Connexion by Boeing
Proposed Rules Governing Operation of Multiple 800 MHz Air to Ground Systems

Mike de La Chapelle
Boeing Technical Fellow
The Boeing Company
September 10, 2004

Introduction

This report responds to the FCC staff's request for an evaluation of performance of air-to-ground (ATG) systems under various licensing scenarios and proposed rules to accommodate the sharing of the ATG band by multiple licensees using 2.5 MHz of spectrum in that band. The staff set out three licensing scenarios. Under the first, there would be two exclusive licenses, one for 2.5 MHz of the ATG band and the other for the remaining 1.5 MHz. Under the second approach, spectrum would be assigned in two overlapping 2.5 MHz licenses. Under the third approach, there would be four overlapping 2.5 MHz licenses. As demonstrated below, the user experience does not vary with the number of licensees. A single 2.5 MHz exclusive license does not produce a higher data rate to the user than two or four overlapping licenses. Rather, the seat experience is a function of the network implementation (base station sectorization, etc.) and the network loading (number of aircraft, passengers, etc.), both of which service providers control. The variations at the seat caused by those factors are the same regardless of the number of licensees.

Boeing has proposed sharing rules that would permit the operation of up to four overlapping licenses in the ATG band. The rules to permit this shared use of the band are straightforward, technology-neutral, and cost effective. Service providers can use off-the-shelf base stations. Aircraft transceivers will need to be designed and built, but that would be the case if the Commission licensed only a single 2.5 MHz provider. A new design is necessary for any broadband ATG offering. It is not a function of the number of licensees. Our proposed rules are detailed below, but they are readily summarized:

(1) Base Station EIRP

Maximum base station EIRP spectral density = -38.6 dBW/Hz
Below 10,000' and within 20 miles of airports, max EIRPSD = -52.6 dBW/Hz
Base station antenna gain roll-off with elevation angle, θ:
= $0.225\,\theta + 9.75$, for θ between 10° and 70°
=25 dB between 70° and 90°

(2) Aircraft EIRP

Maximum aircraft EIRP spectral density = -68 dBW/Hz
Below 10,000' and within 20 miles of airports, max EIRPSD = -82 dBW/Hz
Aircraft antenna gain roll-off of:
= 0.25 θ - 2.5, for θ between 10° and 90°

(3) Base Station Separation Distance[1/]

Inter-System >102 miles
Intra-System > 227 miles

(4) Band Plan

The foregoing will support the use of four 800 MHz ATG systems with overlapping spectrum in the following configuration:

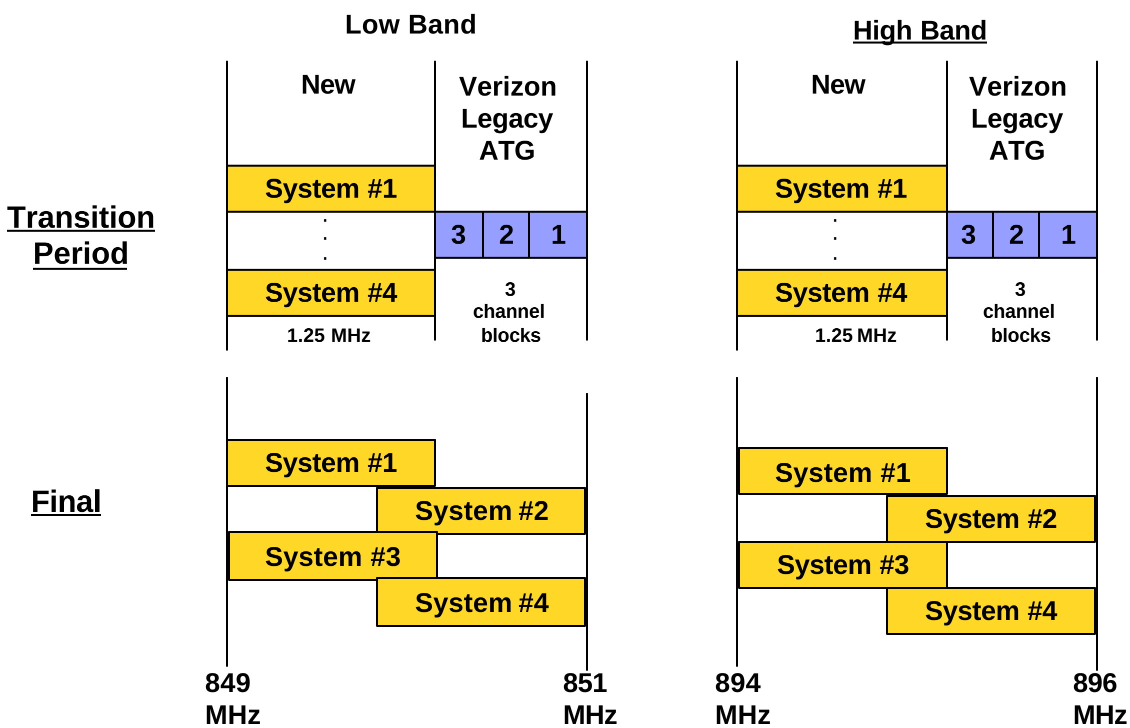

Figure 1. Proposed ATG band plan.[2/]

1/ Derivation of the base station separation requirements is described in Boeing's ATG Update Report, filed July 13, 2004, at pp 8-10. To the extent necessary, the results of competitive bidding for ATG licenses could be used to determine which licensees have priority over others in selecting base station locations.

2/ Figure 1 purposely does not specify that the high and low bands only support one direction of communication (air-to-ground and ground-to-air) and it purposely does not specify polarization. This allows implementation of both AirCell's and Boeing's sharing proposals. In addition, although not shown

Boeing's proposal will permit competition among providers of ATG services in the 800 MHz band.[3/] With a choice of providers, airlines and ultimately the flying public can be assured of the best possible broadband ATG experience. While satellites are the only means of providing broadband data service over oceans, terrestrial systems may complement satellite systems in delivering broadband service offerings over land. Only a licensing scheme that accommodates multiple terrestrially-based providers will ensure the competitive availability of the full suite of broadband connectivity services within the continental United States.

Seat Experience Under Various Scenarios

A user's seat experience will not be degraded if multiple providers share the ATG band. This is because the isolation methods proposed by Boeing (and AirCell) make the inter-system interference negligible. Rather, user experience will vary due to sector loading, the throughput limitations of the assumed communication standard (CDMA20001xEV-DO, also known as IS-856), and each system's own self-interference. In particular, the user experience may be maintained or enhanced even as usage increases by deploying additional sectors per base station.

With 3.1 Mbps delivered to each sector and 45 users per sector (scenario #1), each user can expect a minimum 957 kbps broadband experience for 99.9% of the time. With a little more than twice as many users in a sector (scenario #2), each user will experience a minimum 284 Kbps (low-end DSL) broadband service for 99.9% of the time. Both of these results assume that all users will employ the system simultaneously and have typical traffic usage characteristics. Although it is less probable, a customer could burst to substantially higher data rates, up to the full sector data rate of 3.1 Mbps, even when the sector is fully loaded. It is also important to note that service providers have control over the passenger user experience that they provide, through both their system implementation and by controlling the number of customers using their system.

---

in Figure. 1, Boeing agrees with Qualcomm that guard bands are required on either side of the 1.25 kHz channels. This may be accommodated by increasing the amount of spectral overlap between the staggered channels.

[3/] An ATG licensee with only 1.5 MHz of spectrum will not be capable of offering broadband services. The proposal for exclusive 2.5 MHz and 1.5 MHz licenses thus has two material flaws. First, it will result in the licensing spectrum for narrowband operations when no potential entrant believes that such a service will be viable. Second, it will eliminate the possibility of competition among 800 MHz ATG licensees.

				Results - User Experience		
	Aircraft/Sector	Users/Aircraft	Users/Sector	1 System	2 Systems	4 Systems
Scenario #1	3	15	45	957 kbps	957 kbps	957 kbps
Scenario #2	10	10	100	284 kbps	284 kbps	284 kbps

Table 1. Summary of FCC scenarios and resulting user experience.

<u>Bases and Assumptions</u>

This section sets out the bases and assumptions underlying the results set out in Table 1. As an initial matter, Boeing assumes that the base station sector capacity of forward and reverse links for CDMA20001xEVDO, are 3.1 Mbps and 1.8 Mbps, respectively.[4/] It is important to note that passengers on a given aircraft access ATG services on a shared network, regardless of the number of licensed service providers. As with other shared broadband services, a user's experience will vary depending on the level of congestion of the network. The FCC itself has recognized that the broadband experience on a shared network can vary based on the amount of users on that network.[5/] This analysis identifies the burst data rate (pipe size) available to a user given a 0.1% probability of congestion. In other words, the analysis calculates the user pipe size assuming that the user can get that pipe 99.9% of the time. Thus, we define the user experience based on the pipe size that the user can get 99.9% of the time.

The sector forward link and reverse link capacity are modeled as shared resources, *i.e.*, shared between aircraft and passengers. We assume that passenger access to the forward and reverse link capacity are statistically uncorrelated events. Furthermore, we model passenger access as on-off events, that are defined by a mean data rate and a peak burst rate (passenger pipe size).

The mean passenger usage can be a function of many parameters such as the Internet applications being used (web browsing, e-mail, VoIP, etc.) and the method of billing (flat fee for unlimited access, pay by bits sent/received, etc.). We assume a mean data rate of 5.3 MB/hour forward and 1.1 MB/hour reverse based on actual usage data for

---

[4/] Qualcomm, IS-856 Revision A and EV-DO Enhancements (http://www.qualcomm.com/technology/1xev-do/enhancements.html).

[5/] *See, e.g., Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, Third Report and Order,* 17 FCC Rcd 2844, Appendix B ¶ 21 (2002) ("because of the shared architecture of the cable networks, the bandwidth -- and consequently the speed -- available to any single user drops as the number of simultaneously active users increases."); *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, Second Report and Order,* 15 FCC Rcd 20913 ¶ 33 (2000) (accord); *Inquiry Concerning High-Speed Access to the Internet Over Cable and Other Facilities, Declaratory Ruling and Notice of Proposed Rulemaking*, 17 FCC Rcd 4798 n.37 (2002) (actual subscriber experience on a shared network "depends on the specific network architecture and traffic load").

customers paying for unlimited access.[6/] This 5:1 asymmetry (forward/reverse) of passenger data rate usage makes the forward link the band limiting link. Using these mean data rates, we applied the Norros equation with a Hurst parameter of 0.75 to model statistical multiplexing of multiple users sharing the forward link sector capacity to derive the user experience described above.[7/]

Results

Figure 2 shows a plot of the passenger user experience (pipe size) as a function of the number of passengers sharing the forward link sector capacity of 3.1 Mbps. In scenario #1 each sector contains 15 users/aircraft on 3 aircraft, for a total of 45 users all sharing the forward link. The plot shows that the user experience is equivalent to a 957 kbps experience for this scenario. For scenario #2, there are 100 total users per sector on 10 aircraft with 10 users per aircraft. The pipe size available to each user (99.9% of the time) is at least 284 kbps for this scenario. Thus, a broadband user experience is available to the passengers in both scenarios.

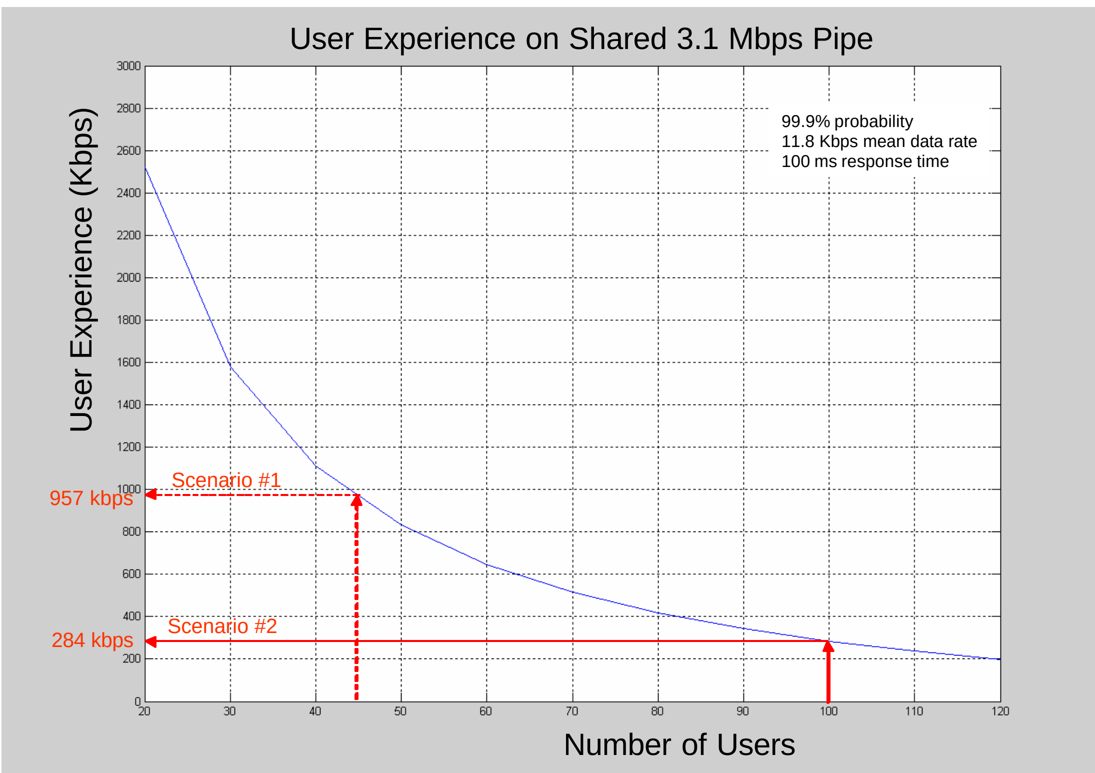

Figure 2. Plot of user experience versus number of users sharing a 3.1 Mbps pipe.

6/ Users do not send and receive traffic 100% of the time they are logged-on to the system. Rather, user traffic is intermittent and “bursty.” The mean data rates reflect Boeing’s experience regarding the average data rate for the entire period a user is logged-on to the system.

7/ “On the use of fractional Brownian motion in the theory of connectionless networks”, Ilkka Norros, September 24, 1994.

Proposed Sharing Rules

All that is required for four licensees to share the ATG band is the establishment of base station EIRP limits (with minor accommodation for base stations located near airports); aircraft EIRP limits; and minimum base station separation distances. Once these minimal rules are established, licensees may operate with significant administrative flexibility. Below we set out proposed EIRP limits and distance separations and the assumptions underlying them.

(1) Base Station EIRP Limit

The simple link budget of Table 2 shows that a maximum of 22.4 dBW (about 175 W) of EIRP is required when the aircraft is at maximum range and experiencing maximum interference.

Slant range	160	km
Frequency	0.85	GHz
Wavelength	0.35	m
Path loss	-135	dB
Channel bit rate	3100	Kbps
Mobile terminal G/T	-37	dB/K
Threshold Eb/No	5	dB
Inter-system interference	1	dB
Intra-interference	3	dB
Multi-path fading	2	dB
Margin	3	dB
Required transponder EIRP	22.4	dBW

Table 2. Simple forward link budget

An EIRP of 175 W produces an EIRP spectral density (EIRPSD) of 22.4 dBW – (61 dB-Hz) = -38.6 dBW/Hz when spread over the assigned 1.25 MHz channel. This is our proposed EIRPSD limit for base station emission towards the horizon.

The capacity of a base station under this limit scales with the number of sectors. Standard base station antennas are available with up to 12 sectors, which can increase the base station capacity by a factor of approximately 6 for a total of 18.6 Mbps (assuming 3.1 Mbps/sector and frequency reuse in every other sector).

(2) Aircraft EIRP Limit

The rules should place a limit on the maximum EIRP transmitted from each aircraft and an aircraft antenna gain roll-off requirement to provide intersystem interference protection. Based on the link budget of Table 3, we propose a maximum EIRP per aircraft of –7 dBW or –68 dBW/Hz when spread over the 1.25 MHz channel bandwidth. This EIRP supports an aircraft data rate of 350 kbps under worse case conditions.

Slant range	160	km
Frequency	0.895	GHz
Wavelength	0.34	m
Path loss	-136	dB
Channel bit rate	350	Kbps
Mobile terminal G/T	-16.6	dB/K
Threshold Eb/No	4	dB
Inter-system interference	1	dB
Intra-system interference	4	dB
Multi-path fading	2	dB
Margin	3	dB
Required transponder EIRP	-7.0	dBW

Table 3. Reverse link budget.

Other Issues

Airport Rules

Aircraft in the vicinity of airports (20 miles are less) will generally be operating below 10,000' (traffic above 10,000' is serviced by standard base stations). As shown in Figure 3, service to these aircraft can be accommodated by base stations operating at a transmit EIRPSD that is a factor of 25 (14 dB) less power than normal base stations to account for the factor of 5 reduction in maximum range. The same EIRPSD reduction of 14 dB is proposed for aircraft transmissions within the airport area. Mandated spatial isolation between systems in the limited area around airports is unnecessary because aircraft data requirements are relatively low. FAA regulations require that passengers must have their electronic devices turned off and stowed. Accordingly, the only ATG traffic below 10,000' is airline traffic operational communications.

Boeing does not believe that there is a significant market for ATG services below 10,000' outside of airport areas. The only aircraft flying in this air space are light single engine aircraft used for recreation, aircraft could not accommodate an ATG terminal.

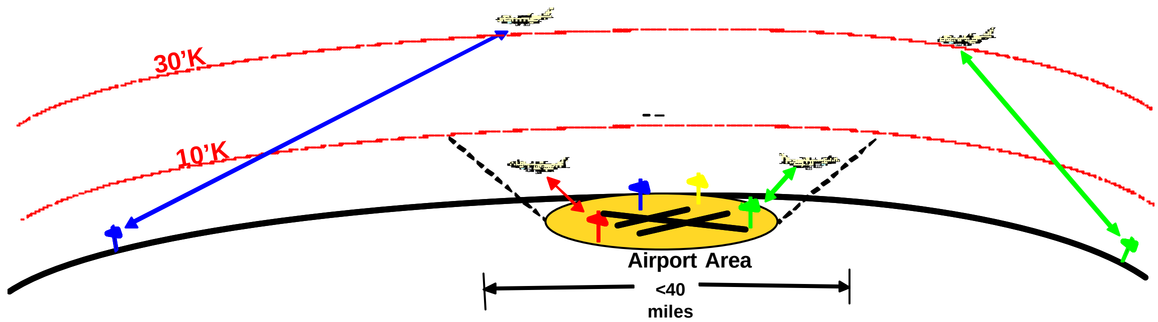

Figure 3. Airport area operation.

Forward Link Inter-System Interference

Boeing has claimed that inter-system interference can be reduced well below intra-system interference using the sharing rules proposed in this report. The ATG sharing rules must include an antenna gain roll-off requirement on both the base station antenna and aircraft antenna, to reduce interference into other systems on the forward and reverse links.

To understand why an antenna gain roll-off specification is required, consider the very unlikely scenario in which an interfering system uses non-standard base station antennas that have substantial gain towards zenith (most standard base station antennas concentrate their radiation towards the horizon and have nulls overhead).

This example assumes:

- The victim aircraft is flying over another system's base station.
- Both aircraft and base station have omnidirectional antennas.
- The victim aircraft is at 10,000' altitude (approximately 2 miles range from the interfering base station) and 100 miles away from its closest serving base station, as shown in Figure 4.

These assumptions can produce interference noise from the interfering base station that is $(100 / 2)^2$ = 2,500 (34 dB) times stronger than the signal from the distant serving base station. This is the near-far "problem" to which Airfone and Telcordia have commented.

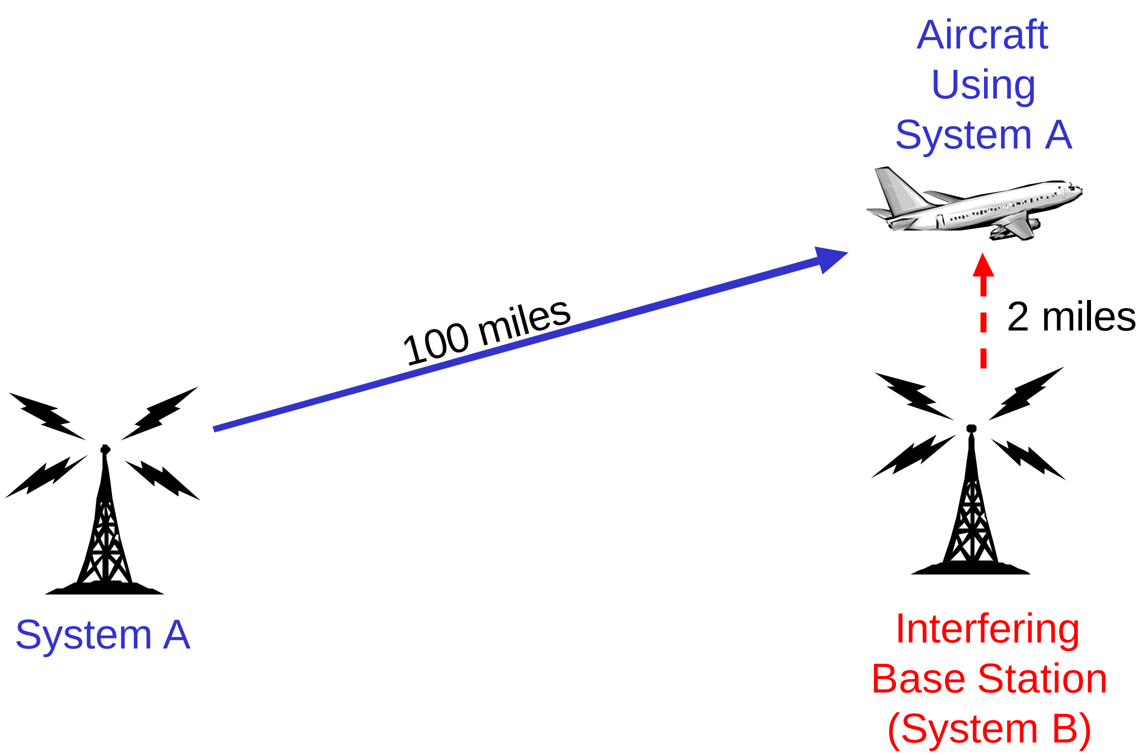

Figure 4. Forward link interference scenario.

The proposed rule requires that gain, and hence EIRPSD, be limited as a function of elevation angle above the horizon. If the radiated emissions from a base station are 34 dB down directly overhead relative to the horizon, then the near-far problem is solved, because there is no difference in the interference level from near to far. The ideal base station antenna gain roll-off with elevation angle would exactly compensate for the $1/R^2$ range loss so that the received interference power remains constant, independent of distance from the interfering base station, as shown in Figure 5. Antennas having this characteristic are not commercially available, but standard off-the-shelf cellular base station antennas have the required characteristic of very rapid gain roll-off with elevation angle as shown in Figure 5 for the "plain-old" 6-sector base station antenna that Boeing identified in previous presentations to the FCC (Decibel part number DB876G60A-XY).

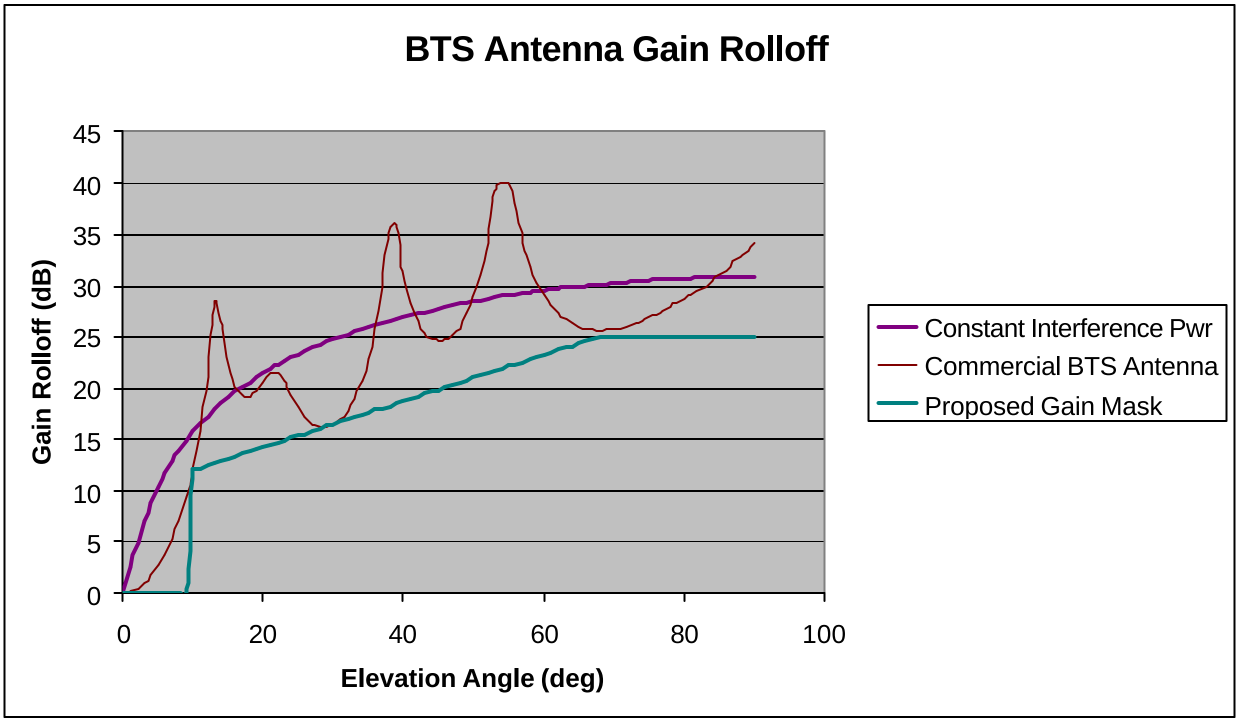

Figure 5. Proposed and actual base station gain roll-off requirements

The green curve in Figure 5 is Boeing's proposal for the base station gain roll-off rule. Figure 5 also shows that the "plain-old" base station antenna meets the proposed requirement. The proposed gain roll-off envelope requires that the base station antenna gain directly overhead be at least 25 dB down from what it is at the horizon, which mostly solves the 34 dB near-far interference problem previously mentioned. The remaining interference reduction is achieved by the gain roll-off of the aeronautical antenna and the inter-system isolation methods listed below. A typical monopole blade antenna has a deep 35 dB null directly below the aircraft. This rejection, together with the BTS roll-off, is sufficient to eliminate the near-far problem for the scenario of Figure 4. Note that the proposed base station gain roll stays within 8 dB of the $1/R^2$ curve in Figure 5, so the worst case the near-far difference never exceeds 8 dB for any scenario, not just the scenario of Figure 4.

The signal to interference noise ratio (SINR) for the scenario in Figure 4, with the victim aircraft at 10,000' just above an interfering base station, and the interfering base station transmitting at maximum EIRP to communicate with its aircraft at maximum range, is presented below. Assuming omnidirectional-antennas, and equal EIRP from three interfering base stations (4 total systems), the total worst-case interfering signal power can exceed the signal power by:

Worst case ratio of ranges squared = $(100/2)^2$ =	34 dB
Number of interfering systems = 3	5 dB
Total =	39 dB

The interference is reduced by the following factors:

Proposed base station gain roll-off near zenith	>25 dB
Proposed aero antenna roll-off @ nadir	>20 dB
Polarization/spectral isolation (AirCell)	>16 dB
Spatial/spectral isolation (Boeing)	>18 dB
Total	>79 dB

Table 4. Total worst case inter-system interference and total inter-system isolation.

The difference between these numbers gives a positive SINR of greater than 40 dB. We need an SINR of about 5 dB for reliable operation, so there is 35 dB of margin when both spatial and spectral isolation methods are applied. It is also obvious from Table 2 that either spectral or spatial isolation by itself provides sufficient isolation, although the use of both achieves the greatest isolation.

In other scenarios in which the victim aircraft is not directly above the interfering base station, the gain roll-off requirements for the base station and the aeronautical antenna assure that there is margin for any interference geometry. This can be verified by repeating the simple calculation of Table 4 for other scenarios.

Reverse Link Inter-System Isolation

The reverse link interference problem is the reciprocal of the forward link problem, so the worst-case scenario occurs when interfering aircraft are in the vicinity of the victim base station, as shown in Figure 6. Table 4 can be modified for the reverse link by substituting 15 dB (for 32 interfering aircraft) in place of 5 dB (for 3 interfering systems). The reverse link margin is therefore 30 dB when the inter-system isolation methods we propose are used.

The proposed aircraft antenna gain roll-off requirement varies linearly from 20 dB at 90° elevation (nadir) to 0 dB at 10° elevation. The proposed aircraft antenna gain roll-off can be achieved with a standard monopole antenna having electrical length equal to one half wavelength.

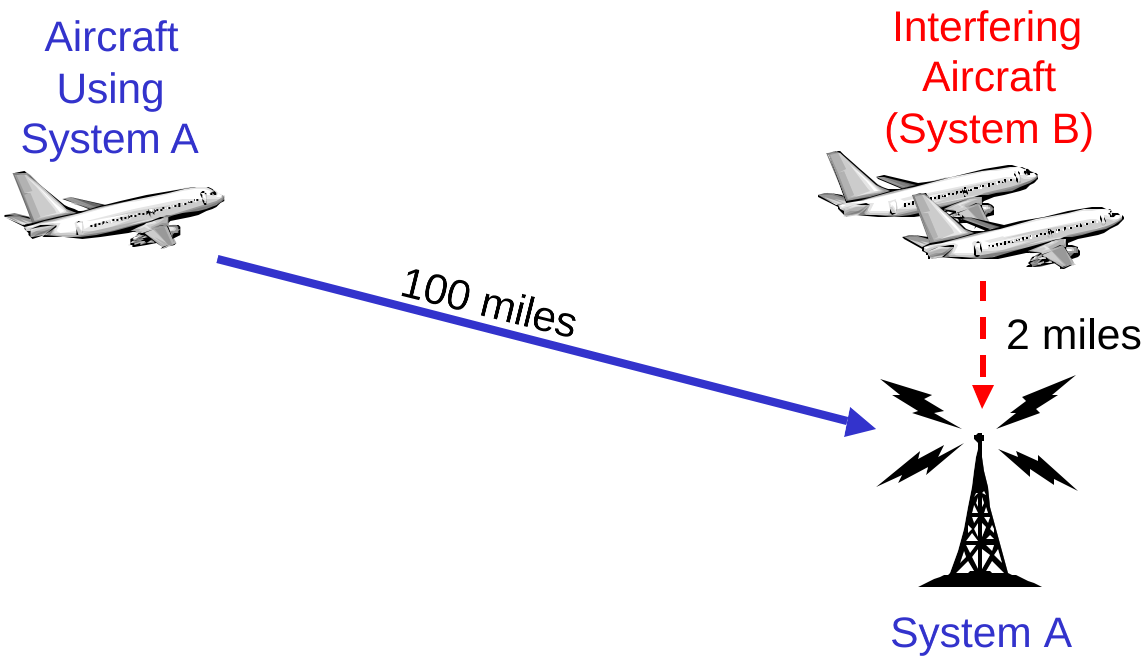

Figure 6. Reverse link interference scenario

<u>Response to Staff Inquiries</u>

The foregoing discussion was principally designed to provide further information regarding the spectrum sharing rules necessary to adopt Boeing's proposal. The following information is intended to address other questions raised by the FCC's staff.

<u>Effect of Boeing Proposal on Future and Current ATG Systems</u>

Tracking Software. Boeing has proposed an aircraft directional antenna, and Airfone is testing a similar system. In both cases and in any others where directional antennas are used, the antenna must be electronically steered in the general direction of the target base station in order to "track" the base station while the aircraft moves. In both cases, therefore, aircraft will require the use of tracking software. Antenna beams under both proposals are so large (60° full width at half max) that high precision pointing is not necessary. Moreover, both Boeing and Airfone have proposed the use of phased array antennas that are electronically scanned and do not use any moving parts. The use of tracking software would therefore not pose a significant technological or cost issue for either system.

The use of directional antennas and accompanying tracking software is not required under Boeing's sharing rules. We note that AirCell does not propose the use of such antennas. Boeing's sharing rules would accommodate AirCell's proposed non-directional aeronautical antenna.

Modulation Schemes. Boeing's proposed sharing rules allow virtually any waveform to be used. Boeing's proposal assumes that that the spectral envelope of the waveform selected by the service provider is confined to the assigned channel bandwidth and that base stations and aircraft do not exceed the specified maximum EIRP spectral density. The 1.25 MHz channel may be divided into smaller channels (for OFDM and MF-TDMA), each with its own carrier, or a single carrier may be used with a spectral spread across the entire channel (CDMA2000).

System Expansion. So long as licensees observe the spatial separation requirements, no coordination would be required for them to upgrade their networks. For example, each licensee could upgrade their network by adding more sectors, using smart antennas, changing layer 1 & 2 designs (upgrading to the latest rev of CDMA2000), or upgrading aeronautical antenna (omni to directional),
all without any coordination with other systems.

Effect on Incumbent Operator

As Boeing has previously explained, the proposed separation rules would require the following changes to Airfone's system:

- 40 stations decommissioned
- 20 stations moved
- 77 of original base stations remain active in current locations

This estimate likely overstates the impact on Airfone, because under Boeing's latest formulation of the spatial separation requirements, there will be no separation requirement for low power airport base stations.

Cost of Antennas

In its July 13, 2004 report to the Commission, Boeing provided information regarding the cost of the aeronautical antenna system that it envisions implementing. By way of summary, the price for an entire aircraft installation kit (6MCU electronic chassis, blade antennas, cables, etc.) is estimated to be about $50,000 in quantity of 1000 shipsets. This compares favorably with satcom systems which start at approximately $168K. The Commission should note that there is no requirement to use any particular aeronautical antenna implementation and that every proposed system will require some type of aeronautical antennas.

As Boeing also noted in previous submissions to the FCC, the base station antennas that may be used in the ATG system are off the shelf units that have been in production for approximately 20 years. Boeing provided information concerning an Andrew antenna (model no. DB876G60A-XY), which is a six sector (60°) version. However, the same product line includes 45° (8 sector) and 35° (10 sector) antennas. Accordingly, there should be little difference in the base station antenna cost of an ATG system using Boeing's recommended proposal and any other alternative.