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Title	**Coexistence of Neighboring Systems: Uplink Co-Channel Interference Simulations at 3.5 GHz Using Adaptive Beamforming Antennas**	
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Re:	Coexistence psd Simulation Estimates in Support of 802.16a System Design	
Abstract	This document examines uplink psd requirements at 3.5 GHz when adaptive beamforming antennas are used at the victim base stations. The conclusions are specific to the system model selected. Other system model parameters may modify the distance coordination requirements. This contribution follows the coexistence scenario and system parameters previously adopted by TG2 and presented in documents C802162a-02_01 and C802162a-02_02.	
Purpose	This document is provided to TG2a for consideration and inclusion in the amended Coexistence Practice Document for PMP systems operating below 11 GHz.	
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Coexistence of Neighboring Systems: Uplink Co-Channel Interference Simulations at 3.5 GHz Using Adaptive Beamforming Antennas

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Introduction

The co-channel, adjacent-area analyses presented so far to TG2a have assumed conventional antennas at Base Stations (BS) and Subscriber Stations (SS). It is the intention of this contribution to investigate the impact of the utilization of the Adaptive Antennas (AA) with beam forming capabilities at the victim base stations on the results of the coexistence simulations. Adaptive antennas have been successfully implemented at the base stations for many years. AA increase the coverage and capacity of the wireless networks and enhance their performance through spatial processing, beam forming, and interference mitigation. The direct effect of AA on coexistence, however, is due to the fact that the RF energy radiated by transmitters is focused in specific areas of the cell and is not constant over time. This characteristic plays a major role in determining the likelihood of interference in coexistence scenarios. While an absolute worst case may look prohibitive, the statistical factor introduced by the use of AA determines the percentage of time/occurrences that the worst case happens. If this percentage is satisfactorily small, the coexistence rules may be relaxed, thus helping the economics of the deployment.

While AA can be implemented in both TDD and FDD systems, the benefits of AA are more in the TDD systems where forward and reverse links use the same frequency, thus channel conditions can be assumed as the same in both directions. The analyses presented here assume the interference is applied continuously at a given time, e.g. within a time slot.

The simulations presented here follow the scenario and assumptions presented in C802162a-02_01 and C802162a-02_02. Other scenarios and assumptions, such as adjacent channel interference or other bands of interest, will be investigated in subsequent contributions.

Simulation Channel Model

The channel propagation model described in contributions C802162a-02_01 and C802162a-02_02, i.e. dual-slope model, was adopted for consistency. The following formula has been used to calculate path loss at distance *d*.

$$PL(d) = \begin{cases} 32.4 + 20\log_{10}(f) + 10\gamma_1 \log_{10}(d) & d \le r_b \\ 32.4 + 20\log_{10}(f) + 10\gamma_2 \log_{10}\left(\frac{d}{r_b}\right) + 10\gamma_1 \log_{10}(r_b) & d > r_b \end{cases}$$

In the above formula, r_b is the breakpoint, assumed to be 7 km, *f* represents frequency in MHz, and γ_1 and γ_2 are path loss exponents for distances up to and beyond r_b, respectively. Figure 1 depicts the dual-slope path loss compared to free space and γ=4 at 3.5 GHz.

Simulation Transmission Parameters

The transmission parameters used in C802162a-02_01 and C802162a-02_02 was adopted for consistency.

Antenna RPE

The RPEs for SS is the same as in C802162a-02_01 and C802162a-02_02. No coordination in terms of using of orthogonal polarizations has been assumed. It is clear, though, that this type of coordination enhances the coexistence situation.

The victim BS is assumed to be equipped with beam forming capability, thus having a narrow beam in space within any given time slot. For simplicity, a key-hole pattern is being assumed for the AA beam's horizontal pattern as shown in Fig. 1. Vertical pattern is not being taken into consideration in consistency with C802162a-02_01 and C802162a-02_02.

In Fig. 1, the values of G_{max} and G_{min} are given below.

$$G_{\max} = G_0 + 10\log_{10}(M)$$

$$G_{\min} = G_0 - 20\log_{10}(M)$$

In the above formulas, M is the number of elements in the AA array, and G_0 is the gain of a single element, assumed as 10 dBi. It should be noted that the AA is generally capable of steering a deep null in the direction of multiple interferers unless the interferer is coming in through the main beam of the AA. This capability of the AA is not included in this analysis and G_{min} is considered to be the average value of the side and back lobes of the antenna.

Limiting psd Considerations

In order to have a baseline for analyzing the interference effects, the limiting pfd thresholds presented in C802162a-02_01 and C802162a-02_02 are converted to psd values. Below is a sample calculation used to find the equivalent psd value (in dBm/MHz) of –125.1 dBW/MHz/m^2.

$$psfd(dBW/MHz/m^2) = psd(dBW/MHz) - \text{antenna effective aperture}(m^2)$$

$$psfd(dBW/MHz/m^2) = psd(dBW/MHz) - 10\log\left(\frac{G\lambda^2}{4\pi}\right)$$

$$psd(dBW/MHz) = psfd(dBW/MHz/m^2) + G_{dB} + 20\log(\lambda) - 10\log(4\pi)$$

$$psd = -125.1 + 20\log(\lambda) + G_{dB} - 10\log(4\pi)$$

$$psd = -125.1 + 20\log(.0857) + 14.5 - 10\log(4\pi)$$

$$psd = -142.93 \quad dBW/MHz$$

$$psd = -112.93 \quad dBm/MHz$$

The resultant psd value is used as the limiting interference threshold level in interpreting the results of the statistical simulations.

Simulation Methodology and Results

The geometry used for this analysis is similar to Fig. 3 in C802162a-02_01, reproduced in this document in the Annex in Fig. 3. What is different is that the victim BS is assumed to use AA instead of 90^o sector antennas, thus having a narrow beam pointing to a randomly changing direction at any point in time. It is assumed that all the interfering SS are at the cell edge and actively transmitting with their maximum power on the same carrier as the victim link in Fig. A1 within the given time slot. It is also assumed that only one of the SS at the cell edge is transmitting in the time slot of interest. The interference power from the interfering SS arriving at the victim BS is then calculated to form a snapshot of the interference power. The simulation was then repeated for many times to reveal the likelihood of various interference levels through CDF plots.

Adaptive beam forming provides the capability of steering nulls towards a number of interferers. Such nulls are usually deeper than what has been assumed in the key-hole pattern, thus further reducing the interference. This effect has not been included in this analysis.

Unless otherwise specified, the plots apply to a dual-slope propagation model as described in C802162a-02_01, one narrow AA beam per frequency at any given time in the victim cell, and 16QAM uplink. The results of the analysis are as follows.

Figure 4a shows the likelihood of interference psd at the victim BS for various inter-cell separation distances. Figure 4b is a zoomed in version of Figure 4a. It shows that the interference psd is lower than permissible value of –112.93 dBm/MHz in about 99% of the time for an inter-cell distance of under 20 km.

The effect of modulation on the interference at the inter-cell distance of 20 km was also analyzed and depicted in Fig. 5. It should be noted that 4QAM interfering subscriber stations create the worst interference among the three modulations due to highest transmit power. This, of course, assumes that all three modulations are possible at the cell edge.

Safe Distance and Worst Case Interference

In the case of 16QAM, the 99% interference-free criterion is met at an inter-cell distance of 18.6 km, as depicted in figures 6a and 6b. In that condition, the worst-case interference is –82.96 dBm/MHz.

In order to create an interference-free environment, namely, no interference stronger than –112.93 dBm/MHz, the distance needs to be increased to 72.5 km, as depicted in figures 7. In that case, the maximum interference occurred is –113.03 dBm/MHz.

The study shows that, with the utilization of AA, the occurrence of worst-case interference scenario due to main beam to main beam coupling between the victim and the interferer is limited to a very small percentage of time/cases. This interference is, however, more severe than the case with conventional antennas. Comparison of Figures 6 and 7 reveal that large separation distances are required to completely remove the interference altogether. However, with AA, these extreme cases happen only a small fraction of time and/or interference cases due to the statistical factor introduced by the randomness of the AA main beam orientation in time/space. Therefore, the safe inter-cell distance can be reduced to less than 20 km if 1% severe interference cases can be tolerated.

It is clear that upon occurrence of the uplink interference, the subscriber(s) served by the victim link will face outage. Since the location of the interfering subscriber of the neighboring system is fixed, it is, however, easy to locate the severely interfered victim links upon installation and use protective measures such as switching to another frequency and/or orthogonal polarization. Such protective measures, since the need for them rises only with a small likelihood if adaptive antennas are used, should solve the coexistence problem at short inter-cell distances and effectively reduce the coordination distance.

Depending on the implementation of the adaptive antenna in practical cases, intra-cell reuse of a frequency could become possible. In such cases, at any given time, more than one beam on a certain frequency could illuminate the cell area. Depending on the implementation, this capability affects the coverage and capacity of every cell. Due to the fact that implementation details of such capabilities are not discussed in the 802.16a draft standard, a generic approach has been adopted and the effects of multiple, simultaneous, co-channel beams on the system coverage and capacity have been ignored. The result of the multi-beam analysis is reported in Figure 8 with tolerable interference likelihood of 0%, 1%, and 5% for up to 5 simultaneous co-channel beams.

Conclusions

The simulations reported here show that there is a clear advantage in using the adaptive antennas on the uplink for solving the co-channel, adjacent area coexistence problem. Coordination will not be necessary for cell-to-cell distances of greater than 18.6 km for 16QAM subscriber stations interfering with the uplink of a BS with AA assuming acceptable interference likelihood below 1%. In the cases where interference happens, it is severe and outage occurs unless inter-cell distances are large. In such cases, however, protective measures such as switching to other frequencies and/or orthogonal polarization can potentially solve the problem. Taking advantage of the null steering capabilities would reduce the coordination distance even further.

Annex: Graphs

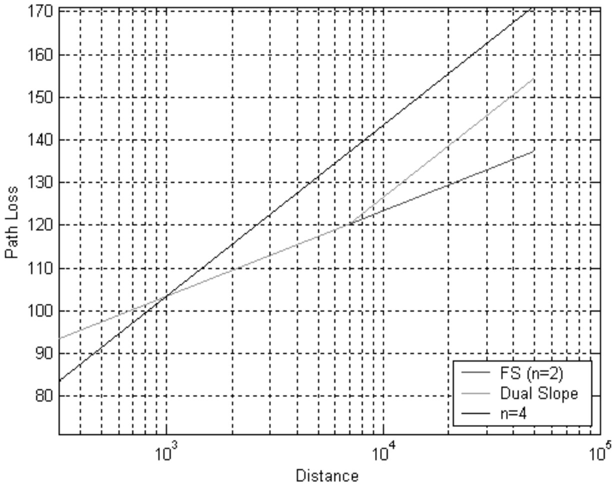

Figure 1. Comparison of path loss models

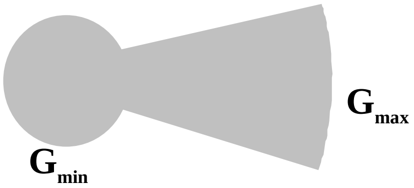

Figure 2. Key-hole horizontal pattern for BS AA

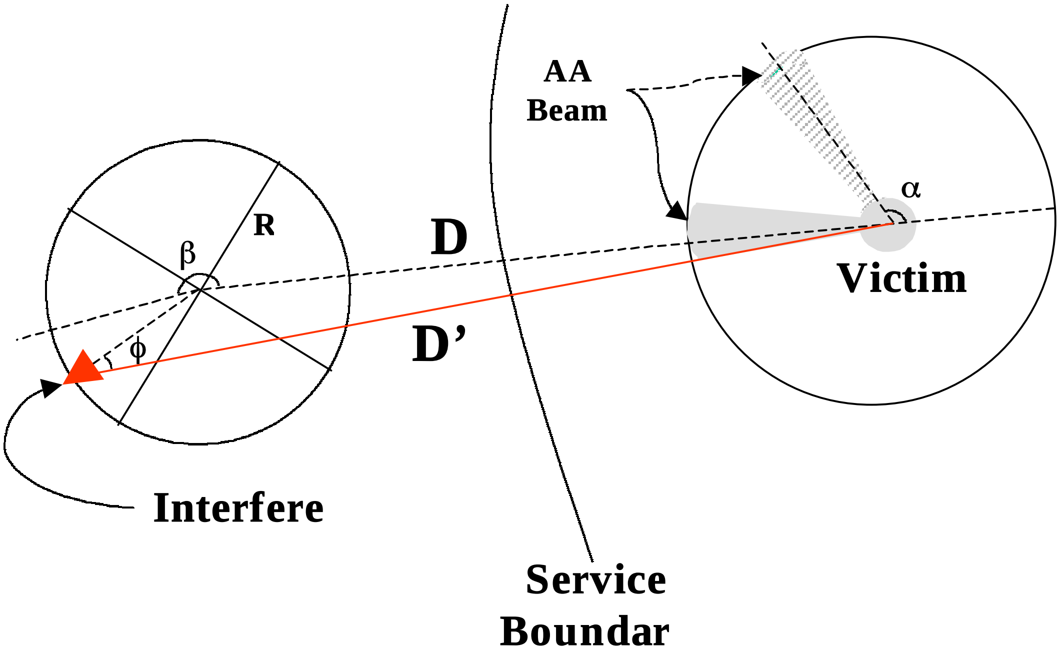

Figure 3. Interference Geometry

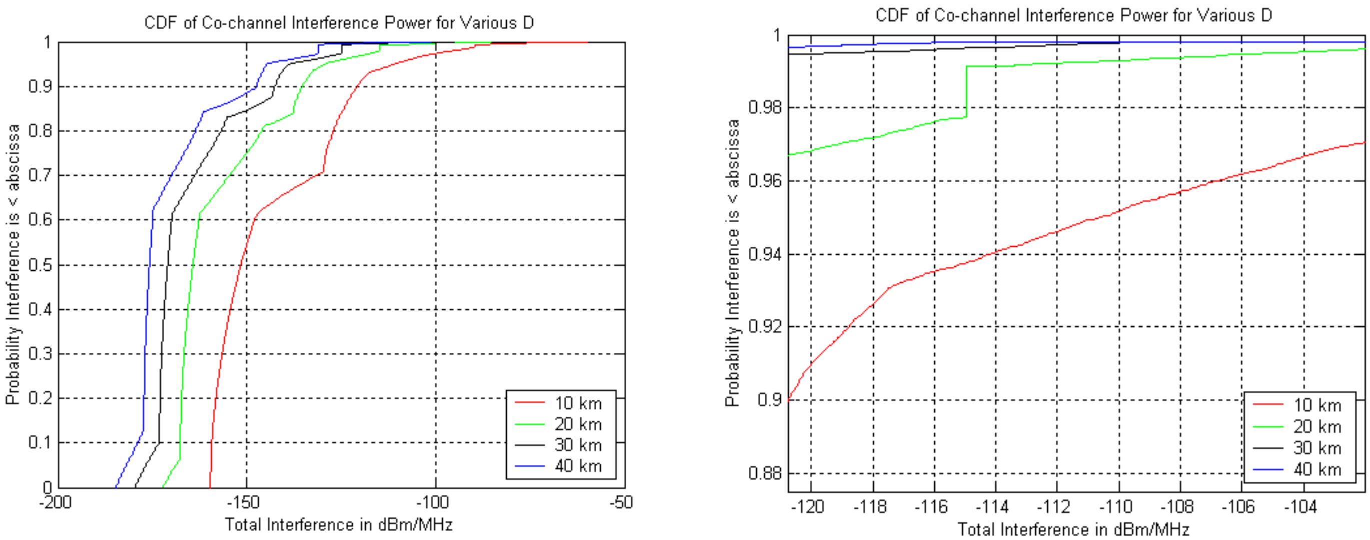

Figure 4. (a) CDF of uplink co-channel interference power spectral density for various inter-cell distances assuming 16QAM interferers, (b) zoomed-in version of (a).

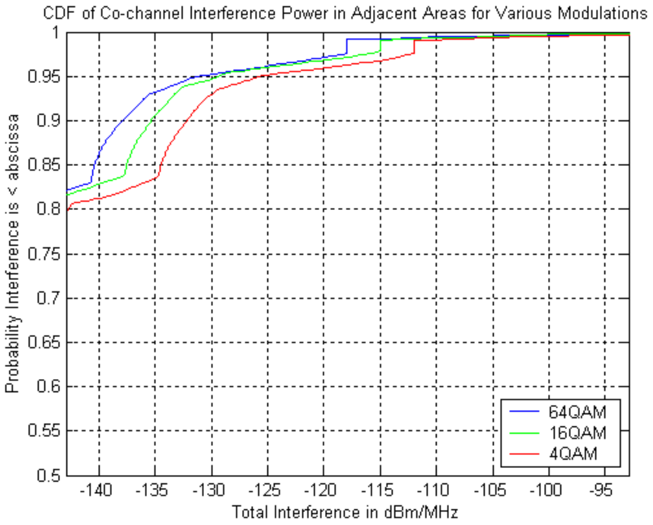

Figure 5. CDF of uplink co-channel interference power spectral density for three modulation schemes assuming an inter-cell distance of 20 km.

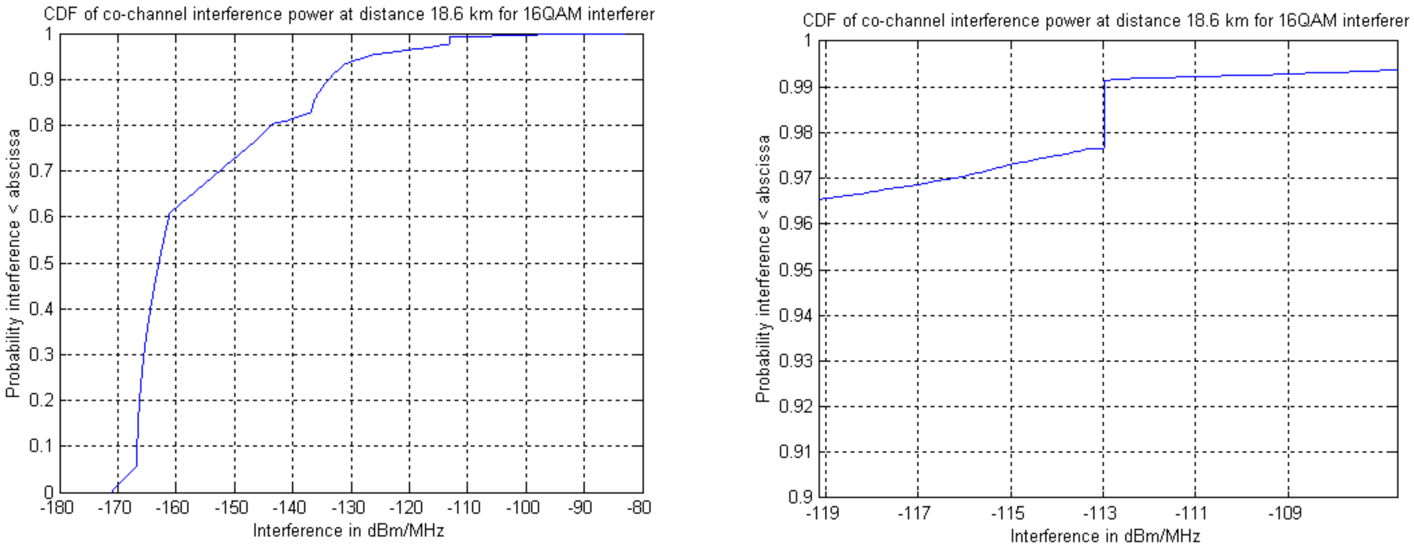

Figure 6. (a) CDF of uplink co-channel interference power spectral density for 16QAM interferer at an inter-cell distance of 18.6 km, (b) zoomed-in version of (a), the –112.93 dBm/MHz interference criterion is met 99% of the time.

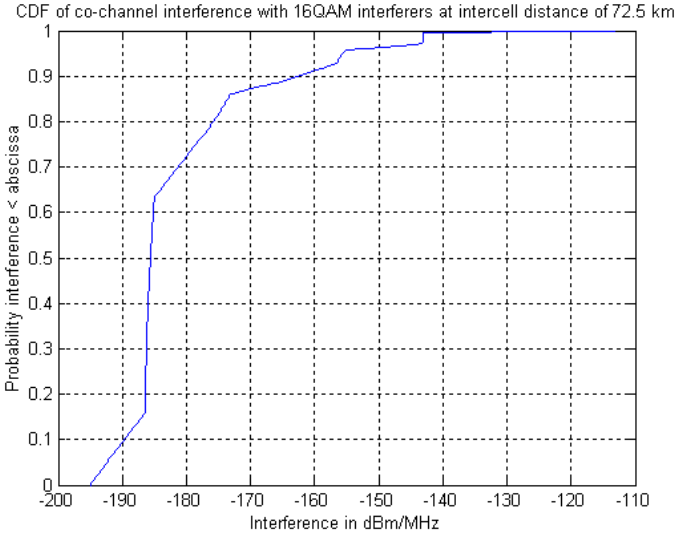

Figure 7. CDF of uplink co-channel interference power spectral density for 16QAM interferer at an inter-cell distance of 72.5 km. The –112.93 dBm/MHz interference criterion is met 100% of the time.

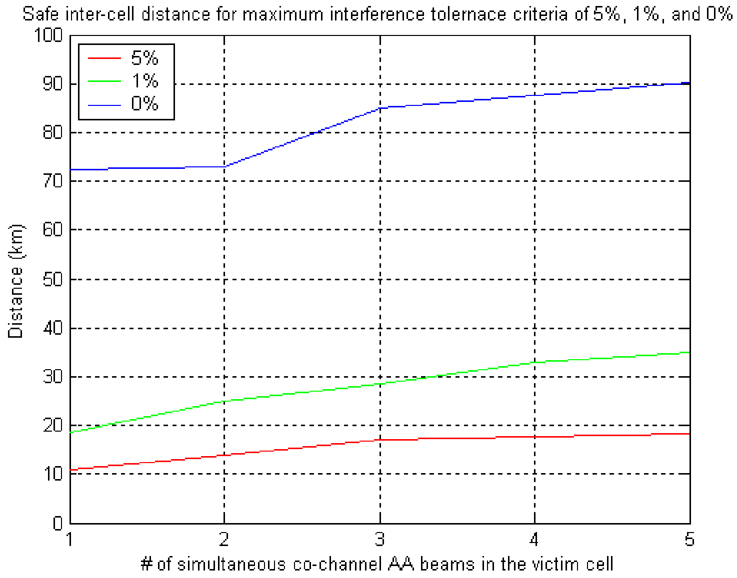

Figure 8. Safe inter-cell distances (in km) for maximum interference tolerance criteria of 5%, 1%, and 0% as a function of the number of simultaneous, co-channel AA beans in the victim cell (this number is implementation-dependent).