) a one-mile intercept b(D) (see Equation 1) of –28 dB instead of the -48 dB used by Lee for rural propagation,
(3) an assumption that gain due to antenna height for aircraft transmission is equivalent to propagation from an antenna on a 200 foot tower.

[7] This assumption applies only to the antenna height factor of the Lee equation: line-of-sight for the signal is calculated based on aircraft altitude AGL.

3.2 Cellular System Operation

This study makes an effort to capture all details of ordinary cellular operations which might bear on the interference issues at hand. The factors accounted for in analyzing signal behavior in the mixed airborne/ground environment are

(1) system configuration, as twelve-cell omnidirectional or seven-cell trisectored frequency reuse,
(2) typical base station link budget parameters,
(3) base station antenna patterns, specifically using both vertical and horizontal antenna pattern information derived from standard industry antennas,
(4) reverse-link power control, with the base station maintaining reverse-link signal level at the base station by power control commands to both ground-based and airborne mobile units,
(5) handoff, with the base station monitoring reverse link signal level, and handing off a mobile to the neighboring cell with the highest measured signal level on the handoff candidate.

Concerning (1) above, a square array (30 by 30) of regular hexagonal cells was created, all with equal radii. The twelve-cell system was assumed to be operating in rural conditions, and the seven-cell system was assumed to be operating in urban conditions.

Concerning (2) above, the base station antennas are taken to have typical gains (9 dB for the omni, 14 dB for the directional), 5 dB of diversity gain, 6 dB of net LNA gain, and 2 dB of loss in cables and connectors going down the tower to the input to the diplexer, which will be taken as the reference point for all signal levels mentioned hereafter. Base station antenna heights were taken to be 100 feet in the urban situation, and 200 feet in the rural situation. The cell radii supported by these budgets are 2.7 miles for the urban cells and 5.2 miles for the rural cells.

Concerning (3) above, the antenna used for the twelve-cell system was an Antenna Specialists Co. 9 dB omni, Model ASP-951, and the antenna used for the seven-cell sectored system was the 14 dB Decibel Products DB878H120. The horizontal and vertical patterns of these antennas were accounted for in detail in measuring signal levels from the airborne mobiles, but the vertical patterns of the antennas were ignored for ground-based mobiles. The reason for this is that an aircraft could quite easily be positioned in a vertical sidelobe of a cochannel cell's antenna, as shown in Figure 3, but it is very rare that a ground-based mobile would appear in a vertical sidelobe.

There is thus a strong mitigating factor, i.e., poor base antenna pattern directed skyward, acting on an illegal airborne signal when an aircraft is very near or over a cochannel cell. However, as the results of the simulation will show, this mitigation is not adequate to prevent severe degrading effects from illegal airborne calls.

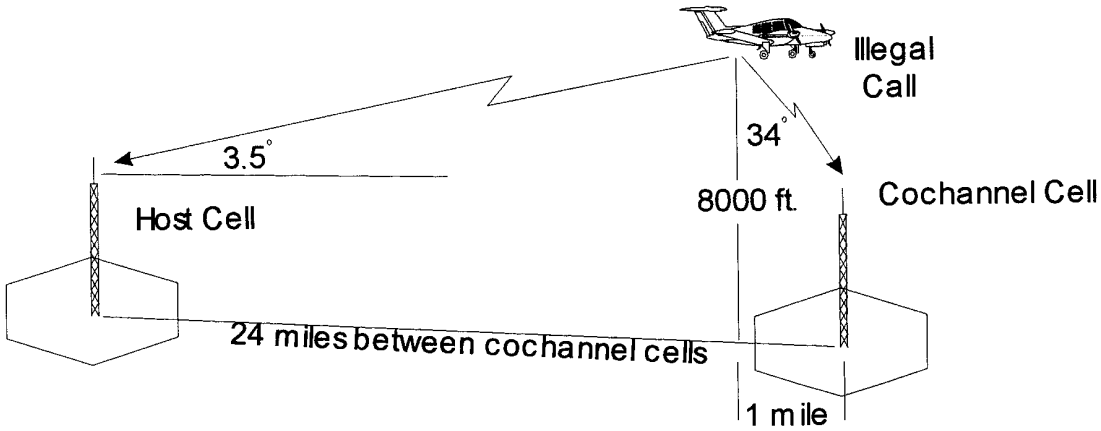

Figure 3 – Geometry of Illegal Calling Aircraft/Base Station Antenna Interaction

Concerning (4) above, the base station reverse power control operates to maintain reverse link signals at approximately –84 dBm at the input to the diplexer, and ramps power up or down in 4 dB steps[8], as is typical in AMPS installations. All calls begin at 0.6 watts and are ramped down to whatever power level achieves the –84 dBm level at the base station, but by at most three power control steps. All mobiles, both airborne and ground-based, are assumed to be handhelds with 0.6 watts transmit power and 0 dB antenna gain, in order to provide a fair comparison. All mobile transmit signals for both illegal airborne and ground-based calls are assumed to be subject to an 8 dB in-vehicle fade, for aircraft or car. Since cells are designed to accommodate 0.6 watt mobiles at the cell boundary, use of more than 0.6 watts even by a higher power mobile would only occur in unusual shadowing situations or when the mobile was approaching handoff. However, the signal level as seen at the base station antenna would, due to the power control and handoff protocol, still remain within the range as seen for the 0.6 watt mobiles.

Concerning (5) above, the illegal airborne calls are held by a host base station until the reverse link signal level reaches –94 dBm, and then the host base station polls its immediate neighbors (including same-cell sectors for the trisectored system) to determine the cell reading the strongest signal level from the handoff candidate. Handoff then occurs to the cell/sector with the highest signal level, or may not occur if the host cell still has the strongest signal. An illegal airborne call, because of the excellent free-space propagation conditions, can be held by the original host base station even as the aircraft flies tens of miles. Since cellular calls have a mean length of about 2.5 minutes, handoffs were in fact very rare in the simulation, and for all practical purposes can be ignored.

3.3 The Simulation Process

As has been described in the previous section, all reasonable aspects of signal propagation in cellular systems have been accounted for in this analysis. The simulation itself is an event-driven simulation in which an illegal airborne call is initiated over the

[8] AMPS permits a maximum of 7 such power levels, for a 28 dB total power range from the mobile transmitter.

central cell in the array of cells, and then the aircraft flies in a straight line at a fixed altitude for the duration of the call. After the call is initiated, the simulation steps the aircraft position at one second (simulated time) intervals, and, in each such interval

(1) measures the reverse-link signal level as seen at the base station in the six nearest cochannel cells (signal path angle relative to the horizontal and vertical antenna patterns at the cells of interest is accounted for, so that signal level is the sum of path loss and antenna pattern effects),
(2) ramps power up or down in the airborne mobile as needed,
(3) checks to see if the handoff threshold has been reached, and if so schedules a handoff process to occur 3.5 seconds later,
(4) determines when the end of call is due, and terminates the call.

Inputs to the simulation are

(1) mean length and standard deviation of calls (assumed normally distributed),
(2) minimum and maximum altitude of flights (taken to be from 3000 to 15000 feet AGL, chosen to be uniformly distributed in the selected range)
(3) range of speeds for the aircraft (taken to be from 100 to 250 knots, chosen to be uniformly distributed in the selected range),
(4) type of cellular system (rural twelve-cell omnidirectional, 5.2 mile cell radius, or urban seven-cell/trisectored, with 2.7 mile radius,
(5) nominal reverse-link power level for power control (set at –84 dBm),
(6) nominal reverse-link power level for handoff (set at –94 dBm),
(7) number of calls to be simulated,
(8) the random number seed initializing the simulation.

The primary outputs of the simulation were

(1) the histograms of interference signal levels from the illegal airborne calls as measured at the six cochannel cells in the first cochannel tier around the host cell,
(2) the interference histogram aggregated from the six cochannel cells mentioned in (1),
(3) the histogram of the worst interference at each measurement opportunity, independent of which cochannel cell experienced it,
(4) the measurement of the worst interference in any cochannel cell at the time of call termination.

There was no need to use simulation to obtain the reverse-link statistics of the ground-based mobiles. In effect, if we assume circular cells, then the Lee propagation model can be used to solve for the radii at which any specific power level would occur (as seen at the base station) for the mobiles on the ground, as shown in Figure 4. As seen in Figure 4, a constant power level of –84 dBm is maintained for all mobiles out to a radius R_{84}, at which distance the mobiles must supply a full 0.6 watts transmit power in order to supply –84 dBm at the base station. From that point on out, we may subdivide the cell into contour bands wherein the signal level at the base station is constant to within a dB[9], but

[9] The choice of one dB steps is, of course, arbitrary.

is falling as we approach the cell boundary. At the cell boundary, the radius R_{94} represents the distance at which the full 0.6 watts transmit power can just achieve the needed – 94 dBm at the base station, and handoff is imminent.

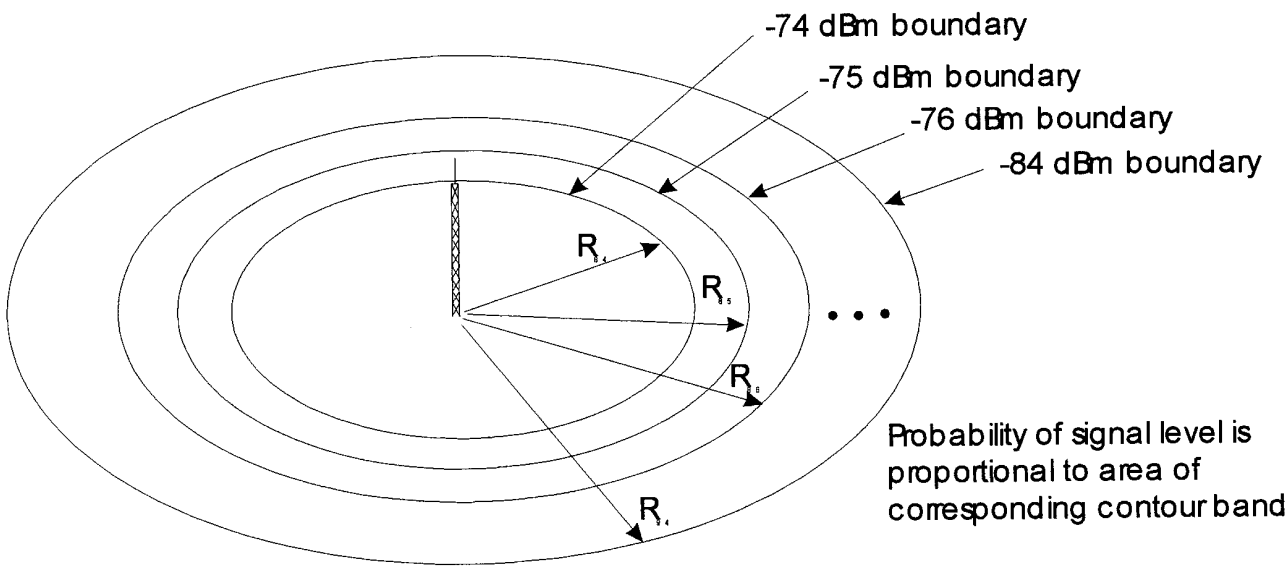

Figure 4 – Geometry Associated with Ground-Based Mobile Signal Levels

If we assume that ground mobiles are uniformly distributed in the cell, then the areas of these contour bands, divided by the area of the cell, provide the probability density for each signal level from –84 dBm to –94 dBm. However, the mobility of cellular transmissions also causes a substantial rapid variation in signal levels due to multipath effects. Generally, the variation in signal strength due to multipath effects is characterized as a random variation, the log of which is normally distributed. That is, the reverse-link signal level, expressed in dB, has a normal variation about its static value (the component which depends only on distance) and this normal variation, in urban conditions, is usually taken to have about an eight (8) dB standard deviation.

The final form of the ground-based signal density will then be as derived from the considerations of power contours (Figure 4), but with each static level of signal being affected by an eight (8) dB standard deviation. The signal strength probability density corresponding to this model will be illustrated in the next section.

The simulation is used to evaluate the interference effects of illegal airborne calls by collecting the observed illegal airborne signals as measured in the cochannel cells, and compiling a probability density of interference signal level. The illegal airborne interference can be expected to display multipath effects, also, but that is not directly accounted for in the signal measurements taken during the simulation. Thus a three dB standard deviation log-normal fading effect is imposed on the probability densities for

illegal airborne calls to achieve the fading effect[10]. The manner in which the signal and interference are used to characterize degraded cellular operations will be described in the next section.

4.0 Simulation Results

This section will explain the use of the simulation and display the results in graphical form.

4.1 General Execution of the Simulation

The simulation program written for this study examined the interference effects of 1000 illegal airborne calls originating over a specific cell with the interference levels measured in cochannel cells on a second-by-second basis. The flight profiles and call lengths were randomly selected within the limits

(1) aircraft initial position, uniformly selected as anywhere within the host cell,
(2) aircraft course, uniformly chosen from 0 to 360 degrees,
(3) aircraft altitude, uniformly chosen between 3000 ft. and 15000 ft. AGL,
(4) aircraft speed, uniformly chosen between 100 and 250 knots,
(5) illegal airborne call of mean length 2.5 minutes and standard deviation 0.5 minutes, chosen using a normal probability distribution with the specified parameters.

The individual values of each of the aforementioned parameters were gathered during simulation and their means and standard deviations were computed at the end of simulation. Agreement of the computed parameters with the originally specified parameters served to check the integrity of the pseudorandom processes used in the simulation.

One of the outputs of the simulation was a plot of the aircraft trajectories pseudorandomly selected during the simulation overlain on top of the cells, as shown in Figures 5 and 6. These plots clearly indicate that for flights within the envelope of specified parameters (for call length and aircraft speed), illegal airborne calls rarely extended in duration past the first tier of cochannel cells, and then only slightly, primarily because cellular calls tend to be very short That is why this study limited the analysis the interference effects to the first tier of cochannel cells. However, the rural cell radius is larger (5.2 miles) than the urban cell radius, so illegal airborne calls over urban areas can easily extend into the immediate vicinity of the cochannel base station receiver. This effect is offset however, by the use of directional antennas in the urban cells, so that there is only a very small net difference in interference levels for the rural and urban case, as will be borne out by Figures 8 and 10.

[10] Fading for a signal emanating well above the ground, and arriving at the base station antenna would be less than for mobiles moving in ground clutter.

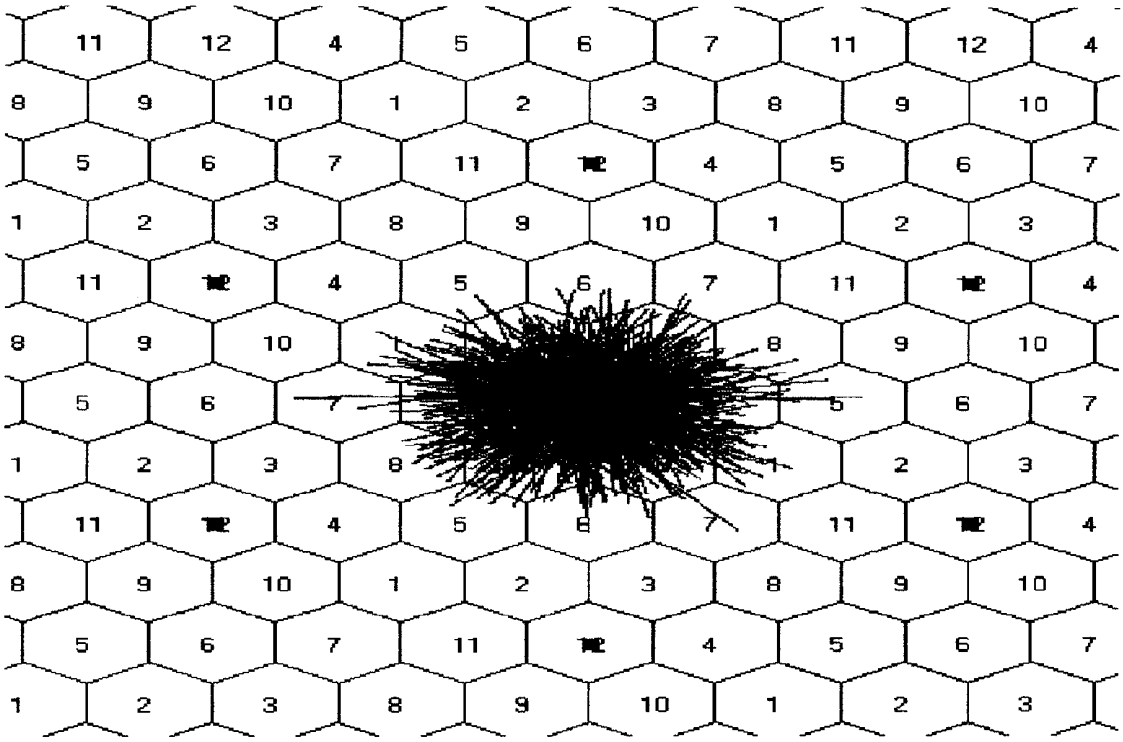

Figure 5 – Overlay of 1000 Flight Paths on Rural Cellular Grid (5.2 Mile Radius)

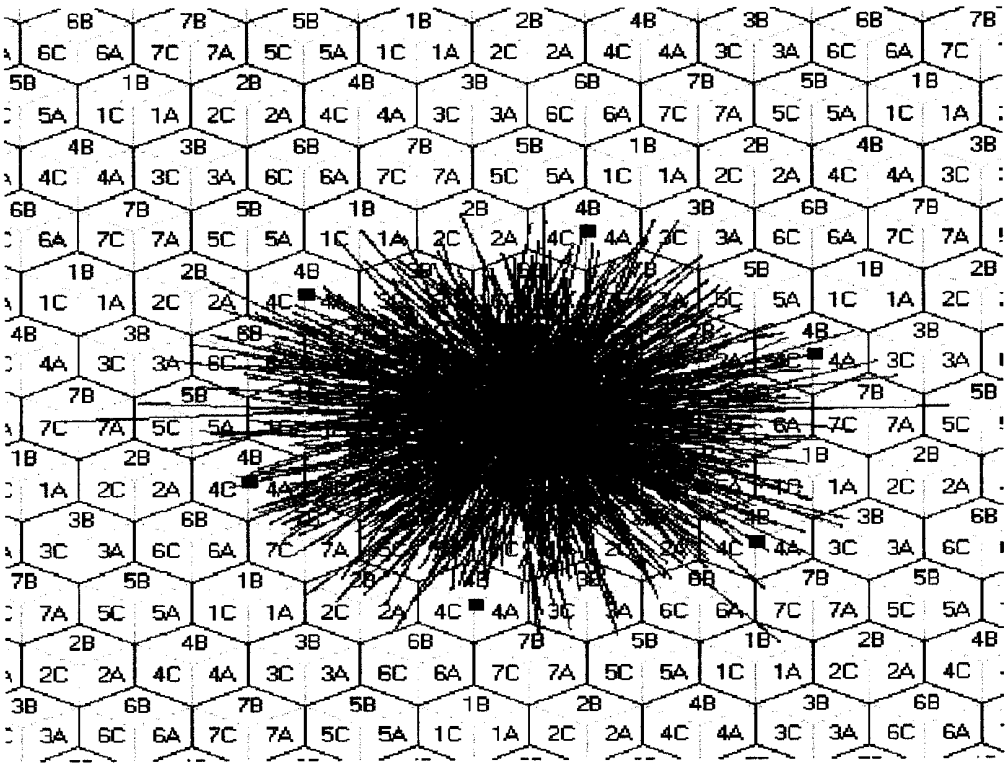

Figure 6 – Overlay of 1000 Flight Paths on an Urban Cellular Grid (2.7 Mile Radius)

4.2 Basic Simulation Results

Now we examine some of the interference data collected during the simulation, based on the aggregate of 1000 flights selected according to the parameter ranges discussed in Section 4.1. The simulation interference measurements aggregate interference signal levels collected at one second intervals in the first tier of cochannel cells over the duration of each call. The simulation did not examine multiple calls simultaneously, but set up and examined 1000 separate calls. Thus, the data collected represents a statistical average of interference to be expected from a single call, but with the conditions of that call representing the entire range of directions, altitudes, aircraft speeds, and call lengths which might be encountered for a single call[11] set up over a specific host cell.

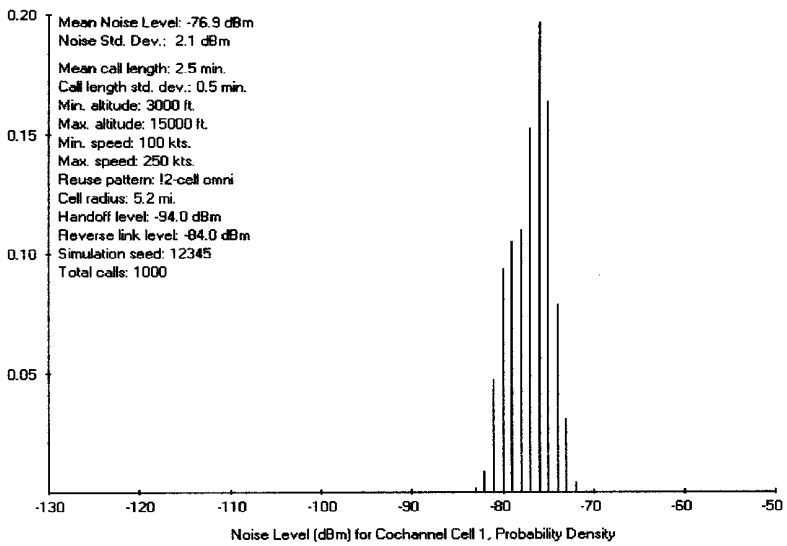

Figure 7 – Interference Levels from 1000 Illegal Airborne Calls over a Single Cochannel Cell, Rural System

Figure 7 shows the probability density of interference strength for one cochannel cell in the rural situation, and Figure 8 shows the aggregate data for all cochannel cells. The close similarity indicates that the cochannel cells are on average affected equally by illegal airborne calls. Figures 9 and 10 display analogous plots for the urban situation[12]. Note that the mean values of the interference are about the same for the rural and urban situations, but that the rural situation has a much smaller spread about the mean. This no

[11] This study does not explicitly address the possibility of multiple simultaneous airborne calls, although the expected interference could be obtained from the present simulation data.
[12] The effects of 3 dB multipath fading have not been depicted in Figures 7 – 10, in order to exclusively delineate the geometry and antenna pattern effects.

doubt is due to the directionality effects of the 120° sector antennas in use in the urban system.

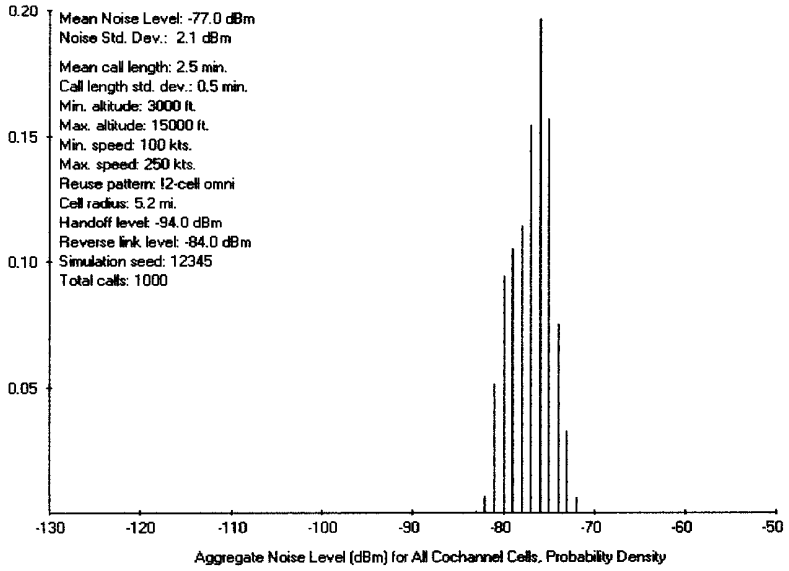

Figure 8 – Aggregate Interference Levels from 1000 Illegal Airborne Calls for All Cochannel Cells, Rural System

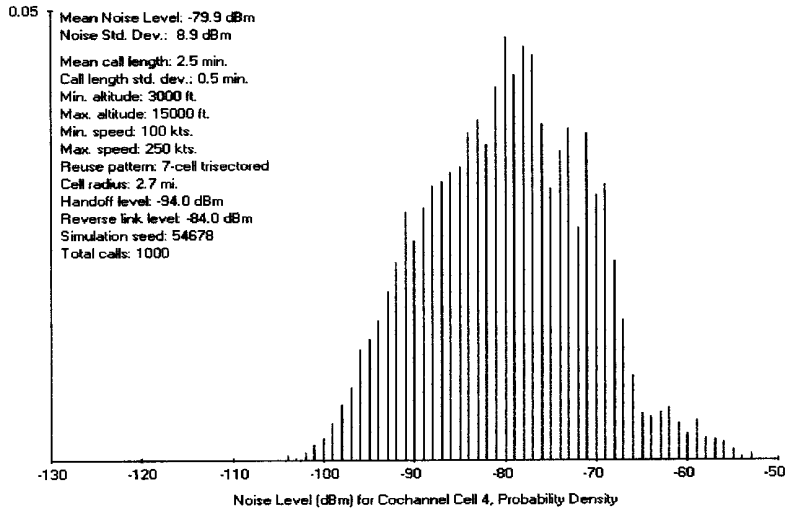

Figure 9 – Interference Levels from 1000 Illegal Airborne Calls for Single Cochannel Cell, Urban System

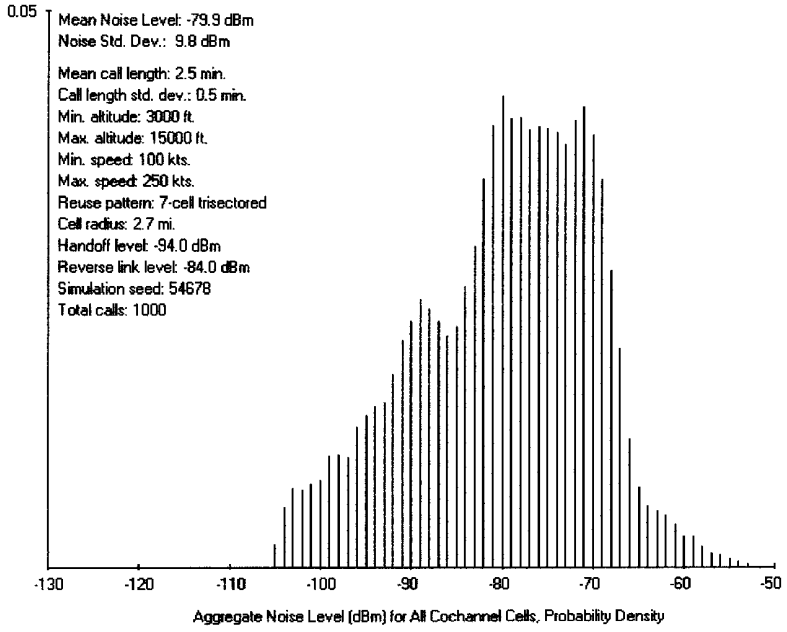

Figure 10 – Aggregate Interference Levels from 1000 Illegal Airborne Calls for All Cochannel Cells, Urban System

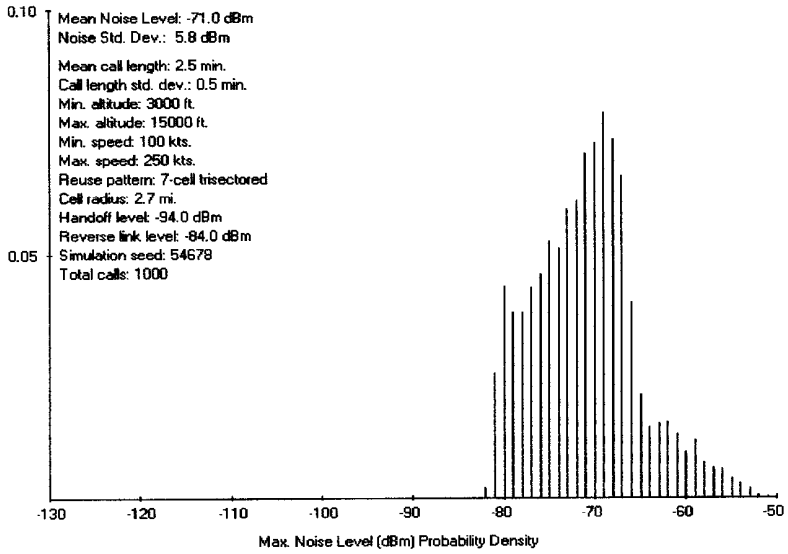

Figure 11 – Worst Interference from 1000 Illegal Airborne Calls in Any Cochannel Cell, Urban System

Figures 8 and 10 illustrate the average interference profile at a cochannel cell, based on all possible flight configurations emanating from the host cell. This aggregate representation of the data is actually quite conservative, however, since during any specific illegal airborne call, the aircraft will be flying toward some cochannel cells, and away from others.

Figure 11 demonstrates this rather marked effect, by showing the probability density of the maximum interference as measured in all six of the cochannel cells. Note that in general, some cochannel cell is experiencing interference about 9 dB higher than represented for the aggregate of all cochannel cells.

In general, the "worst" interference will persist in one cell for some interval, but may hop to another cell for a later part of the call. Thus we cannot safely claim that the worst interference will last long enough in any one cell to actually cause dropped calls, but may cause transient poor call quality, although that is highly likely to be true in some flight profiles.

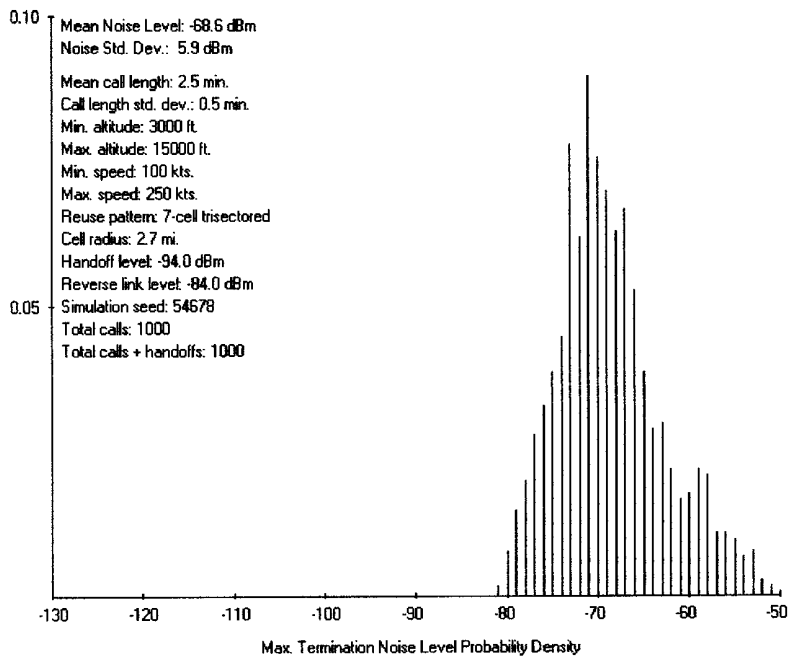

Figure 12 – Interference Level to a Ground Mobile at Time of Illegal Call Termination, Urban System

Finally, Figure 12 is offered to illustrate the worst interference levels exhibited at the time of call termination. Thus, the data on which Figure 12 is based are a subset of that

supporting Figure 11, but at the final moment of a call, when the aircraft is farthest from the host cell, and of course closest to some of the cochannel cells. This data is in fact very significant, because at the moment of call termination, the reverse link of the illegal airborne call is sending the supervisory "hangup" signal to the base station. A call on the same channel in the affected cochannel cell will also be terminated by the illegal airborne call's signal, and at the interference levels shown in Figure 12, it is a virtual certainty that this will happen, if the ground-based call has not already dropped due to the extreme interference level, which on average is equal to or less than the reference reverse-link power control signal level in use by the base station. Under these circumstances, a cochannel ground-based call cannot possibly survive.

4.3 The Analysis Scenario

Figures 7 through 12 are instructive, in that they focus on the interference effects of illegal airborne cellular calls and represent several perspectives as to the likely effects on the underlying AMPS system. In this section, we will select a specific scenario to analyze, and determine what effect illegal airborne call interference has on the S/I (signal-to-interference) ratios of legitimate AMPS calls on the same channel. We will limit this case to the urban cellular system, since most sizable airports which might originate noticeable air traffic are in urban areas. However, as we have seen, noise levels in rural cells from illegal airborne calls will be as just as significant, and the rates of dropped calls or heavily affected calls will be just as severe in rural cells, should an aircraft overflying such a system initiate an illegal airborne AMPS call.

Also, we will accept the aggregate cochannel noise data of Figure 10 as the representative probability density of interference from illegal airborne calls, although as has been mentioned previously, any specific flight is flying toward three cells and away from three others, so the overall aggregate no doubt underestimates the level of interference for at least three cells. Since the data of Figure 10 are those of interest, Figure 13 depicts the same data after it has been convolved with the 3 dB log-normal spreading process representing multipath fading.

The interference levels shown in Figure 13 are those measured at the base station on the reverse link from any single illegal airborne call, and we must compare these levels to those of a legitimate signal on the same channel emanating from a mobile on the ground using the affected cell as a host cell. As was mentioned in Section 4.2, the probability density of the legitimate mobile signals in a cell are derivable from the propagation model in use, bearing in mind that the base station exerts reverse-link power control. Figure 14 shows the probability density for the legitimate reverse-link signal, before the effects of 8 dB multipath fading are included, and Figure 15 depicts this same density with fading included.

Now to determine S/I ratios from the probability densities for signal (Figure 15) and interference (Figure 13), let

PS(u)	= probability that the signal level in Figure 15 = u dB,
PN(v)	= probability that the interference level in Figure 13 = v dB,
PS/I(w)	= probability that an S/I ratio based on these figures = w dB,

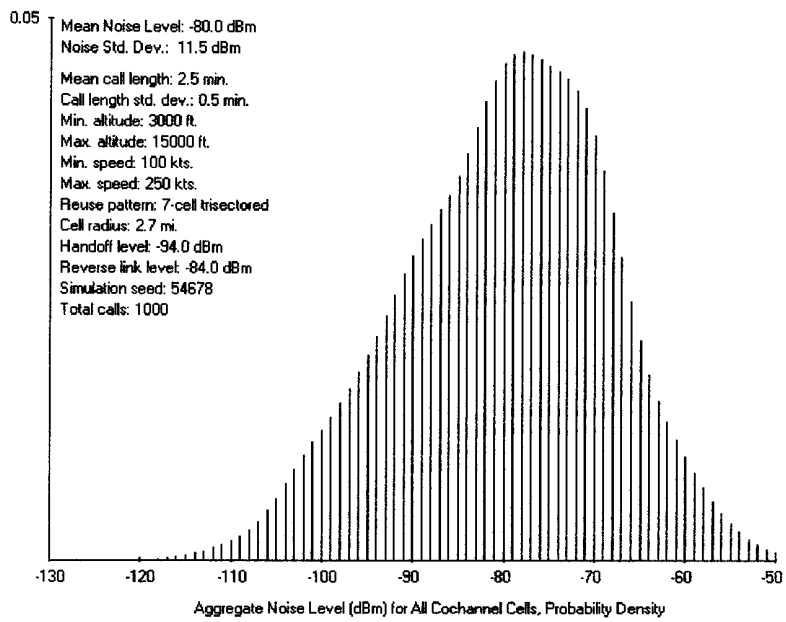

Figure 13 – Interference Signal Level from 1000 Illegal Airborne Calls with 3 dB Fading Flying over an Urban Cell System

The specific S/I ratio probability density then can be computed from Equation 2 below.

$$P_{s/i}(w) = \sum_{u-v=w} P_s(u) P_N(v) \qquad (2).$$

Figure 16 illustrates the probability distribution for the S/I ratio visited upon a legitimate ground-based AMPS call by the illegal airborne use of an AMPS phone. Note that Figure 16 describes three specific levels of S/I, .

(1) the probability of an S/I ratio < 6 dB (the level at which the base station will certainly drop the call) is 0.84,
(2) the probability of an S/I ratio < 10 dB (the level at which the caller will experience severe degradation and probably terminate the call) is 0.9,
(3) the probability of an S/I ratio < 17 dB (the nominal level of acceptable call quality for AMPS calls) is 0.96.

These results certainly imply that the consequences of illegal airborne AMPS calls are being visited on the AMPS providers and their customers throughout the nation, and in

the next section, the likelihood of a specific AMPS call being affected will be determined.

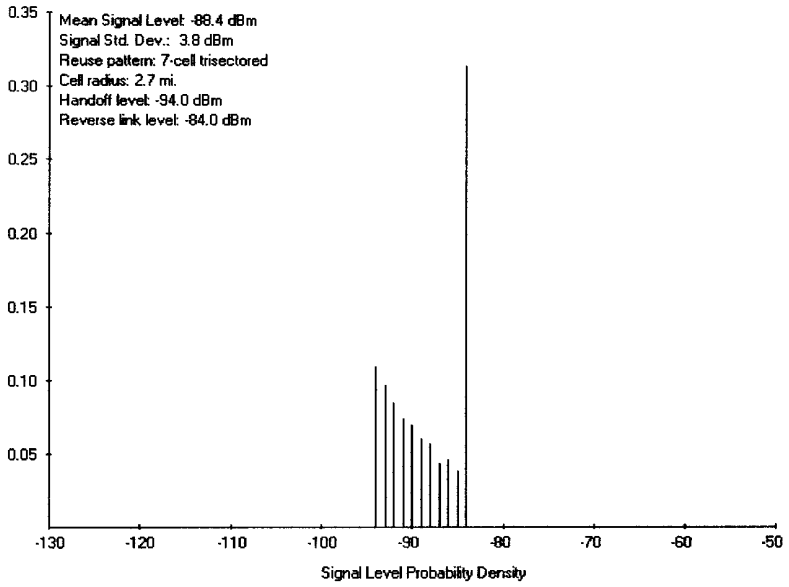

Figure 14 – Probability Density for AMPS Mobile Signal Levels before Fading

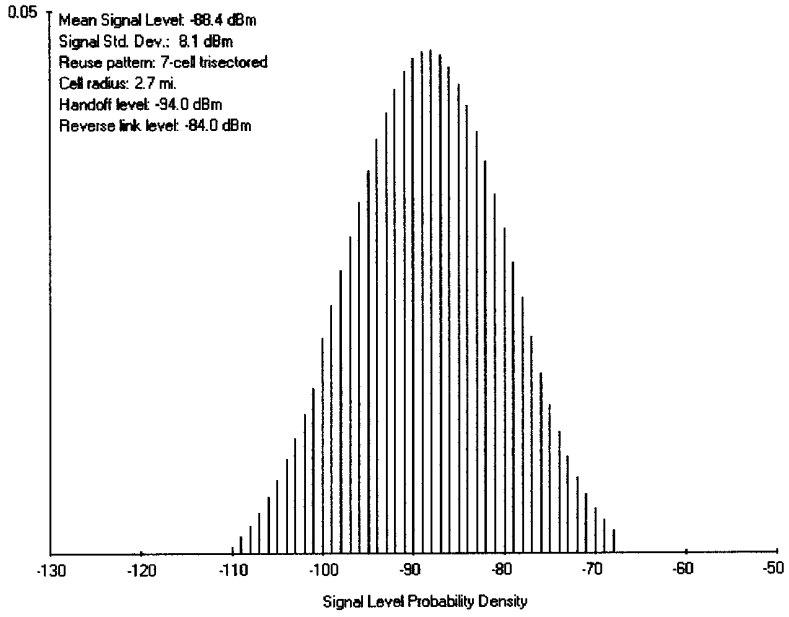

Figure 15 – Probability Density for AMPS Mobile Signal Levels, 8 dB Fading

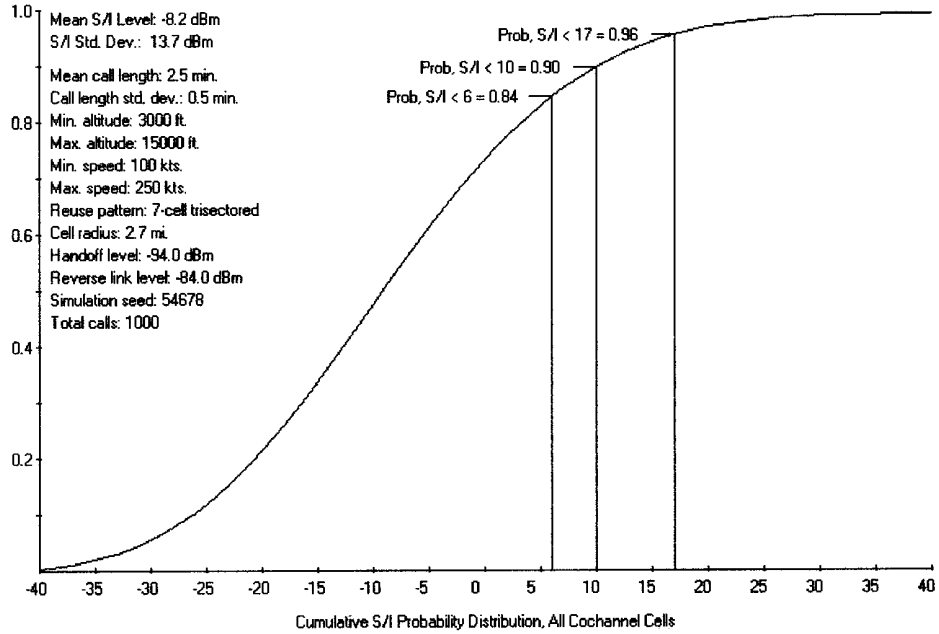

Figure 16 – Cumulative Probability Distribution for S/I Ratio in Cochannel Cell Resulting from Illegal Airborne Call

5.0 Assessing the Damage

The previous section supports the argument that an illegal airborne AMPS call will almost certainly create serious interference with a legitimate ground-based AMPS call using the same channel in a nearby cell. Such an argument is not complete, however, until we examine the probability that an illegal airborne call is in fact sharing a channel with an AMPS call in progress, and in a cell which is cochannel to the cell supporting the illegal airborne call. In fact, a case can be made that an illegal airborne call has a serious effect on idle cochannels as well, and that will be covered in this section.

5.1 Illegal Airborne Call Effects on Busy Cochannels

In particular, what is the probability that a specific channel supporting an illegal airborne call is simultaneously in use in at least one of the nearby cells which is cochannel to the cell supporting the illegal call? To address this question, note that cell systems are designed to support a particular capacity, subject to a *blocking* constraint. The blocking constraint is expressed as the percent of time that a new call must be rejected because all channels are currently busy. Most cellular systems assign channels or adjust cell size so that the expected demand in a cell will not cause blocking to exceed 1%[13].

The Erlang-B probability density enables cell system designers to balance demand and blocking. For our present situation, we exploit the fact that in a seven-cell trisectored AMPS system, there are 395 traffic channels available which must be subdivided into 21 subsets, which permits 18 – 19 channels per sector. The maximum demand that a sector can then support with 19 channels is 11.2 Erlangs of traffic, with the usual 1% blocking criterion. An Erlang of traffic simply represents the full use of a channel, i.e., 60 minutes of traffic per hour, so the overall utilization of any specific channel is just the maximum load of the cell, in Erlangs, divided by the number of channels available in the cell. Since a cell with 19 channels can support 11.2 Erlangs of traffic, the individual utilization per channel should be

$$U_c = 11.2/19 = 0.59 \qquad (3).$$

Now there is normally no coordination of channel assignments between nearby cochannel cells, so for any specified channel, the probability of it being in use in any cochannel cell is just the value U_c shown in Equation 3. Since the uses in separate cells are independent, the probability P(n; N) of the same channel being in use n times in N cochannel cells adheres to the binomial probability density, i.e.,

$$P(n;\, N) = \binom{N}{n} U_c^{\,n} (1 - U_c)^{N-n} = \frac{N!}{(N-n)!\, N!} U_c^{\,n} (1 - U_c)^{N-n} \qquad (4)$$

[13] The demand in a cell varies over the day, but the blocking criterion normally applies to the expected traffic load for the cell's the busy hour.

Using the binomial distribution, we can now focus on the practical effects of an illegal airborne call. First, for the value of U_c shown in Equation 3, and with N = 3 (i.e., the illegal airborne call is affecting three of the cochannel cells), we can use Equation 4 to compute that, when an illegal airborne call is active at the busy hour loading of the cell,

0.93 = probability of at least one call being active on the same channel within the three most heavily affected cochannel cells,

0.30 = probability that exactly one call is active on this channel,

0.43 = probability that exactly two calls are active on this channel

0.20 = probability that three calls are active on this channel.

From these probabilities, we may compute the mean number of calls which will be active on the same channel as an illegal airborne call at busy hour, which will be

1.76 = mean number of calls active on a single channel = 1(0.30) + 2(0.43) + 3(0.20).

However, we must also factor into our accounting the probability that a call, when simultaneously active with the illegal airborne call, will be affected adversely by the illegal airborne call. From Figure 16, we may consider that an S/I ratio lower than 17 dB will degrade a call, and that an S/I ratio lower than 10 dB will almost certainly cause the call to be voluntarily terminated or dropped by the base station. In order to assess these situations, we may modify our binomial density given by Equation 4 by modifying U_c as follows:

$$U_d = U_c * \text{Probability}\{\text{S/I ratio is lower than 17 dB}\} = (0.59)(0.96) = 0.57,$$

$$U_e = U_c * \text{Probability}\{\text{S/I ratio is lower than 10 dB}\} = (0.59)(0.90) = 0.53.$$

Using U_d and U_e in the binomial in place of U_c permits us to determine the probabilities of calls being active and either degraded (U_d) or ended (U_e) when an illegal airborne call is active. The results of these computations are displayed in Table 1 below.

	Number Active Calls				
	0	1	2	3	Mean
Probability	0.07	0.30	0.43	0.20	1.76
Pr(Degraded)	0.08	0.32	0.42	0.18	1.70
Pr(Ended)	0.10	0.35	0.40	0.15	1.60

Table 1 – The Effects of Illegal Airborne Calls at Busy Hour

The row of Table 1 labeled "Probability" shows the probabilities of 0 – 3 calls being simultaneously active at busy hour. The row labeled "Pr(degraded)" shows the probabilities of 0 – 3 calls being degraded, i.e., at an S/I ratio lower than 17 dB when an illegal airborne call is active. The row labeled "Pr(Ended)" shows the probabilities for 0 – 3 calls being terminated, i.e., at an S/I ratio of 10 dB or less due to an illegal airborne call.

The most important information in the table is that, ***for each illegal airborne cellular call which is placed over an urban cell system at busy hour, 1.7 legitimate AMPS calls will be degraded or ended, and of those two categories, 16 out of 17 of the degraded calls will be degraded to the level that they must be terminated.***

If we are not operating at busy hour, then the utilization of each channel in a cell drops below that at busy hour. In urban areas, we might expect the traffic load to decay to about 80% of its busy hour level during most of the "dawn-to-dusk" period[14]. In that case, the utilization per channel would be

$$U_c = 0.8*(11.2)/19 = 0.47,$$

And using the same reasoning as for busy hour, we compute

$$U_d = (0.47)(0.96) = 0.453,$$

and

$$U_e = (0.47)(0.90) = 0.423.$$

Table 2 below shows the same results for the non-busy hour period as was shown by Table 1 for busy hour. Again, we find that the illegal airborne calls still have very serious consequences: ***for each illegal airborne cellular call which is placed over an urban cell system at non busy hour, 1.36 legitimate AMPS calls will be degraded or ended, and of those two categories, 16 out of 17 of the degraded calls will be degraded to the level that they must be terminated.***

	Number Active Calls				
	0	1	2	3	Mean
Probability	0.15	0.40	0.35	0.10	1.40
Pr(Degraded)	0.16	0.41	0.34	0.09	1.36
Pr(Ended)	0.19	0.42	0.31	0.08	1.28

Table 2 – The Effects of Illegal Airborne Calls at non-Busy Hour

[14] We would expect that almost all illegal airborne calls would be made in the same period, i.e, 7 A.M. to 7 P.M., as are legitimate AMPS calls.

If we consider busy hour as approximately three hours of the 12 hour period from 7 A.M. to 7 P.M., then we can weight these results together to obtain an overall assessment of the effects of illegal airborne calls: using the values from Tables 1 and 2, an illegal airborne call causes serious degradation to

$$(0.25)(1.7) + (0.75)(1.36) = 1.45 \text{ legitimate AMPS calls, on average,}$$

and causes termination of

$$(0.25)(1.6) + (0.75)(1.28) = 1.36 \text{ of these calls on average.}$$

Thus we may generally conclude that

an illegal cellular call placed over an urban area during the period from 7 A.M. to 7 P.M. will on average interfere seriously with 1.45 legitimate AMPS calls, causing termination of 94% of the affected calls.

Returning to the data gathered concerning the frequency of illegal airborne calls (see Section 2), we can expect that in the area of AirCell's busiest cells, where 510 illegal airborne calls per day are occurring, there would be on average

$$(510)(1.45) = 740 \text{ calls per day which are seriously degraded,}$$

of which

$$(740)(0.94) = 695 \text{ must be terminated.}$$

Of course, calls in cellular systems drop for other reasons as well, but this number of *additional* calls being dropped, even in a large system, would normally only be associated with a very badly balanced system. Thus the effects of the illegal calls is about equivalent, in a large urban area, of constantly operating a cellular system which is in a serious state of imbalance. In fact, illegal airborne calls, which are no doubt almost never detectable in the system, may be responsible for a large portion of many AMPS providers' maintenance budget, not to mention customer complaints and churn.

5.2 Illegal Airborne Call Effects on Idle Cochannels

So far we have dealt with illegal airborne calls affecting cochannels which are in use by legitimate AMPS customers. But there is another effect of these illegal cellular calls that may be visited on cochannels not in use, that perhaps has far more impact in many systems. Many systems, depending on the provider's equipment, have the automated capacity to detect a channel which is subject to serious interference and remove it from the list of assignable channels at the affected base station. Normally, this deallocation is not reversed without the intervention of maintenance or OMCR (Operations Maintenance Center - Radio) personnel. The length of time for which the channel remains unavailable may vary widely in different systems, but certainly the consequences of a channel (or

channels) completely out of use may be severe. Using the results in Tables 1 and 2, during busy hour, the mean number of free channels in the three cochannel cells which are cochannel to an illegal airborne call would be

$$1.24 = 3 - 1.76$$

and for non-busy hour, the mean number of free channels would be

$$1.60 = 3 - 1.4.$$

If a system has the capability to detect channels with interference and deallocate them, then using the same weighting as before for combining busy and non-busy hour, we expect that on average, an illegal airborne call could cause deallocation of

$$1.33 = (0.75)(1.24) + (0.25)(1.60) \text{ cochannel cell channels,}$$

The exact effects of this in any particular system would depend on the protocol for handling these events, but is clearly the case that in busy hour, the consequences of a deallocation will rival the consequences of interference to legitimate calls. For example, if a cell operating at busy hour load with 19 channels loses a channel for an hour of the busy hour period, then blocking will climb from 1% to to 1.7%. In an hour, the sector at 1% blocking would service

$$266.1 = (11.2)(0.99)(60)/(2.5) \text{ customer calls, averaging 2.5 minutes in length,}$$

but at the higher blocking rate, the number of calls handled is

$$264.2 = (11.2)(0.983)(60)/(2.5).$$

As mentioned above, an illegal airborne call will on average cause deallocation of 1.33 channels in the three cochannel cells it is interfering with, so the average number of additional customers blocked from service in an hour[15], due to the illegal call, will be

$$2.5 = (1.33)(266.1 - 264.2).$$

In a non-busy hour environment, where the demand on the system is substantially lower, the temporary deallocation of a channel may be insignificant. But if the service provider does not correct the de-assignment by busy hour, then the same affect will occur.

5.3 The Net Effect Illegal Airborne Calls on Busy and Idle Cochannels

However, if we ignore such non-busy-hour deallocation caused by illegal airborne calls, we still can make a net assessment of illegal airborne calls. Bear in mind that a single such call will degrade customers on cochannels that are active, and may cause

[15] We are assuming here that such a channel deallocation will not be corrected for at least an hour.

deallocation of cochannels that are inactive. We have separately examined the number of legitimate customers that may be affected by these phenomena, but in a system in which this channel deallocation function occurs, we can combine the consequences, and state that on average, ***a single illegal airborne call will adversely affect***

$$3.95 = 1.45 + 2.5 \text{ customers,}$$

either by seriously degrading their call (usually causing termination), or preventing access to the system in the first place.

Finally, this analysis is in fact quite conservative, primarily because

(1) we assumed that the aggregate S/I ratio for all six first tier cochannel cells applied to the worst three cochannel cells, i.e., the three toward which the aircraft is flying,
(2) we did not consider the S/I ratios in the remaining three cochannel cells, which, although lower than the aggregates, would no doubt be severe enough to cause some level of each of the above difficulties to occur,
(3) we did not include the rural case, where the aggregate interference levels were on average 3 dB higher,
(4) we did not account at all for the ambient interference levels in the cellular system, which would have pushed our breakpoints for degradation and call termination substantially higher: almost certainly, with ambient S/I considered, the probability of an S/I being below 17 dB (when an illegal call is active) would have been 1.0 instead of 0.96.

Each illegal airborne call can thus have a substantial multiplier effect in wreaking havoc on a provider's system, and the values given here for mean numbers of customers affected by an illegal airborne call can be safely considered to be a lower bound. The actual values could easily be double what we have accounted for in this very conservative analysis. AMPS providers in all parts of the US are no doubt substantially affected by illegal airborne calls, and should no doubt want to consider any actions which can ameliorate the number of illegal airborne calls which are being placed.

6.0 Summary and Conclusions

Anyone familiar with the concepts of RF propagation would immediately recognize that illegal airborne calls using the AMPS system may interfere with the legitimate calls being made by AMPS customers. Data concerning the frequency of such calls was gathered by AirCell, Inc.[5] demonstrates that such calls occur on a remarkable percentage of private flights. Since this is the case, there is cause to analyze what effects illegal airborne calls are in fact having on cellular providers.

Ideally, the analysis would rely on field test data, i.e., the propagation of airborne AMPS calls, and the measurement of effects in an underlying cellular system. Such an approach is impractical for three major reasons:

(1) the transmissions from aircraft are illegal, and even if a experimental authority were obtained, they might cause interference in AMPS systems other than the one participating in the test;
(2) cost of establishing test equipment and personnel at a set of at least six cochannel sites would be very expensive,
(3) the participating AMPS provider would have to accept some disruption to customers' service during the duration of the tests.

The analysis in this paper thus relied on simulating the propagation effects associated with illegal airborne cellular calls. Simulation can never match the fidelity of reality, but cellular propagation is itself a very well-studied and documented field, so that a simulation, carefully crafted, can certainly capture the situation quite accurately[16].

The simulation used for the present analysis used a simulated placement of a 30 by 30 grid of cells, and considered both rural cells (times-12 reuse with omnidirectional antennas) and urban cells (times-7 reuse with 120° sectored antennas). The ubiquitous Lee propagation model was used to characterize the signals from the simulated ground-based legitimate AMPS callers, and a modified Lee model was used for the illegal airborne calls, with the primary modification being in terms of path loss as a function of distance (see Section 3.1).

The simulation effectively "flew" aircraft over a cellular system, in an event-stepped manner where illegal airborne calls were established over a serving cell, and then the interference levels caused by these calls were determined and stored as the aircraft moved. The specific effects of both horizontal and vertical antenna patterns were accurately modeled in the simulation. Measurements of signal and interference were computed at one second intervals, and the usual mechanisms for reverse-link power control and handoff were also implemented. The simulation results were based on 1000 overflights, with altitudes, directions, speeds, and call lengths being varied

[16] After all, virtually all cellular systems are designed and committed to sites based on simulation and or closed-form analyses.

pseudorandomly, and the net output were probability densities of the interference levels measured (i.e. computed) in the first tier of cells cochannel to the serving cell.

The probability densities of various interference levels are shown in Figures 7 – 13, and equivalent signal level probability densities for ground-based AMPS calls (computed from analytical considerations), are shown in Figures 14 and 15. Now once signal and interference probability densities are available, it is possible to compute the probability density of S/I (signal-to-interference) ratio for the urban cellular system, which is shown in Figure 16.

Once the S/I ratio has been so determined, we can state that a call which is on a cochannel to the illegal airborne call has a certain probability of operating at or below any specified S/I ratio. We chose

17 dB S/I as the minimum at which a call will not be degraded,

10 dB S/I as a level below which the user will probably terminate the call, and

6 dB S/I as the level below which the base station receiver will drop the call.

Using these values, and considering only three of the six first-tier cochannel cells (i.e., those toward which the aircraft is flying), we also could calculate (from typical cell loading profiles) the likelihood of utilization of one or more cochannels in the three designated cells. Thus for each illegal airborne call, there was a probability that 0, 1, .. 3 cochannels would be busy serving legitimate AMPS customers, and there was also the probability that any such call would be degraded or ended. Standard probability theory was applied to compare the expected number of customers affected by a single illegal airborne call. This was done for a mix of busy hour and non-busy hour conditions, and the net result was that

an illegal cellular call placed over an urban area during the period from 7 A.M. to 7 P.M. will on average interfere seriously with 1.45 legitimate AMPS calls, causing termination of 94% of the affected calls.

But there are other serious consequences of an illegal airborne call which might be visited on an idle cochannel. That is because many cellular infrastructures monitor interference on idle channels, and will deallocate a channel which is experiencing severe interference. When a base station does not have access to its full complement of channels at busy hour, the number of calls which must be turned away (blocking) increases. Such a channel will remain out of service until a technician checks the situation and places the channel back in service. If we assume that in such a system, a one-hour delay is likely before the channel is placed back in service, then we conclude that some customers will be denied service in the cell due to the illegal airborne call (which, of course, need no longer be active).

Factoring this effect into the damage done to customers, we conclude that

a single illegal airborne call will adversely affect

$$3.95 = 1.45 + 2.5 \text{ customers,}$$

either by seriously degrading their call (usually causing termination), or preventing access to the system in the first place.

From the results of the analyses done in this paper, it is obvious that cellular providers can be substantially affected by illegal airborne calls, and really have no means whatsoever to detect this activity and thereby press action against such transgressors. Cellular providers should therefore welcome the AirCell, Inc. product, which provides a legal means to provide pilots and there passengers the capacity to make cellular calls which effectively visit no interference on their systems.

Appendix – Resume' of the Author

Dr. Doner is a Chief System Engineer at GE-Harris, where he is responsible for overseeing and designing large-scale optimization processes to support the management of railroad resources. At present, he is designing the top-level architecture for a global system which will coordinate all aspects of railroad resources.

Prior to this assignment, Dr. Doner was Chief Scientist of AirNet Corporation and provided system engineering, analysis, design, simulation skills and technical leadership in the general areas of network and wireless communications. Most of Dr. Doner's 23 years of experience have focused on the design of communications systems, during which time he has developed many algorithms and analysis tools related to network design.

For the three years at AirNet, Dr. Doner's main responsibilities have been in the area of broadband cellular communication system design. During his tenure at AirNet, he was responsible for the development of many new communications principles which become possible only through the use of broadband technology. Among these concepts were the following:

1) use of forward power control and dynamic channel assignment algorithms to increase spectral reuse for both analog and digital wireless protocols; specifically, AirNet's four-cell frequency reuse for analog systems and three-cell frequency reuse for digital systems are Dr. Doner's inventions;
2) derivation of power demand statistics for the shared power supplied by a broadband linear amplifier simultaneously serving many subscribers;
3) analysis of broadband implementation of wireless local loop, including high spectral reuse factors (two-cell reuse) in cells using a mix of yagi and omnidirectional antennas;
4) use of neural network technology to locate vehicles in a cellular service area.

Dr. Doner also is an excellent technical writer, and has frequently served as technical editor of proposal teams. He has actively published in the technical literature over the length of his career, numbering sixteen articles in journals and proceedings. He also wrote several of AirNet's major marketing white papers, and served as the technical point of contact for AirNet's marketing organization.

Related Experience:

1984 -1994, and 1981 - 1983 Member of System Technology Section, Harris GCSD, during which time Dr. Doner was technical leader on many projects, including development and design efforts on

-- a network vulnerability testing methodology,
-- a generic network simulation tool (GENESIS) widely used at Harris Corporation,
-- a closed-form network traffic analysis tool,

-- network security concepts,
-- algorithm development and test procedures for cellular monitoring systems,
-- an RF design simulator incorporating neural network paradigms.

1983 -1984 Dr. Doner was on the Professional Staff at DBA systems, and performed research on photogrammetric algorithm development and computational efficiency.

1974 - 1981 Dr. Doner was on the Professional Staff at Mitre Corporation (McClain, VA.), and provided technical leadership and analytical support in the design or improvement of numerous military communications systems.

1972 - 1974 Dr. Doner began his career at The Center for Naval Analysis, during which interval he analyzed, created simulations for, and recommended improvements to several US Navy communications systems.

Awards and Recognitions:

Dr. Doner is or has been a member of
-- the Institute for Electrical and Electronics Engineers (1978),
-- the American Mathematical Society (1970),
-- the Society for Industrial and Applied Mathematics (1973),
-- the Mathematical Association of America (1969),
-- Phi Kappa Phi National Scholastic Honorary (1963),
-- Pi Mu Epsilon Mathematics Honorary (1962).

Additionally, Dr. Doner was invited to and attended the National Science Foundation Summer Institute in Combinatorial Theory in Brunswick Me. (1971). He has served as Session discussant and Session Chairman at numerous conferences.

Dr. Doner has two patents, three pending patent applications, and 15 additional patent disclosures in broadband wireless technology. He has received a Harris Engineering Achievement Award, and has received three Harris awards for Customer Focus and New Business Development.

Education:

BS (Magna Cum Laude)	Mathematics/Physics	University of Toledo	1964
MA	Mathematics,	University of Toledo	1965
Ph.D.	Mathematics,	University of Michigan	1972

Publications and Patents:

1. "A Markov Chain Structure for Riff Shuffling", (with V.R.R. Uppuluri), SIAM J. Applied Math., Vol. 18, 1970, pp 191 - 209
2. "CIP Neofields and Combinatorial Designs", invited address at the American Mathematical Society Annual Meeting, St. Louis, MO, 4/1/72

3. "Combinatorial Designs and Cyclotomy in Finite Cyclic Neofields with Additive Inverse Property", doctoral dissertation, University of Michigan, Ann Arbor, MI, 8/72
4. "Modeling the Error Process on Record Communications Channels", Proceedings of the 1979 Summer Computer Simulation Conference, Toronto, Canada, 16 - 18 July, 1979
5. "A Frame Synchronization Algorithm for High Noise Environments", Proceedings of MILCOM `83, Alexandria, VA, 31 Oct-2 Nov, 1983
6. "GENESIM", IEEE J. on Selected Areas in Communications (JSAC), Vol. 6, No. 1, Jan. 1988, pp 172 - 179
7. "Scheduling Considerations in Discrete Event Simulation", Proceedings of 1988 The Southeastern Simulation Conference (SCS), Orlando, FL, 17 - 18 Oct., 1988
8. "Communications Network Topology Inference Using Locally Available Transmission Delay Data", Proceedings of the 1989 Southeastern Simulation Conference (SCS), Pensacola, FL, 16 - 17 Oct. 1989
9. "Design and Simulation of a Dynamic Queueing Algorithm for Multimedia Communication Networks", Proceedings of the 1990 Southeastern Simulation Conference (SCS), Huntsville, AL, 22 - 23 Oct. 1990
10. "Improving Unsupervised Learning in the Neocognitron", Proceedings of SIMTECH 91 (SCS), Orlando, FL, 21 -23 Oct 1991
11. "A Dynamic Queueing Algorithm for Multimedia Communications Networks", Transactions in Simulation (SCS), Vol. 10, No. 1, March 1993, pp 25 - 38
12. "A Vehicle Location and Speed Detection Process Using GSM Mobile Handoff Data", Paper JTC(AIR)/95.06.05-198, Joint Technical Conference on Wireless Communication, Nashua, NH,6 June 1995
13. "An Analytical Model for Telephone Systems with Correlated Channel Demand", Proceedings of SouthCon 96, Orlando, FL 27-29 June, 1996
14. "Broadband Software Radio: Moving the Boundaries" Communications System Design, November 3, 1996
15. "A New Paradigm – Broadband Digital Wireless", *The Annual Review of Communications 1997*, February 1997, International Engineering Consortium, Chicago, IL
16. "Obtaining Improved Frequency Reuse in Wireless Communications Systems", U.S. Patent 5,649,292, 15 July 1997
17. "Mobile Telephone Location Process Making Use of Handoff data", U.S. Patent 5,657,487, 12 August 1997
18. "Progress in Broadband Digital Wireless", to be published in *Broadband* and *Multimedia Services: Recent Developments and Applications,* International Engineering Consortium, 1998

Appendix C

1997 Texas Test Flight Geometry & Aircraft Photos

The Opposition, as well as V-Comm went to some length to critique the '97 TEC Test Report because, they claimed, the aircraft did not provide a variety of orientations from the Aircraft to the serving cell and that the aircraft flew directly over the Madill site[1], which caused blockage due to antenna nulls and physical blockage by the control surfaces.. In fact, the flight routes in that test were purposely offset about 2 miles east of the Madill site (a fact which can be determined by detailed examination of the flight route data supplied by TEC at that time) to eliminate these concerns.

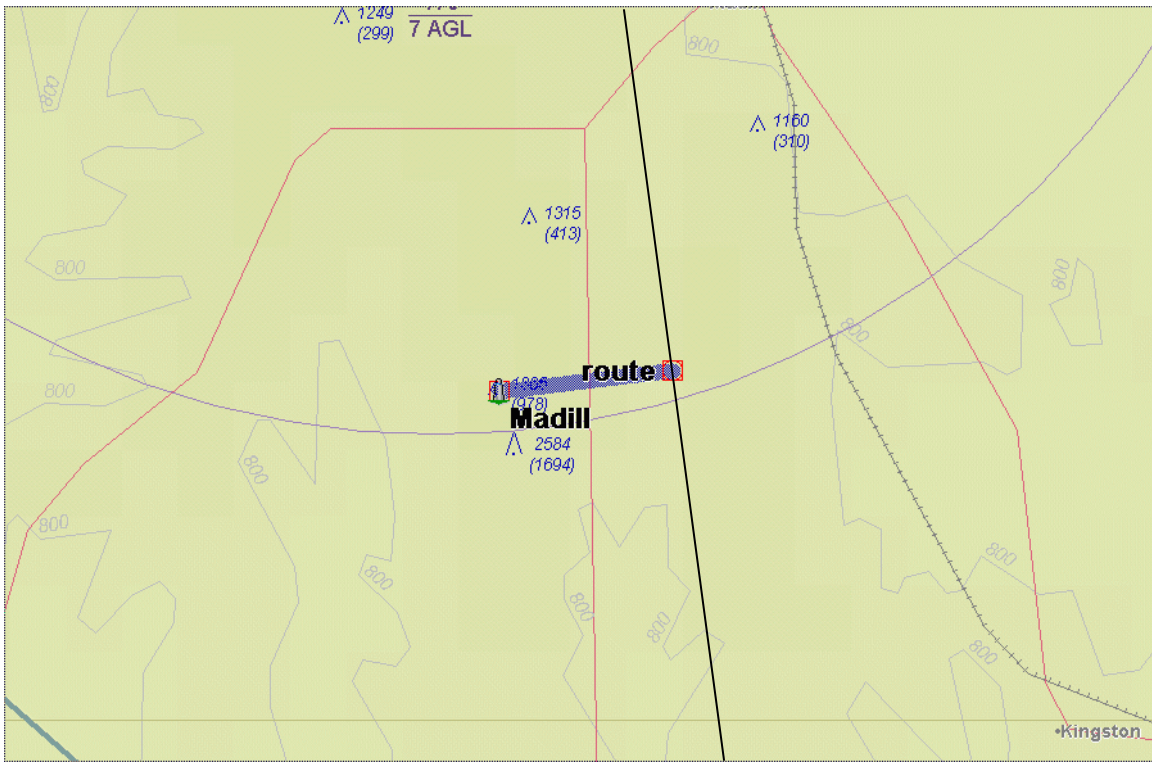

Figure C-1 - Flight Route of 1997 Test showing 1.8 mile offset

Several sketches of the approximate geometry of the flyby are shown below. The first is a front-to-rear representation showing the aircraft at 5000 ft, the cell site two miles to the side, and the null below the aircraft. While there is a design null below the aircraft, it is in the order of 15 dB over an angle of about 30 degrees,. The main cause of that null is due to the mounting of a dipole antenna in close proximity to a vertical metal surface (the vertical stabilizer) which directs the pattern away from the tail surface, creating a null

[1] *"Comments in Opposition to Petition for Extension of Waiver"*, page 26

along that surface. This null has no effect on a cell site two miles away when only one mile high, as in some of the flight paths in 1997.

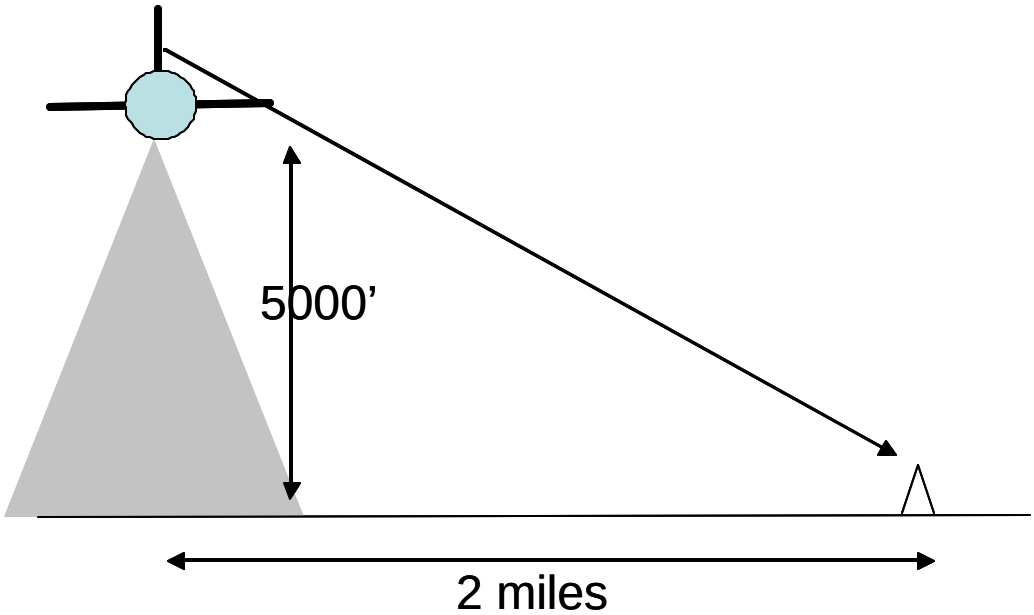

Figure C-2 5000 ft fly by geometry

The sketch on the following page shows a top down view of the aircraft flying approximately 2 miles offset from the victim site. In this sketch, the path of the cell site below the aircraft is shown as the dot-dash line. It is clear from this geometry that at some angles down and to the side, the horizontal stabilizer can block the line of sight signal to the ground. However, this small angle is a relatively small portion of the total flight route. The rest of the time the aircraft antenna is in view of the ground site.

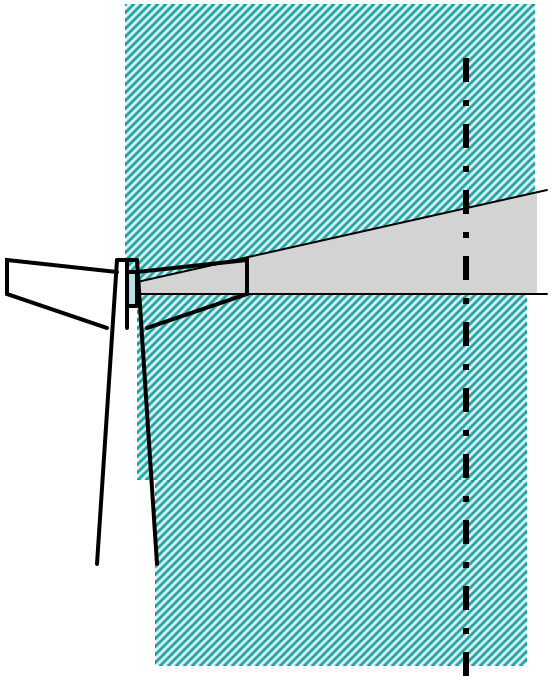

Figure C-3 Top Down View

It is also clear from this figure that with the exception of a small angle, most other angles from forward to directly to the rear of the aircraft are presented to the cell site on the ground as well, so V-Comm's claim to require additional flight tests to explore this area is without merit.

Just for interest, here are a few of pieces of Clip Art that clearly show that you can see the vertical stabilizer (where the AirCell antenna was mounted in the 1997 tests) of an aircraft flying nearby overhead:

Figure C-4 View of Vertical Stabilizer

In order to show this effect (or lack thereof) on received site data, the AirCell data for the Texas Test aircraft flying by the Madill cell site at 5000 feet is reproduced in the following sketch produced from the raw data that was included in the TEC 1997 report. (The blips to – 140 dBm at the 5 mile increments are markers, not data). First off, at

5000 feet and 2 miles offset, the ground cell site never falls in the design null under the aircraft. The blockage of the horizontal stabilizer would subtend less than 1 mile at this 2 mile offset, per the V-Comm calculations. Therefore, one would expect to see the signals rise by a substantial amount about ½ mile on either side of this "directly abeam" point, represented by the zero point on the data axis. Surprisingly, this does not occur (other than the glitch caused by the marker). You can clearly see the signals that arrive at the cell site from angles in front of, and behind, the horizontal stabilizer are still very low.

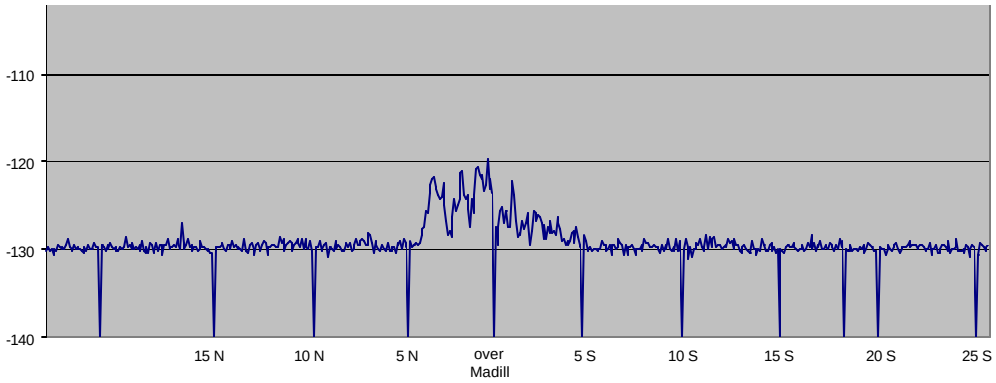

Figure C-5 - Example Madill 5000 ft data record, from 1997 data

Thus:

V-Comm's assertions about blockage are significant overstatements.

Further regarding orientations, in addition to the 1997 tests, additional flight tests were conducted in 1998 with another AirCell provider partner, involving circular flights around the Madill site. This data is reviewed in section 2.6, and shows that AirCell and TEC did do additional testing that presents all orientations of the aircraft antenna, from nose to tail, to the serving site, and the data remains consistent with AirCell's proven non-interference.

Based on these test results, V-Comm's assertions about limited flight orientation are also incorrect. Their purpose for their test was NOT to add data that had not previously been taken, but to use those tests, in conjunction with a misconfigured serving cell and an unrepresentative victim site, to make an overly pessimistic case for interference.

Aircraft Misrepresented

Perhaps some of the confusion is due to the aircraft on which V-Comm apparently did their calculations. V-Comm, in their "Engineering Response to AirCell's Petition for

Waiver Extension", provides several photographs of aircraft. However, the Aircraft shown in the V-Comm photos in Fig 3B, page 11 are ***not*** the aircraft actually used in the AirCell tests, although they re represented as such. ***In fact, neither of the aircraft is a Cessna Conquest, as they represent.*** These aircraft appear to have foreign registration as well. We are not sure of where these photos came from or why V-Comm would represent them as the actual test aircraft, but perhaps the VOR antenna install on these aircraft (which are likely not AirCell antennas, since we don't provide service outside the US) is in a different location from the actual test aircraft and thus their calculations are faulty.

Fig C-6 - Reproduction of V-Comm figure 3-B

Their flight data, if it had been done correctly with properly configured serving site(s), should provide similar results to the AirCell test data. With the myriad things wrong with their flight test program, it is understandable why they got different values (see section 2.3), but geometry was not the major contributor.