Review of AirCell's September 30, 2004 Paper
"Providing Deck-to-Deck Coverage"

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Executive Summary

AirCell has proposed cochannel sharing of the 800 MHz air-to-ground (ATG) bands among up to four providers using cross-duplexing (reverse banding) and cross-polarization. However, these sharing schemes create several interference problems, including base-to-base interference between cross-duplexed systems operating in the airport environment, where base stations will be relatively close together. In its recent paper [1], AirCell proposes a set of FCC rules intended to manage the cross-duplexed base-to-base interference in the airport scenario. These rules are extremely rigid, placing significant restrictions on where base stations are located and how they are operated. However, as shown here, even if those rules could be successfully implemented, there would still be a significant interference impact on the reverse link of each system, resulting in a reverse link capacity degradation of roughly two-thirds (67% reduction in capacity).

Although there are several other problems, summarized herein, with the AirCell proposals, the cross-duplex base-to-base interference is the only one addressed in [1]. The severe reverse link throughput limit that would be imposed by AirCell's proposed 200 mW aircraft EIRP limit is not discussed, nor is the severe interference to the reverse link in the airport scenario that would be caused by sharing using cross-polarization. Thus, AirCell's paper does not deliver on its stated purpose – *i.e.*, to show how deck-to-deck service can be provided with cochannel sharing, "while maintaining full broadband coverage for the cabin and passengers" ([1], p. 2).

Background

In [2], AirCell proposed a scheme whereby two operators would share the air-to-ground (ATG) spectrum at 849-851 and 894-896 MHz using a "reverse banding" or "cross duplexing" approach as illustrated in Figure 1 and Figure 2.

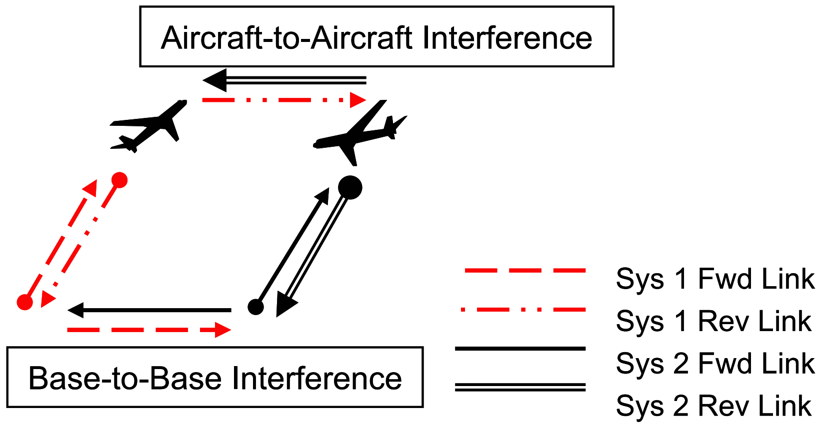

Figure 1: The *reverse-banding or cross-duplexing concept.*

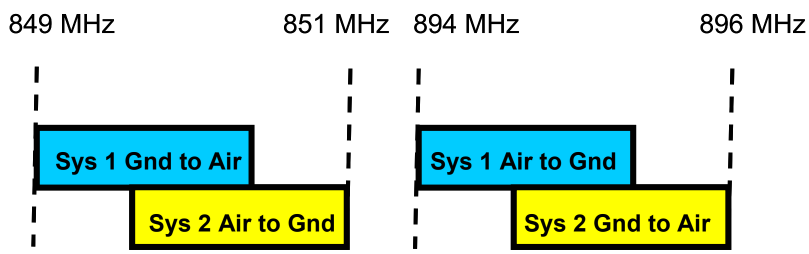

Figure 2: *Example of frequency assignments with cross duplexing.*

With cross-duplexing, there is the potential for interference between airborne radios of the two different systems, as well as between their base stations. In [2], AirCell presented simulation results that showed the performance degradation due to the air-to-air interference is reduced if the aircraft EIRP is hard-limited to 200 mW. The base-to-base interference problem was ignored in [2]. In [3], Telcordia demonstrated that if the aircraft EIRP was allowed to rise to more reasonable levels, to obtain higher reverse link data rates or to overcome non-idealities in the air-to-ground radio link, the impact of the air-to-air interference on forward link performance could be severe. It was also demonstrated in [3] that in the airport scenario, base stations would be near enough to each other to cause mutual interference (i.e., within the radio horizon).

In [4], AirCell introduced cross-polarization as another means of supporting spectrum sharing in the ATG bands. AirCell proposed using both cross-duplexing and cross-polarization to support four operators in the ATG bands as shown in Figure 3.

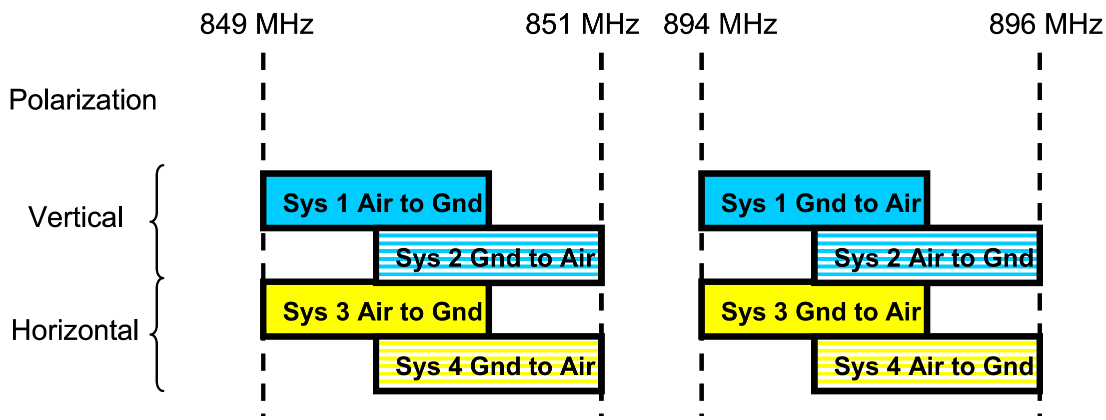

Figure 3: *AirCell's concept for 4-provider sharing using cross-duplexing and cross-polarization.*

AirCell provided simulation results in [4] for two cross-polarized but co-duplexed operators sharing the spectrum. Those results showed that in the airport scenario, the added interference at the base station receivers would be severe. In fact, the interference levels indicated by AirCell's simulation results were far above the nominal maximum operating point for a CDMA reverse link receiver (6 dB or less above thermal noise). AirCell has yet to explain how it would solve this problem with cross-polarization sharing.

In addition, the prospect for successful sharing using cross-polarization is questionable due to the lack of data on cross-polarization coupling on the air-to-ground propagation path. In [4], AirCell claimed that the results described in [6] supported the use of 12 dB cross-polarization isolation in its simulations. However, as explained in [5], a detailed review of [6] revealed no basis for such a claim. To date, AirCell has not addressed this issue.

The discussion about the AirCell sharing proposals prior to [1] can be summarized as:

Air-to-Air Interference with Cross-Duplexing: AirCell's simulations in [2] were based on a hard limit of 200 mW aircraft transmit EIRP, supporting low-rate reverse link communications (48 kb/s average rate per aircraft). Telcordia's results in [3] showed that if the aircraft EIRP is higher, to support higher data rates and allow for imperfect radio link conditions, the air-to-air interference can significantly degrade forward link performance. AirCell seems to have implicitly agreed with this, since in its service rules proposed to the FCC [7], AirCell proposed to limit the aircraft EIRP to 200 mW. However, as Telcordia has explained [5], 200 mW EIRP is inadequate to support broadband transmissions on the reverse link.

Base-to-Base Interference near Airports with Cross-Duplexing: In the airport scenario, a "system 1" base station will be transmitting on the receive frequency of a "system 2" base station, and vice versa. The two base stations will generally not be far enough apart to be isolated from each other by the curvature of the Earth (*i.e.,* will not be separated by a distance exceeding the radio horizon). The interference from one base station will degrade the reverse link reception of the other, and if strong enough, can prevent the reverse link from operating at all. Short of that, the capacity of the reverse link will be reduced by the added interference. The primary purpose of [1] is to propose a set of rules to prevent this problem. However, as discussed in detail below, even if those rules could be successfully implemented, a significant reverse link capacity reduction would still occur due to the cross-duplex base-to-base interference.

Excessive Added Interference near Airports with Cross-Polarization: As shown in AirCell's own analysis [4], even with the assumed 12 dB polarization isolation, the two cross-polarized, co-duplexed systems can significantly increase interference at the base station receiver, which would in practice prevent operation of the reverse link. This was noted in [5] and AirCell has not yet addressed it.

Lack of Data on Cross-Polarization Coupling on the Air-to-Ground Link: There is still the overall question of how effectively the vertical and horizontal polarizations could be isolated on the air-to-ground link. This is likely to be a particular problem in the airport environment, where the potential exists for significant reflections and scattering, which can cause cross-polarization coupling. AirCell suggested in [8] that it had data which supports its claim, but it failed to put any of this data into the record.

Comments on [1]

The main topic addressed by AirCell in its recent paper [1] is a set of FCC rules that AirCell claims would allow four service providers (using cross duplexing and cross polarization) to share the ATG bands and provide service near airports. The emphasis is on controlling base-to-base interference between cross-duplexed systems when base stations are in close proximity, as would be the case in the airport scenario. Although the FCC Rules proposed by AirCell in September 2004 [7] would, according to AirCell, allow sharing by cross-polarization as well, there are no provisions in [1] for controlling cross-polarization interference.

There are a number of colorful contour plots provided in [1] (Figs. 3, 5, and 8-15) which display quantitative results related to interference and performance, presumably from simulation. However, the paper does not explain how these results were developed and does not give enough information about the parameters, assumptions, models, etc., to assess the validity of the results. These results therefore are not useful in evaluating the efficacy of the proposed FCC rules or assessing interference impact.

The main point of the rules proposed on pp. 22-25 of the paper is to require that the EIRP from a "capacity" base station (near the airport) "toward any cross-duplexed candidate site location" be limited to 16 dBm or 40 mW ([1], p. 23). Note that this is even more stringent than the 23 dBm (200 mW) limit AirCell proposed in its September 9 proposal [7]. The stated purpose of this requirement is to limit the interference into a cross-duplexed base station to 3 dB below the noise floor of the victim receiver. The noise floor is assumed to be –109 dBm (corresponding to a 4 dB noise figure), so the target interference level from each cross-duplexed base station is –112 dBm.

The minimum spacing between cross-duplexed base stations is 6 miles ([1], Fig. 16), and the receive antenna at a "capacity" site is required to have an 11 dB null directed at the horizon ([1], p. 23). Free space path loss for 6 miles is about 111 dB. Allowing for the 11 dB null plus another 3 dB cable loss (as does AirCell in its example calculations, *e.g.*, [1], p. 26) gives a received signal of $16-111-11-3=-109\text{ dBm}$, rather than –112 dBm. Thus, under AirCell's proposed rules, the interference from each cross-duplexed base station could be at the same level as the noise floor. With two cross-duplexed base stations at equal distances from the victim, the interference would be 3 dB above the noise floor. The total noise plus interference would be 3 times the noise floor, and the reverse link capacity would be reduced to one-third of its "uninterfered" capacity, assuming a 6 dB allowed noise rise (see Annex A). Thus, even if AirCell's inflexible rules could be successfully implemented, they do not solve the base-to-base interference problem for cross-duplexed systems in the airport environment.

While AirCell again proposes cross-duplexing and cross-polarization, it does not include in this paper any rules pertaining to polarization isolation. AirCell's September 9 filing [7] included a proposed rule intended to limit cross-polarization interference. Airfone observed in its response that such a rule is not practical to implement. Moreover, AirCell still has not addressed the lack of any record evidence that the 12 dB polarization isolation on which its simulation results were based is realistic.

Further, AirCell is completely silent in its paper on interference caused by the cross-polarized but co-duplexed systems to each other. In its June 29 paper [4], AirCell showed that cross-polarized sharing would increase the noise at the base station receiver to harmful, interfering levels. This was also discussed in [5] and AirCell has not responded with any mitigation strategies. It does not even appear that the unexplained analyses or simulations in [1] considered interference between cross-polarized systems; it is simply stated that:

> To allow four carriers to serve the airport, we evaluated the impact of adding additional sites on the ring, employing cross-polarized antenna system [*sic*] to provide isolation from the initial two carriers. The same mechanisms that supported such operation in cross-country routes apply to the airport environment. ([1], p. 16).

No results or even discussion of results are given. Thus, the only results provided by AirCell regarding sharing between cross-polarized systems in the airport scenario are in the June 29 paper [4], which show that the interference impact is considerable for the airport scenario. Thus, interference between cross-polarized systems is a significant issue for deck-to-deck service, even by AirCell's own analysis [4], and yet it is not addressed in [1].

Summary

AirCell's recent paper [1] makes claims that are not supported. It states on p. 2: "Finally, Airfone's repeated statements that AirCell's approach precludes service in areas around airports or precludes deck-to-deck service are fully refuted below." However, the material provided in the body of the paper does not deliver on this claim. It merely offers a proposed set of rules for base station placement and EIRP requirements near airports which purport to solve the base-to-base interference problem for cross-duplexed systems. These rules are extremely rigid and would make it difficult to implement a competitive ATG system, and they fail entirely to solve the interference problems between two cross-duplexed systems, as demonstrated above. Further, the proposed rules do nothing to address interference between cross-polarized systems, which AirCell proposes to allow in [7], and which, by AirCell's own analysis in [4], pose a significant interference threat. The numerical results provided by AirCell in the form of multi-color contour plots are not useful, since the assumptions, parameters, and models used to create them are not explained.

AirCell therefore has still not explained how a broadband, deck-to-deck ATG service could be provided by multiple operators sharing spectrum using either cross-duplexing (reverse banding), or cross-polarization. In [9], Telcordia summarized a set of key questions regarding the AirCell proposals which had not been addressed. They are:

- How can broadband ATG transmissions be supported on a reverse link that is limited to 200 mW EIRP?
- How can the problem of interference between cross-duplexed base stations in the airport scenario be solved?
- What measurement data support the contention that a 12 dB polarization isolation can be reliably maintained?
- How would base station locations and coordination be managed in a 4-provider sharing scenario?
- How can the excessive noise rise (indicated by AirCell's own results in [4]) at the base stations with crossed polarization sharing be realistically managed in the airport scenario?

In [1], AirCell makes an unsuccessful attempt to answer the second question, but completely ignores the others. Telcordia believes that AirCell has failed in its attempt to explain how its sharing proposal would support "deck-to-deck" service because it cannot be supported. As already has been demonstrated in previous submissions, the band sharing mechanisms proposed by AirCell – cross duplexing and cross polarization – will result in substantial interference to competing ATG systems that would preclude service near airports.

Annex A
Impact of Interference on Reverse Link Capacity

In Annex B of [1], Telcordia develops the CDMA reverse link load relationship

$$\frac{I_{tot}}{N} = \frac{1}{1 - K/K_{pole}} \tag{1}$$

where I_{tot} is the total noise plus interference at the base station receiver, *N* is the thermal noise floor, *K* is the number of active mobiles per cell or sector, and K_{pole} is the "pole capacity", which is the asymptotic capacity limit as $I_{tot}/N \to \infty$.

If there are two cross-duplexed base stations visible and each contributes a level equal to the noise floor, then the interference is equal to twice the noise floor. The impact on the capacity of a CDMA reverse link is easily seen by rearranging (1) to be $K/K_{pole} = 1 - N/I_{tot}$, so that if the upper limit on I_{tot} is held constant, then the ratio of the capacity with the added interference (denoted K_2) to the original capacity is

$$\frac{K_2}{K} = \frac{1 - N_2/I_{tot}}{1 - N/I_{tot}} \tag{2}$$

For a 6-dB maximum allowed noise rise (a reasonable value), $N/I_{tot} = 0.25$, so if the added "noise" from the cross-duplexed base stations is twice the noise floor, then $N_2 = 3N$ and $K_2/K = 0.33$. Thus, the added interference from the cross-duplexed base stations has cost the reverse link two-thirds of its capacity. Even if the interference from each of two interfering cross-duplexed base stations is 3 dB below the noise floor of the victim receiver, the total interference is equal to the noise floor and $N_2 = 2N$, which gives $K_2/K = 0.67$, corresponding to a 33% reduction in capacity.

References

[1] AirCell, Inc., "Providing Deck-to-Deck Coverage," September 30, 2004, WT Docket 03-103.

[2] Ivica Kostanic and Dan McKenna, "Evaluation of the ATG Spectrum Migration Concept," March 10, 2004, AirCell report to the FCC, WT Docket 03-103.

[3] Anthony A. Triolo and Jay E. Padgett, "Coexistence Analysis for Multiple Air-to-Ground Systems," June 3, 2004, Verizon Airfone report to the FCC, WT Docket 03-103.

[4] Ivica Kostanic, "Evolution of the ATG Migration Concept (Part 2)," June 29, 2004, AirCell report to the FCC WT Docket 03-103.

[5] Jay E. Padgett, "Response to Recent AirCell Filing and Summary Comments on AirCell Proposals, August 16, 2004, WT Docket 03-103.

[6] C. J. Hall and I. Kostanic, *Final Report of AirCell Flight Tests,* TEC Cellular, July 10-11, 1997.

[7] "AirCell Response to FCC Questions," September 9, 2004, WT Docket 03-103.

[8] A. Chari and V. Tarokh, "Response to Telcordia Technologies Comments on AirCell Proposal, September 10, 2004, WT Docket 03-103.

[9] Jay E. Padgett, "Reply to AirCell September 10, 2004 Response to Telcordia Comments on AirCell Proposals," September 24, 2004, WT Docket 03-103.