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NOTE TO 3GPP REGARDING THE "WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW REPORT ON MITIGATING TECHNIQUES TO ADDRESS COEXISTENCE BETWEEN IMT-2000 TDD AND FDD RADIO INTERFACE TECHNOLOGIES WITHIN THE FREQUENCY RANGE 2 500-2 690 MHz OPERATING IN ADJACENT BANDS AND IN THE SAME GEOGRAPHICAL AREA"

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Working Party 8F is the ITU-R Working Party responsible for the overall system aspects of IMT-2000 and beyond.

Working Party 8F is continuing to progress work on the "Working Document towards a preliminary draft new Report on mitigating techniques to address coexistence between IMT-2000 TDD and FDD radio interface technologies within the frequency range 2 500-2 690 MHz operating in adjacent bands and in the same geographical area", and thanks 3GPP TSG RAN for its contribution presented in 8F/877 that was submitted on its behalf. This document was taken into consideration, along with other input contributions, at our recent meeting on 26th March – 3rd April 2003, in Brazil. The objective is to finalise this new report at the next WP 8F meeting that will take place on 8th – 16th October 2003 in Edinburgh, UK.

The present working document, which was updated at this meeting, is attached for your information and possible contribution. Working Party 8F appreciates the opportunity of collaborating with 3GPP toward the successful completion of this Report.

Attachment: 1

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Attachment

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WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW REPORT ON MITIGATING TECHNIQUES TO ADDRESS COEXISTENCE BETWEEN IMT-2000 TDD AND FDD RADIO INTERFACE TECHNOLOGIES WITHIN THE FREQUENCY RANGE 2 500-2 690 MHz OPERATING IN ADJACENT BANDS AND IN THE SAME GEOGRAPHICAL AREA

1 Scope

This report provides analyses of the potential improvement that can be brought about when mitigation techniques are applied to the results of the TDD/FDD coexistence studies presented in the draft new Report ITU-R M.[IMT.COEXT] shown in reference [3]. That Report identified scenarios where TDD/FDD coexistence was problematic due to Base Station to Base Station (BS-to-BS), Base Station to Mobile Station (BS-to-MS), Mobile Station to Base Station (MS-to-BS) and Mobile Station to Mobile Station (MS-to-MS) interference. In this study we apply various mitigation techniques to those scenarios to qualify and quantify the potential improvements they can bring.

It is recognized that mitigation techniques affect the cost, complexity or performance of the system deployment. As such, there may need to be tradeoffs made between these and the benefits associated with the use of each mitigation technique separately or in combination with others. This report presents the reader with a description of these tradeoffs that may need to be evaluated in selecting which, if any, of these techniques may be implemented economically.

This draft new report specifically addresses techniques that might be applicable for general application when planning deployment of multiple competitive networks operating in adjacent bands and in the same geographical area. As in the related paper, the IMT-2000 technologies considered are the FDD based IMT-2000 CDMA direct spread radio specification and both TDD based CDMA TC modes, more specifically HCR TDD (3.84 Mcps) and LCR TDD (1.28 Mcps).

2 Introduction and Summary

Potential coexistence issues between TDD and FDD IMT-2000 radio interface technologies have been identified during studies into how multi-operator networks may be deployed in the IMT-2000 2 500-2 690 MHz band in the most spectrum-efficient manner. Report [IMT.COEXT], [3], concluded that significant interference was likely to be experienced in BS-to-BS scenarios (whether they be co-located or in proximity) as well as in MS-to-MS scenarios where outages would impact user service levels. Hence, the successful deployment of TDD and FDD systems in adjacent bands may require the use of one or more of these mitigation techniques to resolve any of the BS-BS or MS-MS interference scenarios that may be relevant. When combining two or more techniques, their impact on cost, feasibility, and performance needs to be assessed as a whole as addressed in section 6.

Editor's Note: Material needed on the issue of combination of the mitigation techniques. The introduction needs to elaborate on the issue that the not all mitigation techniques are necessarily covered.

3 Review of the previous related work in ITU-R WP 8F

That Report presented results of the consequences of adjacent channel interference on compatibility of a number of scenarios of TDD and FDD air interface technologies operating in adjacent bands and in the same geographical area. The previous study was based on deterministic interference level calculations for BS-BS scenarios and led to required separation distances and/or isolation requirements or supported cell range. The interference from mobile stations into mobile stations and base stations was also analyzed both with deterministic and statistical calculations leading to capacity loss and/or probability of interference.

The scenarios presented in section 3.1 are only the ones that were identified as problematic for TDD/FDD coexistence in [3]. They will be used as the basis for qualifying and quantifying the benefits of using each of the mitigation techniques presented in this Report. The evaluation criteria presented in section 3.2 are the same as those presented in [3], e.g. required separation distances and/or isolation requirements or supported cell range, capacity loss and probability of interference.

3.1 Reference scenarios

The following interference scenarios have been identified in [3] for coexistence of IMT-2000 FDD and TDD systems.

1. FDD BS <–> TDD BS
2. FDD MS <–> TDD MS
3. FDD MS <–> TDD BS
4. FDD BS <–> TDD MS

While the first case was analyzed by deterministic methods, statistical analysis was used for cases 3 and 4. Case 2 was analyzed by both methods. In this report, case 1 is further analyzed through statistical methods for interference level calculations for base stations using adaptive antennas.

In [3], for the studied Manhattan scenarios with uniformly distributed outdoor-only users, Monte Carlo simulations suggest that MS-BS, BS-MS interference will have a small or negligible impact on the capacity when averaged over the system.

The problematic cases identified in [3] are described below.

3.1.1 Macro TDD BS – macro FDD BS

In [3], the macro TDD BS – macro FDD BS interference is identified as the most problematic case. Some of the parameter values pertaining to this scenario are repeated in Table 1 below for reference. Given these parameters, the maximum acceptable level of external interference, (I_{ext}), is also obtained from [3].

3.1.2 MS-MS interference

In [3], deterministic MS-MS calculations suggest that one mobile might create severe interference to another geographically and spectrally close mobile. It concluded that studies are therefore needed where non-uniform user densities are considered which are more realistic in real systems in hot spot areas. [As it is not possible to mitigate MS-MS related outage through increased BS density or decreased cell capacity, alternative mitigation techniques are required that establish an acceptable service level requirement.]

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Editor's note: Text in square bracket has not been finalized yet. Alternatively, this paragraph could be replaced at the next meeting with the text from the Conclusions section of [3] on MS-MS interference.

[Any mitigation techniques need to address both the FDD downlink and the TDD as victims.]

Editor's note: Text in square bracket has not been finalized yet.

TABLE 1

Summary of parameters for the problematic coexistence cases[4]

Type[1]	P_{tx} (dBm)	Antenna Height (m)	ACLR[2] (dB)	ACS[2] (dB)	I_{ext} (dBm)[3]
FDD BS	43	30	45	46	–114 to –106 (rural) –100 to –95 (urban)
TDD BS	43	30	70	46	
FDD MS	24	1.5	33	33	-
TDD MS	24	1.5	33	33	-

1 FDD BS is WCDMA FDD and TDD BS is HCR TDD.
2 For adjacent channels with 5 MHz carrier separation.
3 The range corresponds to lightly loaded (20%) and highly loaded (75%) systems.
4 For consistency, the values reported in the table are from [3]. Updated values are available from 3GPP TSG RAN4.

In Table 1, ACLR is Adjacent Channel Leakage Ratio and ACS stands for Adjacent Channel Selectivity.

3.2 Evaluation criteria

The evaluation criteria used in this Report are the same as those presented in [3], e.g. required separation distances and/or isolation requirements or supported cell range, capacity loss and probability of interference. Various mitigation techniques are selected and evaluated to determine the amount of improvement they provide to the performance of the reference scenarios in section 3.1, *i.e.* their ability to reduce isolation requirements in terms of separation either in the space or frequency domain, and to reduce the probability of interference.

4 Overview of interference mitigation techniques relevant to TDD-FDD Coexistence

Each of these subsections describes the main attributes of the mitigation techniques. The techniques presented are only those that can be useful in addressing coexistence between TDD and FDD systems operating in adjacent bands and in the same geographical area, recognizing that this may exclude other commonly used techniques in system deployment.

4.1 Site engineering

4.1.1 Antenna coupling and isolation

4.1.1.1 Non-collocated antennas

For interference between two macro base stations

Two macro (over the rooftop) BS antennas that are pointed towards each other in the horizontal plane can exhibit a tight coupling to each other. To mitigate that tight coupling, it is recommended to down tilt the antennas so that they would not be in each other's respective boresight in the vertical plane. In a real system where cell sites have different radiation centers and antenna beams rolls off gradually, sufficient isolation cannot be assured with few degrees of down tilting alone. However down tilting beyond a threshold defined by half of the 3 dB vertical beam width would result in reduced cell coverage and coverage gaps in the system.

Editor's note: Possible reference to 3GPP TSG-RAN Work Item on Remote Control of Electrical Tilting Antennas.

For interference between a macro and micro base stations

In the case of macro and micro BS antennas, mitigating the strong antenna coupling can be achieved by mounting the antennas at different heights. For example, the macro antenna could be mounted on a pole on the roof, while the micro antenna would be possibly on the building outer wall closer to street level. Thus the effective gain that determines the coupling between the two is less than the algebraic sum of the gains.

4.1.1.2 Collocated antennas

It is possible to achieve significant levels of isolation between two collocating base station antennas through proper placement by taking advantage of the antenna pattern. Cellular antennas normally have vertical beamwidth in the range of a few degrees in either side of the horizontal. Also, Sectored antennas typically have horizontal beamwidth in the range of 90 degrees (?45 degrees from boresight) and their pattern falls off rapidly at ?90 degrees off the boresight direction. A high degree of front-to-back ratio could also be used to provide isolation between two collocated base station antennas. Using these characteristics, it is possible to facilitate the coexistence of any two base stations by collocating them on the same tower or rooftop. While it is not always possible to coordinate the collocation process between competing operators, doing so would yield additional isolation over the Minimum Coupling Loss (MCL) assumption in [3]. In those problematic cases identified in [3], this additional isolation can be used to reduce the size of the guardbands between two systems in adjacent blocks/channels. Section 5.1.2 quantifies the potential improvement in coexistence due to collocation. Careful installation techniques allow two antennas that are mounted on the same pole to achieve higher coupling loss of 72 dB. Co-location of TDD/FDD was not specified in 3GPP - only co-existence in the same geographical area is specified [7].

4.1.2 Use of orthogonal polarizations

It is possible to get additional isolation between two antennas by having them orthogonally polarized to each other. Cellular antennas are typically linearly polarized. Therefore, as an example, using vertical polarization on one antenna and horizontal polarization on the other can reduce the degree of coupling between the two of them. The coupling effect is quantified in terms of an antenna characteristic know as Cross Polar Discrimination (XPD). The collective effect of the XPD from both antennas needs to be taken into account. Section 5.1.3 quantifies the potential improvement in coexistence due to use of orthogonal polarization.

4.2 Use of Adaptive Antennas (AA)

Adaptive Antennas 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 is due to the fact that the RF energy radiated by transmitters is generally focused in specific areas of the cell and is not constant over time. Adaptive antennas can be, therefore, modeled as a narrow angular sector in coexistence simulations, thus affecting the likelihood of interference in coexistence scenarios. Moreover, beam forming with the goal of maximizing the link margin for any given user inside the cell coverage area at any given time, makes the AA beams' azimuth and elevation vary in time. These two factors suggest that the

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adaptive antenna pattern and gain need to be considered as random variables both in E- and H-plane. While an absolute worst case may look prohibitive, the statistical factor introduced by the use of AA determines the percentage of time that the worst case happens. If this percentage is satisfactorily small, the coexistence rules may be relaxed.

Another effect of the AA on coexistence involving adjacent bands is due to the fact that the gain of the AA is reduced in the antenna-to-antenna coupling due to loss of coherency in out-of-band operation. This reduction in gain further reduces the interference power into AA from other antennas operating in adjacent bands and vice versa. The impact is especially important since direct AA main beam coupling is the largest contributor to the interference. Simulations point to the fact that the BS-BS direct antenna coupling is the most problematic case for coexistence. With the use of AA, the loss of coherency in out-of-band operations reduces the gain towards the interferers/victims, thus lowering the amount of interference power.

An alternative possible strategy towards interference mitigation exists whereby the AA is operated so as to steer a sharp null towards one or more neighbouring BS in order to reduce the antenna-to-antenna coupling.

4.3 Improved BS or MS equipment specifications

Filtering or linearization or both can be used to reduce the unwanted emissions from one base station to another thus reducing the interference at the victim base station. In a similar manner, receiver filtering may reduce the in band interference to the victim base station. When the overall interference is reduced, base stations could operate closer to each other, or allowed higher TX power or both while maintaining a desired interference level.

Adjacent channel operation (e.g. 5MHz carrier spacing) of FDD and TDD represents the most challenging scenario for MS terminals in close proximity to each other, with both the FDD downlink and the TDD downlink each being potentially a victim of interferrence. A higher carrier spacing (e.g. 10 or 15MHz) can ease the interference due to the shape of the aggressor carrier leakage and the victim selectivity characteristics. However the degree of mitigation by this means alone is limited and cannot be improved by greater carrier spacings unless additional sub-band-specific filters are adopted by both the FDD and TDD MS. Such filtering provides additional suppression of out-of-band modulations, noise and spurious emissions but it also provides important protection for the victim receiver which could otherwise be driven beyond its specified in-band blocking level by the aggressor’s transmit carrier.

The use of sub-band filtering is, to some degree, comparable to the duplex filters conventionally employed in FDD MS and hence similar trade-offs on size, performance, cost, and impairments need to be considered regarding the separation gap.

Editor’s note: Further text may be required depending on other contributions.

4.4 Other techniques

4.4.1 Use of power control

In TDD systems that do not employ power control, the available BS DL power is usually equally divided between the users in the slot. A typical system design will then consist of budgeting that available power to cover path loss, SIR requirements, an allowed interference level that would be equal at all users antennas and some margin. As the allowed interference is the same for all users, it by necessity has to be small if coverage and or capacity is to be preserved.

To mitigate that interference, power control can be used such that different interference levels that are experienced by different users will trigger an increase in the BS DL power allocated to that user.

The net result is that the interference allowed to some users can be increased while maintaining low average interference, and therefore maintaining the capacity and coverage. An additional benefit of the technique is that the interference caused by the TDD DL to the FDD system could also be reduced.

Editor's note: Cost issues should be discussed in Section 5.

5 Effects of the mitigation techniques on the coexistence

In each subsection of this chapter we will address both the benefits and costs associated with each technique for the considered scenarios.

5.1 Effects of using site engineering techniques

Some of the interference mitigating techniques proposed are traditional radio site engineering techniques, such as antenna space separation, in order to get the required additional isolation. Some of the proposed interference mitigating techniques is new advanced solutions, such as adaptive antenna. Each solution has its advantage, but also its limitations. Some of the site engineering techniques mentioned are already used by the systems to mitigate intersystem interference and the realized gains are used to support higher voice capacity or higher data throughput. They are, however, being analyzed in this report since they have not been included in the analyses of the [IMT.COEXT] report. The antenna placement methods may require additional co-ordination in some cases and it will be costly to increase the complexity of cell site engineering.

5.1.1 Effects based on improving antenna coupling and isolation

5.1.1.1 Site engineering and antenna collocation

The effect of antenna coupling on interference among base stations can be reduced through collocation and proper placement. Based on the measurements reported to 3GPP, TSG RAN [4] for a variety of typical antennas, it is possible to quantify this effect. There are several placement options, including the following.

a) Vertical separation: Based on [4], it is possible to achieve at least 60 dB of isolation between two 16 dBi vertically polarized, 90^{o} sector antennas with approximately 3 meters of vertical separation.

b) Side-by-side separation: The measurements in [4] suggest 45 to 50 dB of isolation between two 16 dBi vertically polarized, 90^{o} sector antennas at approximately 4 to 6 meters of horizontal separation.

c) Back-to-back separation: The measurements in [4] suggest 65 to 70 dB of isolation between two 16 dBi vertically polarized, 90^{o} sector antennas at horizontal back-to-back separation distances in the range of 1 to 1.5 meters.

The above isolation is achievable using the antenna patterns only and does not include the use of any additional screening or absorption material.

It is, therefore, possible to facilitate the coexistence of any two base stations by collocating them on the same tower or rooftop. It is shown in [4] that while it is not always possible to coordinate the collocation process between competing operators, doing so could yield, on the average, 60 dB of isolation. This is
30 dB of additional isolation over the 30 dB MCL assumption in [3]. In those problematic cases identified in [3], this additional isolation can be used to reduce the size of the guardband between two systems in adjacent blocks/channels. Using the methodology of section 4.2.1.4 in [3], where adjacent-band FDD and TDD systems are collocated, to generate Figure 1 through Figure 6. Table

31 in section 4.2.1.4 of [3] lists, for both TDD to FDD and FDD to TDD interference scenarios, the amount of interference at the receiver (parameter Int@_Rcvr) for an MCL of 30 dB and compares it with the threshold value of –109 dBm obtained based on an interference to noise ratio of –6 dB. This applies to a large cell, probably a rural application, where maintaining a low receiver sensitivity is important, i.e., to receive a signal from a mobile user operating at the edge of a large cell. The "no mitigation" data on Figure 1 through Figure 6 reflect the additional isolation required to meet that threshold based on the data in Table 31 of [3]. Additional MCL due to separation of antennas, as explained in [4], provide lower required isolation that is depicted by other data points in Figure 1 through Figure 6.

The amount of improvement due to vertical separation of the antennas is depicted in Figures 1 and 2.

FIGURE 1

Required additional isolation due to vertical antenna separation (TDD victim)

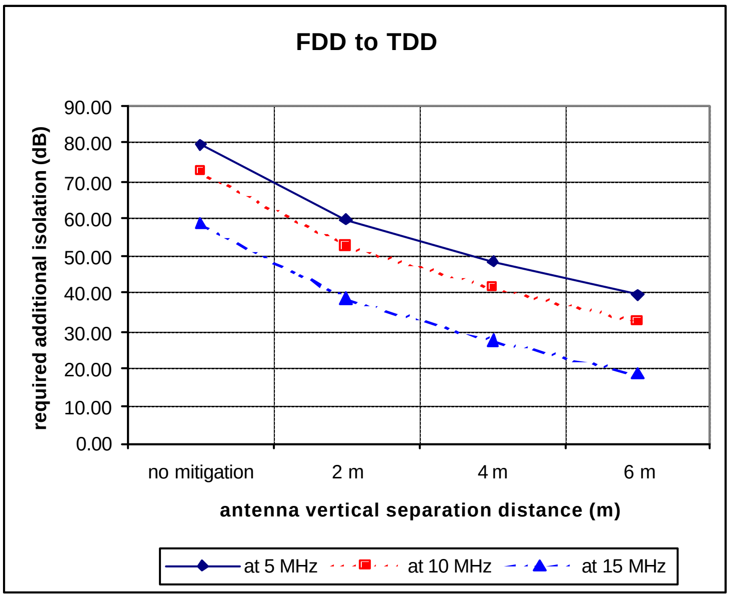
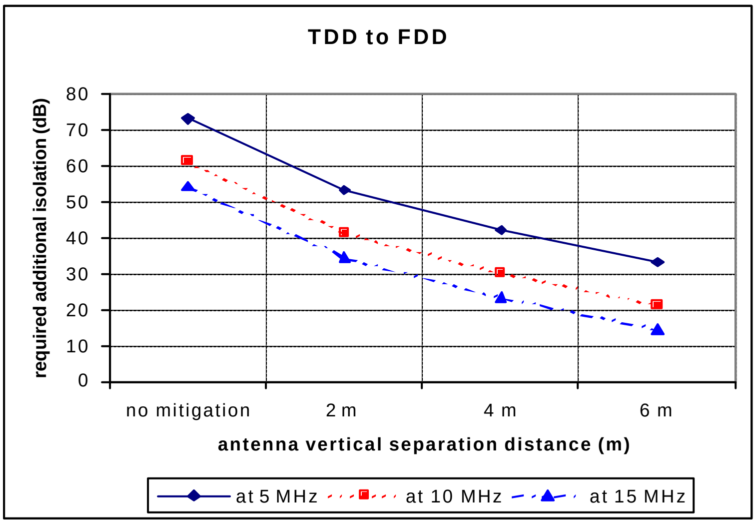


FIGURE 2

Required additional isolation due to vertical antenna separation (FDD Victim)



The amount of improvement due to horizontal separation of the antennas is depicted in Figures 3 and 4.

FIGURE 3

Required additional isolation due to horizontal antenna separation (TDD victim)

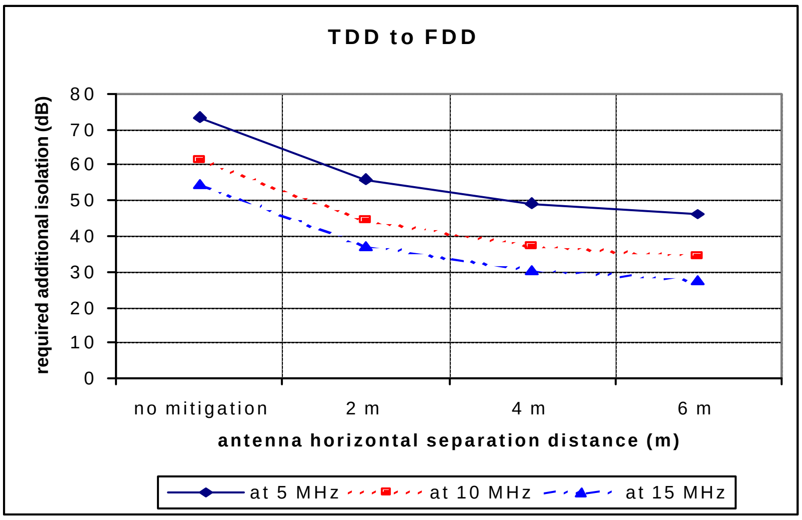


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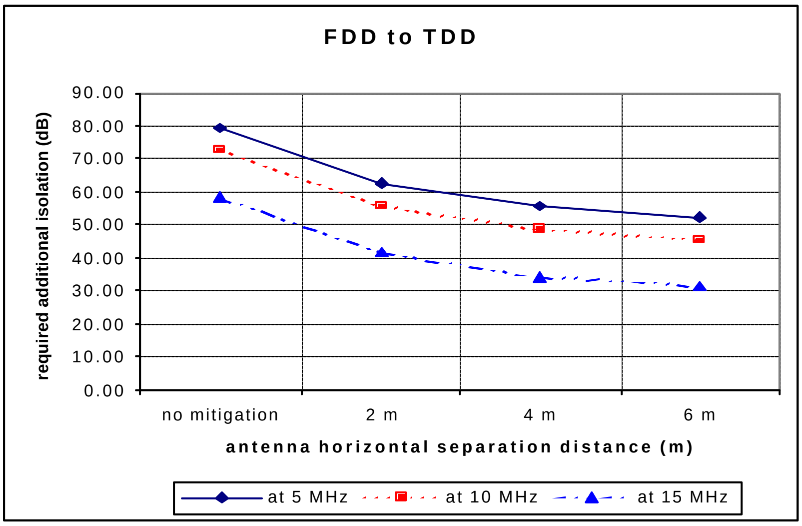
FIGURE 4

Required additional isolation due to horizontal antenna separation (FDD victim)



The amount of improvement due to back-to-back separation of the antennas is depicted in Figures 5 and 6.

FIGURE 5

Required additional isolation due to back-to-back antenna separation (TDD victim)

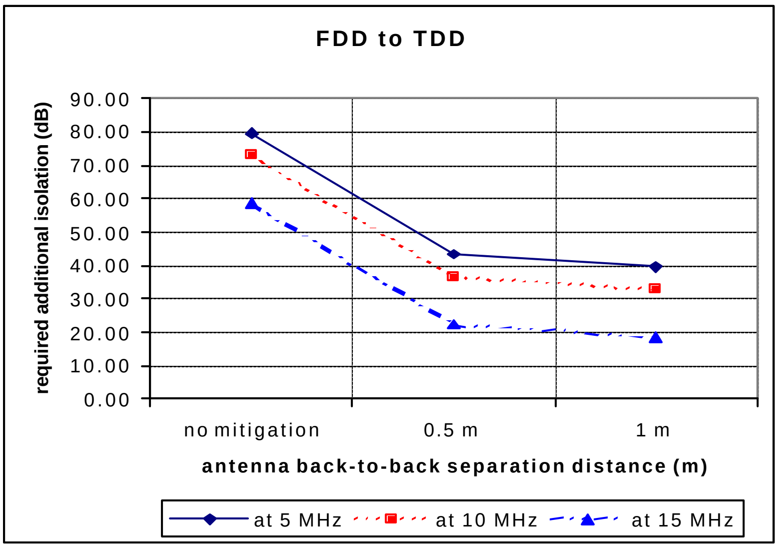
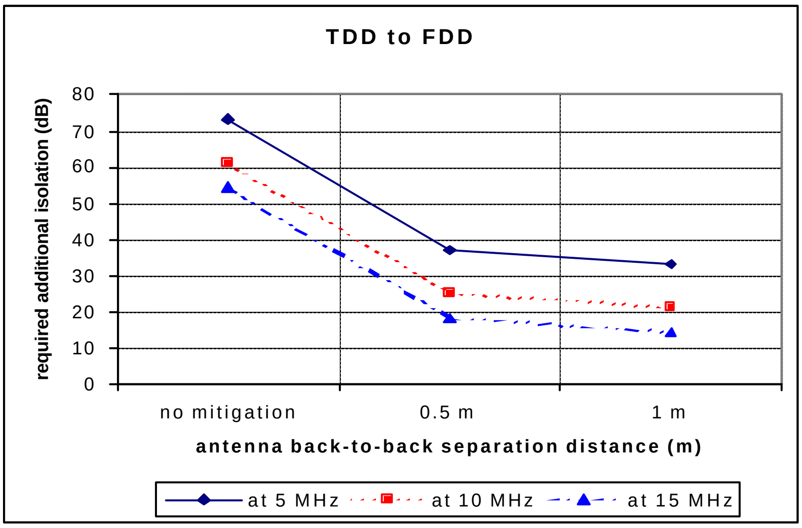


FIGURE 6

Required additional isolation due to back-to-back antenna separation (FDD victim)



In combination with other mitigation techniques, coordinated antenna placement can potentially remove the need for guardbands in collocation scenarios.

The following graph was compiled from measurements in [6] and [4] at 1 900 MHz and 1 710-1 880 MHz respectively. The measurements were made by placing two vertically polarized antennas one above the other on the ground facing the sky, to simulate wall mounting. The data curves for 1 900 MHz represents center frequency performance for four different 1 900 MHz antennas with different beam widths and down tilts. The Min for 1 710-1 880 MHz performance curves represents the worst case isolation achieved over the full GSM 1800 band of 1 710 to 1 880 MHz for three different full band antennas, a 9.47 % BW. The antennas have different beam widths and gains. The isolation is likely to increase for antennas designed for the 2 500 MHz band due to the additional loss expected in the 2 500 MHz band (both propagation and conducted losses will increase). It is also anticipated that the broadband isolation performance for the 2 500 MHz band will also improve due to the reduction in the required operating BW (from 9.47% to 7.32 % BW). Additional isolation performance is also expected for pole mounted antennas.

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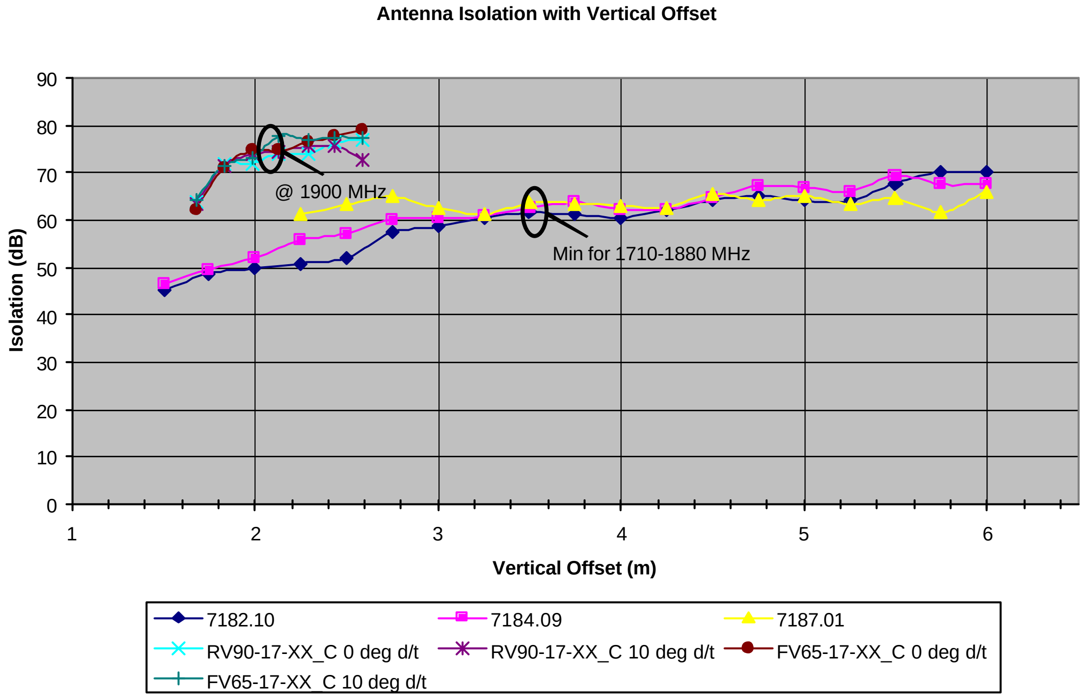
FIGURE 7

Antenna isolation with vertical offset



5.1.1.1.1 Trade off issues

The location for mounting antennas is subject to practical site engineering considerations as space availability, lease agreements, co axial runs, zoning laws etc. It may not be possible to maintain the appropriate separation distance between antennas at all of the collocated base stations. Therefore, the gains may not be fully realizable at all locations throughout the network.

Issues like target area coverage, intersystem interference, frequency reuse pattern also need to be taken into account for antenna placement.

Editor's note: Material needed on the cost issues.

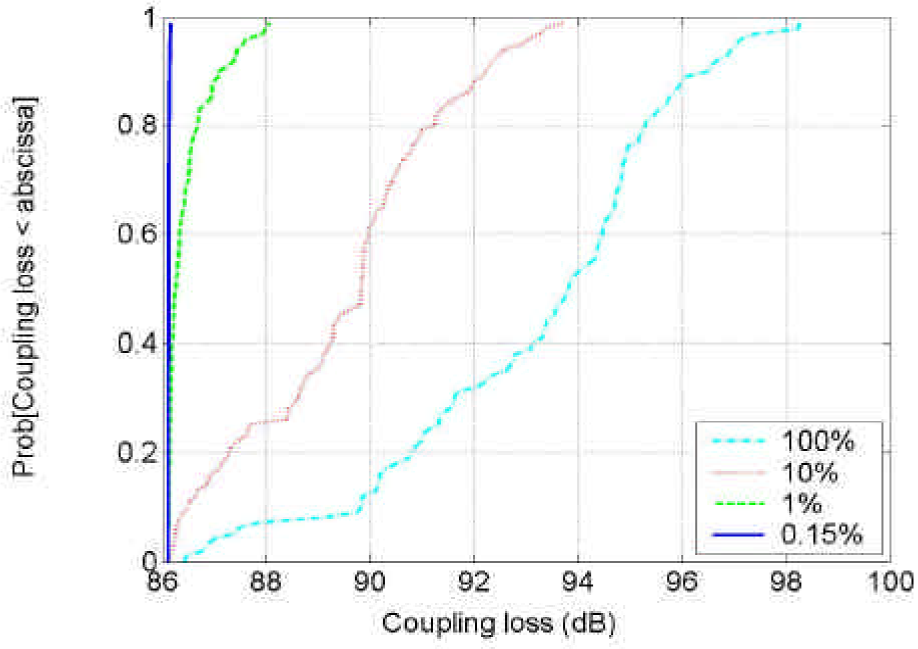
5.1.1.2 Antenna isolation achieved by antenna displacement

5.1.1.2.1 Macro, downtown BS and in building pico BS

Avoiding LOS placement of indoor pico base stations and macro pole mounted antennas achieves an isolation of 86 dB. The isolation is obtained between in building pico BSs located randomly within the buildings of a regular Manhattan type grid and a macro, downtown BS pole mounted on the building located in the center of the grid. (see following graph) The in building pico BSs are distributed in height and building location (See Appendix B for more details).

FIGURE 8

Distribution of the coupling loss between the maro, downtown BS and the most coupled in building pico BS, for different densities of in building pico BS's (100% corresponds 4 BSs per floor, in all floors, in all buildings)



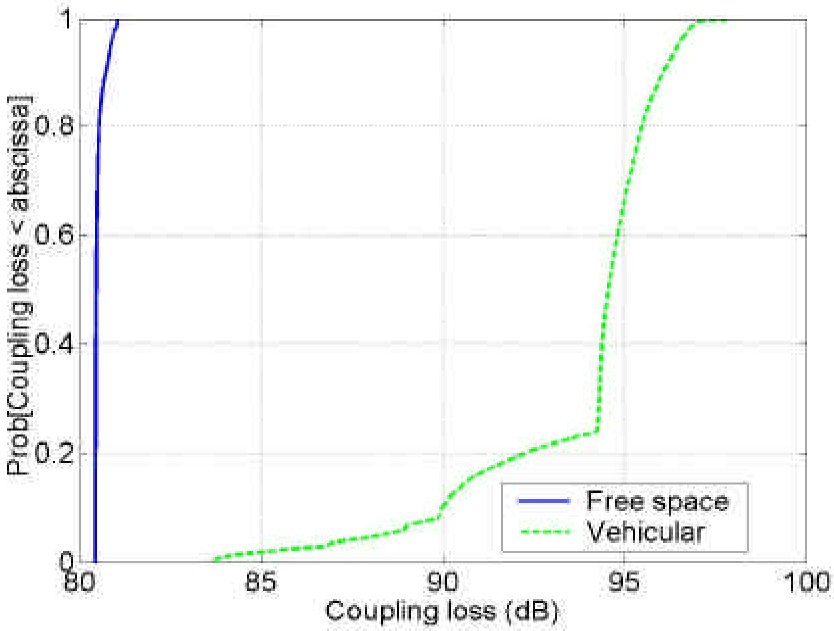
5.1.1.2.2 Macro, downtown BS and outdoor micro BS

Avoiding LOS placement of macro pole mounted and micro antennas can achieve antenna isolation of greater then 80 or 90 dB (depending on propagation model).

The isolation is obtained for >90% of the deployments between in outdoor micro BSs located in a regular rectangular grid and a macro, downtown BS pole mounted in an area at the center of the grid. (see following graph) The macro, downtown BS is placed randomly with in the center area. A height difference of 25 m is assumed between the macro, downtown BS and the outdoor micro BSs. (See Appendix B for more details.)

FIGURE 9

Distribution of coupling loss between a macro, downtown BS and the most coupled outdoor micro BS



5.1.2 Use of orthogonal polarization

Antenna XPD is defined as the ratio of the received signal level in the wanted polarization to the received signal level in the unwanted polarization. The minimum (i.e., worst case) collective isolation achievable between two orthogonally polarized antennas (XPD_{min}) is related to the XPD of both antennas through the following equation [5].

$$XPD_{min} = \left(XPD_1^{-1/2} + XPD_2^{-1/2} \right)^{-2}$$

Citing antenna manufacturers' catalogs, it is possible to achieve XPD in the order of 25 to 35 dB for cellular antennas in the frequency range of interest. This parameter is sometimes specified as inter-port isolation in dual-polarized antennas. As an example, using two antennas each having a main-lobe XPD of 30 dB would produce XPD_{min} of 24 dB in main beam coupling situations.

One possible scenario for implementing this technique would be the case of two base station antennas at close proximity, potentially in line-of-sight to each other. While the underlying path loss could be insufficient to provide enough isolation for adjacent or alternate channel operation, additional isolation due to the use of a polarization orthogonal to that of the interferer could potentially solve the problem. It should be noted that the amount of isolation through XPD of the antennas is likely to be achievable when the two antennas are in the worst-case scenario configuration; i.e., main-beam coupling in line-of-sight, where isolation is needed most.

The amount of isolation, however, reduces in side-lobe coupling or NLOS situations due to deterioration of the polarization purity of the antennas and depolarization introduced by multipath, reflection and diffraction.

It should also be noted that service providers tend to utilize the same type of antenna and installation configuration throughout their network to take advantage of the reduced price of bulk purchases and ease of uniform installation procedures. Switching to different types of antennas or different installation configurations only at some problematic locations involves additional costs that network operators may or may not be able to justify. On the other hand, the use of either receive or transmit diversity limits the availability of this technique for interference mitigation purposes.

This technique, if available, can also be combined with other mitigation techniques to remove specific coexistence problems, e.g., additional isolation requirement for collocation of base station antennas.

5.2 Effects of using adaptive antenna technology

Since the macro TDD BS – macro FDD BS interference was identified as the most problematic case, the analysis reported here is done for this case in both rural and urban areas. Generally, all the assumptions in calculation of the interference levels including antenna heights, Adjacent Channel Leakage Ratio (ACLR), Adjacent Channel Selectivity (ACS), channel bandwidths, receiver sensitivity, etc. are consistent with [1]. The AA pattern and gain are given later in this section. Given these parameters, the maximum acceptable level of external interference, (I_{ext}), is also obtained from [3]. According to the results presented here, it is evident that the use of AA reduces the required additional isolation in less than 2% of the time in rural and urban areas significantly (compare with tables in Section 4 of [3]). The additional isolation needed for coexistence, if necessary, is at a level that can be easily achieved by other coexistence-friendly site engineering practices or better equipment specifications.

5.2.1 General Information

Adaptive antennas impact a wireless system in many ways; through coherent combining of the arrived signals, large diversity gains that combat uncorrelated fading among multiple antennas, and interference suppression and mitigation. An adaptive array with *M* elements is capable of nulling *M-1* interferers perfectly. This capability of the array, however, has been assumed in the current analysis to be solely used for coping with intra-network interference and is not included in the simulations for inter-network interference.

Direct benefit from the use of AA on the coexistence, however, is due to the fact that the RF energy radiated by transmitters is focused in limited, specific regions of a cell rather than wide sectors. Also, the beam forming capability of adaptive antennas at the base stations creates inherent down tilt in the vertical plane, which is determined by the distribution of users within the cell. Since users are distributed within the cell area, the AA is likely to point its beams at user locations, thus lowering the likelihood of creating/accepting interference to/from other stations, as depicted in Figure 10. This lower likelihood of interference is verified by the results presented here.

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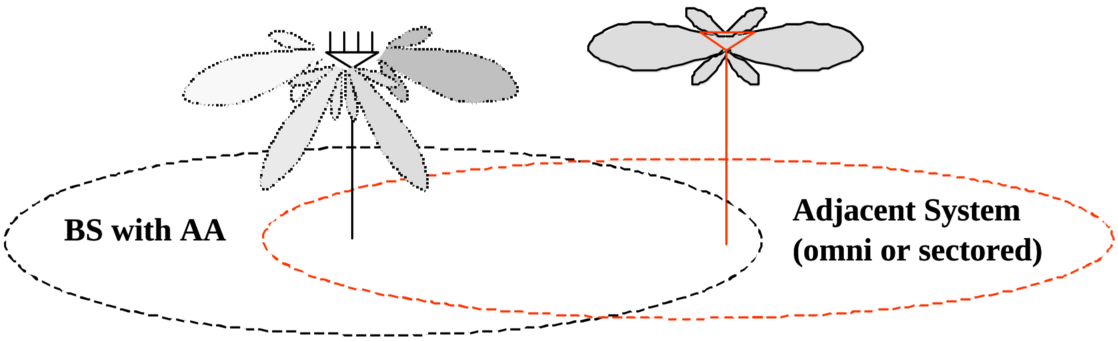
FIGURE 10

Distribution of AA beams in time and space lowers the likelihood of interference



5.2.2 Propagation models

For macro cells, the following path loss model is recommended in [1].

$$L = 40(1 - 4 \times 10^{-3} \Delta h_b)\log_{10}(R) - 18\log_{10}(\Delta h_b) + 21\log_{10}(f) + 80 + FM \quad (1)$$

FM is the log-normally distributed shadowing margin with standard deviation of 10 dB

f is frequency in MHz

Δh_b is the base station antenna height above average rooftop, and

R is distance in km.

Several propagation models are used in [3] for the purpose of coexistence simulations. However, [3] uses a Dual-Slope model from [10] for the case of macro-cell BS-BS interference. This model is formulated by equation (2) for 2.6 GHz.

$$L_{LOS} = \begin{cases} 40.7 + 20\log_{10}(d) & 1 \le d \le d_{break} \\ 40.7 + 20\log_{10}(d_{break}) + 40\log_{10}(d) & d > d_{break} \end{cases}$$
$$d_{break} = \frac{4h_{tx}h_{rx}}{\lambda} \quad (2)$$

In equation (2), h_{tx} and h_{rx} are the transmitter and receiver antenna height above average rooftop, λ is the wavelength, d is the distance between the transmitter and the receiver, and d_{break} is the breakpoint associated with the first Fresnel zone, all in meter. It should be noted that for typical antenna heights above rooftops and the range of frequencies under consideration for IMT-2000 technologies, this model performs as free space LOS for most deployment distances. This is overly pessimistic for urban deployment scenarios since the effects of the perturbation of the first Fresnel zone by buildings in the vicinity of base stations are ignored. It will be shown later that AA introduces improvements even in case of this overly pessimistic model.

5.2.3 Deterministic analysis without AA

Given the ACIR, Adjacent Channel Interference Ratio, it is possible to calculate the required separation distance from the following example of a TDD BS interfering with an FDD BS [3] without the benefit of AA.

The average output power of the TDD BS, including the activity factor of TDD (assumed as 0.5) is the following.

$$P_{ave} = P_{tx} - 3 = 43 - 3 = 40 \quad dBm$$

The overall resulting gain, assuming both BS antennas are aligned through their maximum gain beams with no downtilt (worst case) is

$$G = G_{tx} + G_{rx} = 15 + 15 = 30 \quad dBi$$

Given the ACLR and ACS values in Table 1,

$$ACIR = 10\log_{10}\left(\frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}}\right) = 10\log_{10}\left(\frac{1}{\frac{1}{10^{7}} + \frac{1}{10^{4.6}}}\right) = 45.98 \approx 46 \quad dB$$

The required path loss, assuming tolerable adjacent channel interference of –114 dBm [3] is found as follows.

$$L = P_{ave} + G - ACIR - I = 40 + 30 - 46 - (-114) = 138 \quad dB \tag{3}$$

Using the propagation model given by equation (2), the required separation distance to achieve 138 dB of path loss is calculated to be 9,541 m, which is quite prohibitive.

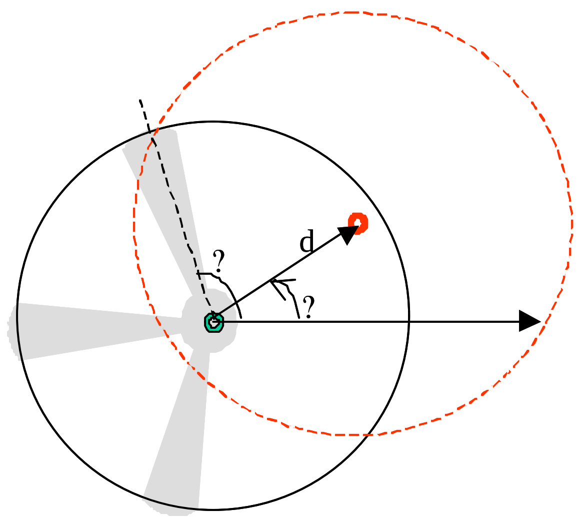
Given distance, equation (3) can also be rearranged to obtain the required ACIR.

5.2.4 Statistical analysis with AA

As described above, implementation of AA at the base station requires statistical analysis. The statistical simulation of AA is performed at snapshots in time. The basic set up for the simulation in the horizontal plane is shown in Figure 11.

FIGURE 11

Simulation in the horizontal plane



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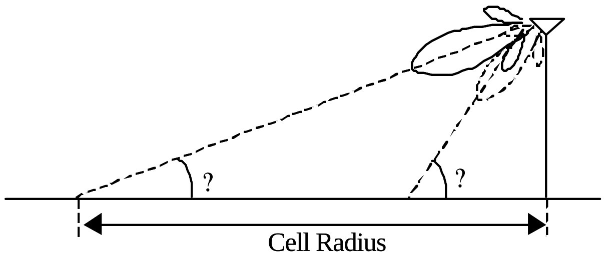
It is being assumed that during any given time slot on any carrier, one downlink beam at the TDD BS with AA illuminates each sector in a random angle ??measured from an arbitrary reference, thus affecting the victim FDD BS, or vice versa, the FDD BS, shown in red, radiates its energy in space, thus affecting the uplink of TDD BS. The distance between the two BS is set to be smaller than the larger of the two cell radii, presumably the FDD cell radius. It is assumed that the TDD base stations are located at random points within the FDD cell area, thus having a random distance *d* and angle *?* to the FDD BS. The Mobile Stations (MS) are assumed to be uniformly distributed within the cell area, thus determining the random direction of the AA beams.

In vertical plane, it is assumed that the AA beams are distributed in the angular area between ? and ? as shown in Figure 12. ? is determined by cell radius and transmitter height while ? is assumed as 45^{o}. Both vertical and horizontal beam width of the AA are assumed to be equal to 10 degrees.

FIGURE 12

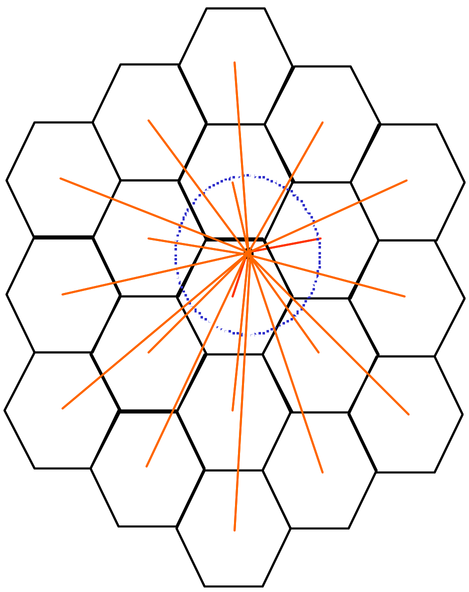
Simulation in the vertical plane



For the purpose of demonstrating the impact of AA on coexistence, a network of 19 cells, as suggested by [1], has been considered. Figure 13 depicts the network of 19 cells being built around a victim station. One such network is simulated for all random points picked within the cell area of the victim BS, the circle in Figure 13.

FIGURE 13

Network of 19 interfering cells



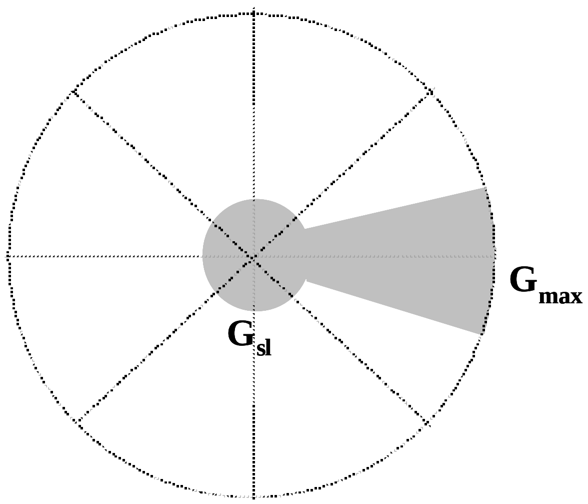
Base station density is based on ETSI Recommendation [9] (cell radius of 4 km for rural and 1.5 km for urban have been assumed). Some comparative simulations were also performed with cell radii as low as 500 m and as high as 9 km. The contribution from interferers beyond the closest 19 is considered to be insignificant. The likelihood of interference is observed by the percentage of the time the victim is protected as suggested by [1].

In all cases, the effect of perfect downlink and uplink power control is taken into consideration. In the downlink, this is implemented by lowering the transmit power of a TDD BS beam as the user moves closer to the BS to take advantage of reduced path loss. For simulations involving FDD network of cells, random values within the power control dynamic range of the FDD BS, as specified in section 6.4.2 of [9], have been assumed. In the uplink, power control is implemented by lowering the transmit power of the MS as it moves closer to the BS.

Throughout the simulation, FDD base stations are considered to have a maximum gain of 15 dBi with some degrees of down tilt such that the gain towards the horizon is reduced by 3 dB. For the TDD base stations utilizing AA, however, each beam is modeled in E-plane and H-plane according to Figure 14.

FIGURE 14

E-plane & H-plane of the AA beam assumed in the analysis



The maximum gain of an AA beam, G_{max}, is generally related to the array parameters as follows.

$$G_{\max} ? G_{element} ? 10 \log_{10} M \qquad (4)$$

In the above formula, M is the number of array elements, $G_{element}$ is the gain of a single array element assumed to be 10 dBi. In the case of adjacent channel interference, due to loss of coherency in out-of-band beam-to-beam coupling, the additional array gain over $G_{element}$ is assumed to be $5log_{10}(M)$ in main beam coupling throughout the analyses. It is also being taken into consideration that despite the random direction of the AA beam and general side and back lobe suppression, the upper side lobes are somewhat larger than other lobes unless highly complicated beam-forming techniques and large arrays are used. If the interferer and the victim share only the horizontal plane (but not the vertical plane), side lobes of the individual array elements affect the interference power. In this case, the gain of the array is assumed to be equal to the gain of the individual element through its side lobes, which is assumed to be 0 dBi. If the victim and interferer share only the

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vertical plane (but not the horizontal plane), the gain of the array is given by equation (5).

$$G \,?\, G_{element} \,?\, 10\log_{10} M \qquad (5)$$

If the interferer and the victim share neither planes, the gain is given by equation (6).

$$G \,?\, G_{element} \,?\, 20\log_{10} M \qquad (6)$$

The results presented in sections 5.2. 5 and 5.2. 6 were obtained assuming M=10, which corresponds to 10 dB and 20 dB side-lobe level from equations (5) and (6), respectively. It should be noted that AA are capable of producing much deeper nulls than 10 or 20 dB. These numbers are only used as average over all side-lobes.

The simulations were run for various antenna heights. The results reported here, though, reflect the case where both antennas have the same height of 30 m, which creates the most interference. With this assumption, the victim and the interferers are always in the same horizontal plane and equations 4 and 5 are in effect used to create the figures reported here.

In reality, antennas are not likely to have equal heights, thus there is likely to be lower interference floor than the results of this study indicate.

5.2.4.1 Broadcast channels

Broadcast information contained in the logical control channels is meant to be transmitted in downlink to all users. This information is typically transmitted on certain known timeslots that are changed only on a long-term basis. For the stations using conventional antennas, as far as this analysis is concerned, this information can be treated as other information contained in traffic channels. Since the FDD base stations in this analysis are assumed to use conventional antennas, there is no effect on the results of the interference analysis into the uplink of the TDD base stations. The case of the TDD BS implementing AA in the downlink, however, needs to be looked at separately. There are two possible implementations. One implementation of AA in TDD BS applies beamforming only to the traffic channels and leaves the broadcast channel as omnidirectional, thus creating interference to all surrounding victims in the periods that such information is being broadcast.

According to 3GPP specifications [11], one out of the 15 time slots in a 10 ms TDD frame is considered for broadcast information such as synchronization or paging. Assuming that there is no coordination between the neighboring TDD and FDD systems, there is a probability of 1/15 (~0.067) for any given FDD uplink timeslot suffering partially to fully from interference due to broadcast channel of a neighboring TDD base station. For a given FDD uplink, the existence or non-existence of TDD broadcast information can be considered as a Bernoulli random variable, which takes up the values of 1 and 0, with the following statistical characteristics.

$$\begin{aligned}
&X : \text{Bernoulli R. V.}, S_X \,?\, ?0,1?\\
&p_1 \,?\, p, \qquad p_0 \,?\, q \,?\, 1 \,?\, p\\
&E[X] \,?\, p\\
&VAR[X] \,?\, pq
\end{aligned}$$

In the above expressions, 1 and 0 represent the existence and nonexistence of interference, respectively.

The interference from the beam-formed traffic channels needs to be statistically added to the interference from the broadcast channel. This effect is analyzed by introducing the above-mentioned Bernoulli random variable in the interference calculations. If this random variable takes the value “1”, interference from the TDD traffic channel is replaced with the interference from the broadcast channel with omnidirectional configuration. The results are reflected in 5.2.5.

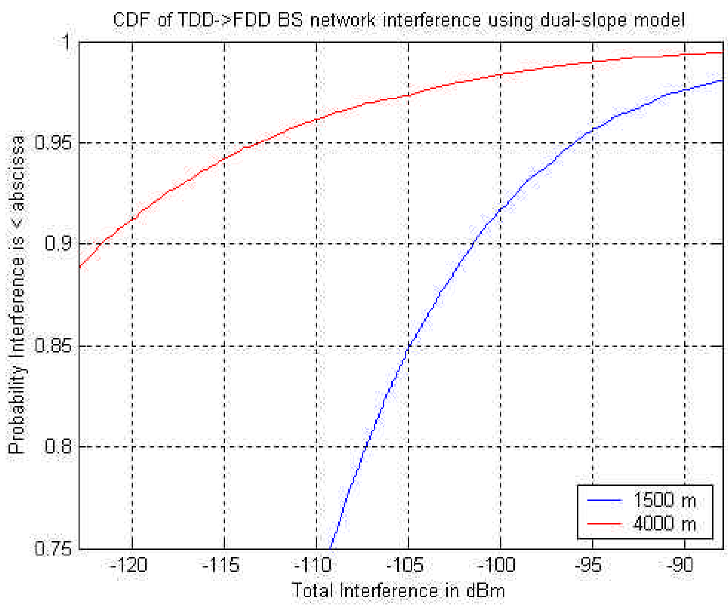
It is, however, possible, as an alternative implementation approach, to apply beamforming to the broadcast channel, thus focusing even the broadcast information to certain areas of the cell at any given time. In this alternative approach, timeslots containing broadcast information should be treated as any other timeslots and broadcast channel will not add any additional interference to neighboring stations. This more favorable approach may involve additional complexity and its implementation is the operator’s choice. For the sake of the present analysis, therefore, it has been assumed that simpler approach, i.e. the first approach, is implemented at the TDD BS. It is highly likely, though, that operators implementing AA at IMT-2000 TDD base stations favor second approach due to its superior performance.

5.2.5 Effect of adaptive antennas in the downlink

The effects of the AA in the downlink pertain to the case where the TDD base station equipped with adaptive antenna uses downlink beamforming. Therefore, the victim has been chosen to be a single FDD base station and interferers are 19 TDD base stations. Corresponding ACLR and ACS values for 5 MHz channel spacing are being used. It can be seen from Figure 15 that with acceptable interference threshold of –114 dBm (rural areas) being met at least 95% of the time, using AA at the BS causes safe coexistence.-For 98% interference criterion, additional isolation in the amount of 4 to 12 dB is required to meet the –106 to –114 dBm requirements. Also, in urban macrocell situations with maximum tolerated interference level of –95 to –100 dBm, 7 to 12 dB of additional isolation is required to meet the 98% criterion.

FIGURE 15

Likelihood of interference as a function of cell radius due to a network of TDD/AA base stations into a single FDD base station, using dual-slope propagation model

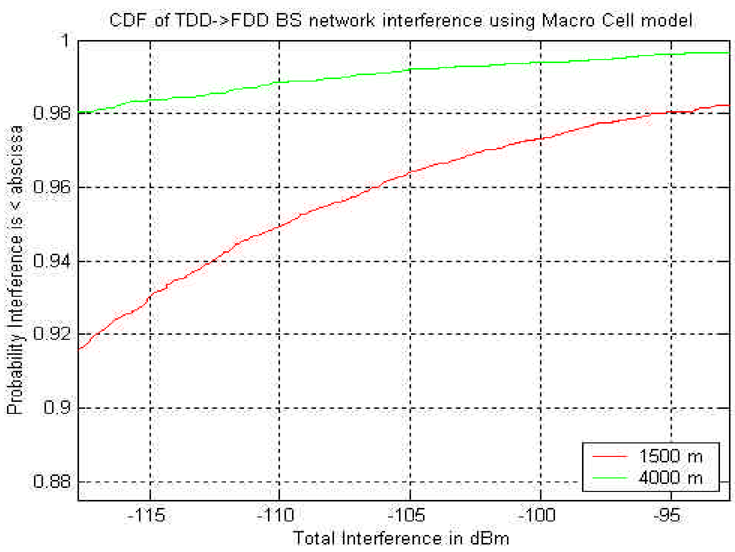


It is important to note that the 9.5 km distance was calculated for a single TDD interferer, while Figure 6 depicts total interference from a network of 19 TDD base stations.

In urban areas, often times base station antennas are mounted to the side of the buildings. The variation in height and orientation of the buildings in urban settings, thus, obstruct the LOS after a few blocks. A more realistic propagation model for non-LOS situations, such as the one introduced in (2), produces the results shown in Figure 16. The improvement introduced by this more realistic model is quite clear. With the same interference protection criterion, safe coexistence is feasible at least 98% of the time for urban cells and for rural cells, the base stations are almost always protected. The additional isolation required to achieve the 98% protection level is tabulated in 5.2.7.

FIGURE 16

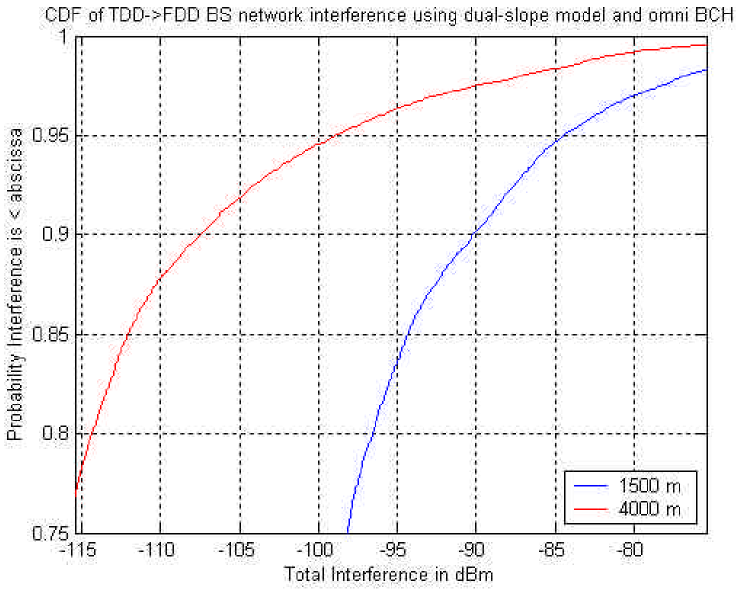
Likelihood of interference as a function of cell radius due to a network of TDD/AA base stations into a single FDD base station, using macrocell [1] propagation model



By introducing a Bernoulli random variable, the effect of the broadcast information in the downlink of the TDD BS on the uplink of the FDD BS is captured in Figure 17 using the Dual-Slope propagation model. As it is apparent from the figure, the omnidirectional interference has a direct effect on the upper tail of the CDF plot. This is due to the fact that, this interference, although present only a fraction of the time, is a strong contributing component to the Monte Carlo simulation. Based on Figure 17, 98% protection criterion would require 18 - 26 dB and 18 – 23 dB additional isolation in rural and urban environments, respectively.

FIGURE 17

Likelihood of interference as a function of cell radius due to a network of TDD/AA base stations, including omni-directional broadcast channel, into a single FDD base station, using dual-slope propagation model



Comparison of Figures 16 and 17 reveals that interference from the TDD system into the FDD system can be significantly reduced specially if the implementation of the AA at the TDD base station follows the second approach with regards to broadcast control channels.

5.2.5.1 Separation distance

In order to directly relate the interference mitigating capability of AA to separation distance, a slightly different analysis was performed. In this analysis, the distance between the victim base station and the closest interferer on the adjacent channel was changed with small increments from 50 m to maximum cell radius of the victim. For each point, a network of 19 interfering cells was created and the total interference was calculated. The calculation was repeated for 360 azimuth angles and then averaged over the azimuths. The total amount of interference into the victim was then plotted for various separation distances up to the cell radius.

Figure 18 and Figure 19 depict the total average interference versus separation distance for omnidirectional and beamformed broadcast channel, respectively.

FIGURE 18

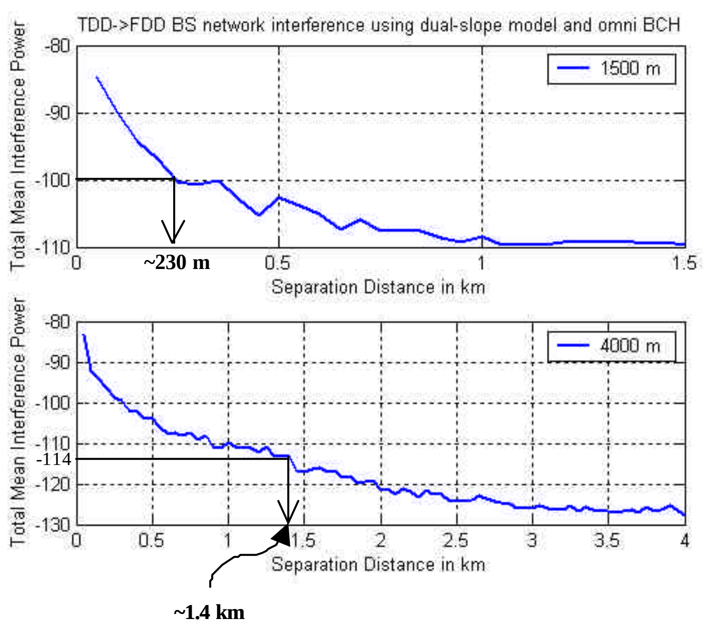


FIGURE 19

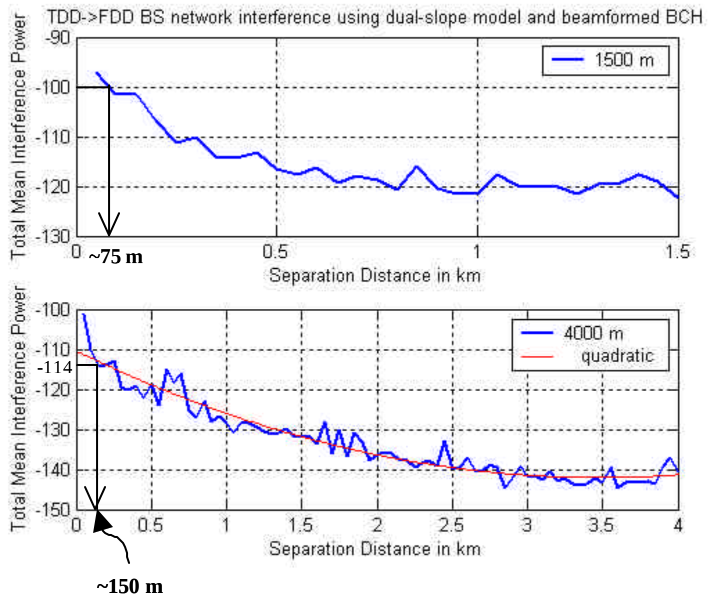


Figure 19 also shows a quadratic fit to the rural scenario (4 km cell radius).

Using these figures, the amount of additional isolation (if needed) for any deployment scenario can be read from the graphs. The distances for threshold values are included in the graphs. As an example for other distances, one could notice that in the case of omnidirectional broadcast channel (Figure 18) in rural areas, approximately 4 dB of additional isolation is required on the average if the victim and the closest interferer are 1 km away from each other.

5.2.6 Effect of adaptive antennas in the uplink

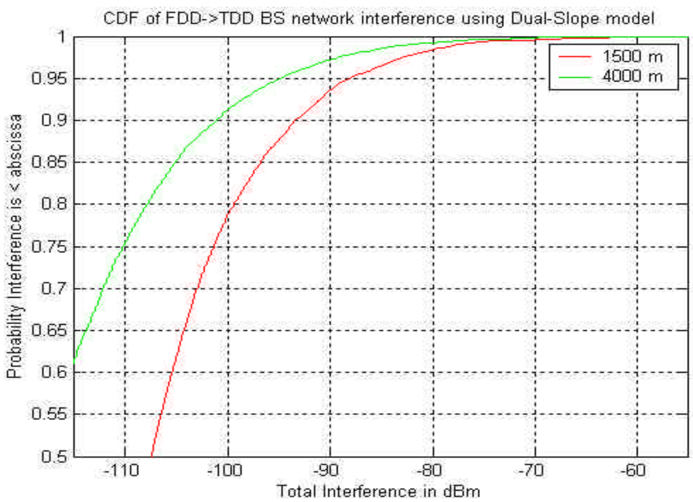
In the case of uplink beamforming at the base station (TDD/AA being the victim), spatial signatures used in the process of forming the beam in the direction of the intended users are uniquely attributed to the propagation environment from the intended user to the base station. These signatures, therefore, could be significantly different from that of an interfering station a distance away, thus the victim being affected by less or no additional gain from the direction of the interferer. This effect, however, has not been introduced in the simulations and full array gain has been applied to the interferer; i.e., worst case.

With the use of AA, in band energy due to out-of-band transmissions by other base stations are not coherently received at the AA. This reduces the gain towards the adjacent band interferers relative to the main beam, thus lowering the amount of interference power into the uplink of the TDD base station.

The effect of an FDD network of 19 cells on a TDD BS with AA was examined. Figure 20 depicts the outcome using dual-slope propagation model.

FIGURE 20

Likelihood of interference as a function of cell radius due to a network of FDD base stations into a single TDD/AA base station, using dual-slope propagation model



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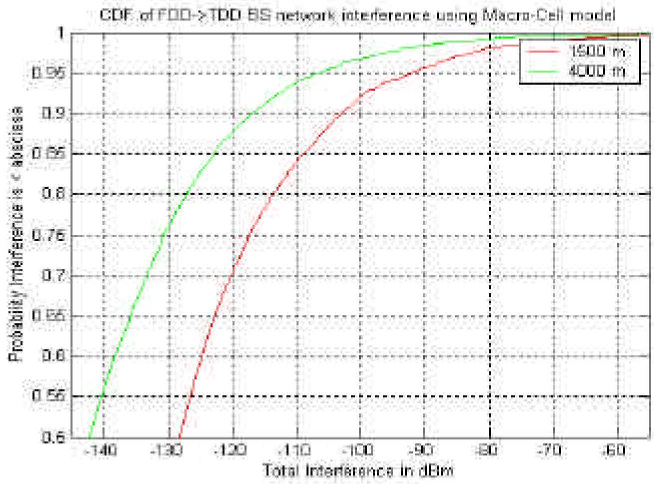
The additional isolation required to achieve the 98% protection level is tabulated in 5.2.7. A more realistic propagation model for non-LOS situations, such as the one introduced in (2) [1], produces the results shown in Figure 21.

FIGURE 21

Likelihood of interference as a function of cell radius due to a network of FDD base stations into a single TDD/AA base station, using macrocell [1] propagation model

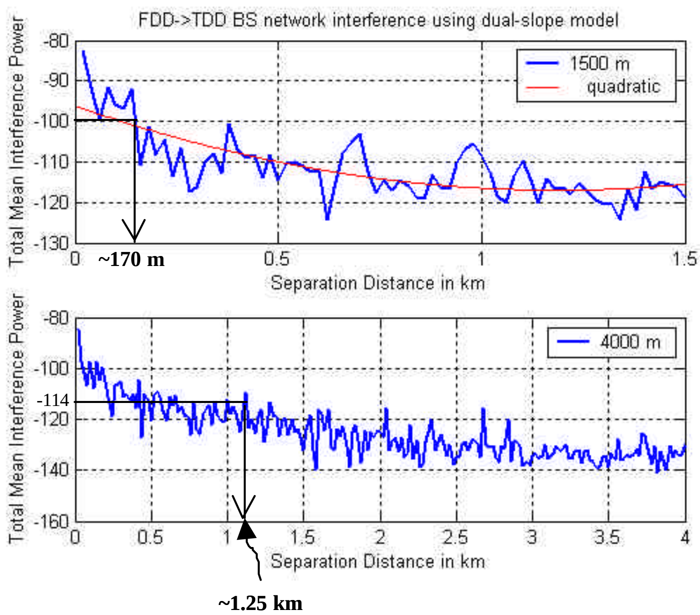


Using the interference protection criterion, safe coexistence is feasible at least 90% of the time for both urban and rural cells.

5.2.6.1 Separation distance

An analysis similar to the one described in section 5.2.5.1 was also performed for the case of TDD BS being the victim surrounded by a network of 19 interfering FDD base stations on the adjacent channel. Figure 22 depicts the results.

FIGURE 22



5.2.7 Cost Analysis

In order to quantify the impact of the cost of AA on deployment of IMT-2000 systems, a scenario involving adaptation of a typical AA implementation for a WCDMA system was considered. The deployment area was San Francisco Bay Area comprising of both dense and light urban morphologies. Appendix D contains more details about the analysis and shows reduction in the total cost of the deployment. Based on the analysis, the number of base stations are reduced by 49% while the total cost is reduced by 24%. The WCDMA deployment is based on a theoretical design not a working system. The number of cell sites for both baseline and AA case may not be realized in an actual deployment.

It should be noted that a similar analysis on IMT-2000 TDD system is likely to yield more cost savings since the increase in performance is even greater for TDD.

5.2.8 Summary of results

The following table summarizes the results for macro BS-BS interference and shows the additional isolation required in less than 2% of the time in rural and urban areas using the dual-slope propagation model. The additional isolation needed for coexistence, if necessary, is at a level that can be easily achieved by other coexistence-friendly site engineering practices.

TABLE 2

Summary of macrocell BS-BS interference with AA and additional isolation required

Scenario	Total Interference Power exceeded less than 2% of the time (dBm) for Rural [1]	Additional Isolation Required less than 2% of the time (dB) for Rural [2]	Total Interference Power exceeded less than 2% of the time (dBm) for Urban [1]	Additional Isolation Required less than 2% of the time (dB) for Urban [3]
TDD/AA Downlink[4]	–100	4 - 12	–88	7 – 12
TDD/AA Uplink	–88	18 to 26	–77	18 – 23

[1] Assuming Dual-Slope propagation model.
[2] Assuming –114 to –106 dBm maximum tolerated interference level [3], cell radius 4 km.
[3] Assuming –100 to –95 dBm maximum tolerated interference level [3], cell radius 1.5 km.
[4] These results are for beamformed broadcast channels.

The radio site engineering solutions proposed in this report is of interest to network engineers. The calculated results are based on theoretical system design. It assumes that mobile and base stations are uniformly distributed in the grid like system with uniform down tilting, perfect power control and same radiation centres, which come from [IMT.COEXT]. There are wide set of variants in an actual system layout. The interference mechanism in the simulation seems to be controlled and systematic which is very different in an actual system deployment. When TDD and FDD users are non-uniformly distributed the results would be different.

In case the adaptive antenna implementation at the TDD BS leaves the broadcast channel as omnidirectional, additional interference is being generated into the uplink of the FDD BS, as captured by Figure 17. Statistically, this approach to AA implementation increases the level of interference, thus increasing the additional isolation required. The second approach to broadcast channel implementation, however, does not change the results of the above table. Also, the broadcast channel implementation does not affect the FDD BS to TDD BS scenario.

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5.2.8.1 Trade offs on cost and complexity with adaptive antennas

The adaptive antenna can bring very high theoretical efficiency in interference mitigation. However, the use of such techniques involves tradeoffs that need to be taken into consideration at the time of deployment. Some of the tradeoff issues are listed below.

1) Higher deployment cost

- The cost of mounting and deploying adaptive antennas could be higher than conventional systems due to multiple antennas and multiple feeding cables, specially compared to basic configuration of conventional base stations where diversity is not used. For example, a 10-element array needs 10 cables to the base station. However, in urban and dense urban areas where conventional base stations are likely to have receive and/or transmit diversity due to coverage and capacity demands, the difference between AA and non-AA requirements could be negligible. If an array is used for each sector for better performance, then the number of cables increase accordingly and tower loading issues need to be considered.

2) Higher equipment cost

- With AA, one power amplifier is required for each antenna. The cost will not go up linearly but will be higher than conventional panel antennas. Also, extra DSP processing power for spatial processing is required. These factors will increase the cost of the AA base station. However, this additional per-BS cost may become offset by the less number of BSs required to serve a certain area or by the larger number of subscribers that could be served. The actual amount of gain and cost would depend on the implementation of the AA on a specific technology (i.e., TDD vs FDD).

3) Performance

- The actual performance of adaptive antennas in increasing coverage and capacity of cellular systems is mainly dependent on the implementation of their adaptation algorithm. Also, the performance varies with environment (urban vs suburban) and technology (TDD vs FDD). It should, however, be noted that the analysis presented here does not assume any specific implementation of AA and merely looks at the side benefits of it for mitigation purposes.

The side benefit of Adaptive antenna in solving coexistence problems may result in reduction, but not an elimination of interference, and with TDD/FDD any interference can be substantial. The analysis presented here assumes that interference cancellation capabilities of the AA are used to suppress intra-system interference. In reality, those capabilities could also be used for inter-system interference mitigation, as is the subject of this report. In such cases, although better results than reported here would be achieved, the system performance would suffer from both coverage and capacity point of view. Adaptive antenna by the nature of the aperture sizes and complexity allowed will have side and back lobes. Additionally, scattering in an urban environment may degrade the performance in the main lobe.

5.3 Effect of improved BS or MS equipment specifications

5.3.1 Effects of BS filtering and linearization

Editor's note: references are needed for the performance numbers and cost numbers mentioned in this section.

Linearization techniques or added filtering or their combination may improve TDD out of band emissions.

Linearized PA’s can enhance ACLR from its baseline of 45dBc by approximately 18dB, to 63dBc. Cavity filters with 6 or 8 sections can additionally provide 30 or 58dB of ACLR improvement respectively. With group delay compensation the filter contribution to EVM is well within budget (<5%).

The added cost of the BS is expected to vary from $500-$1500(US), depending on the specific combination and its implementation.

Base station receive filters may be deployed to provide for antenna duplexing and receiver interference mitigation. These filters can be grouped into two basic classes of filters: Low cost and typical. Both are full band receive filters. Low cost filters are of similar construction to duplexing filters used in MS and are therefore very low cost moderate performance filters. The typical filters are filters currently available on the commercial market for UMTS duplexing and receive band protection. In all cases the filter bandwidth has been increased to ensure adequate performance in the receive band without the necessity for equalization. Effects of equalization techniques and partial band filters (e.g. 15MHz) on filtering are for further study.

Typical expected performance for these filter types is shown in the following table.

TABLE 3

		Rejection (dB)			
Filter Type	**Typical Application**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
Low Cost	Pico BS	1	6	12	18
Typical	Macro/Micro BS	1	10	25	50

5.3.1.1 Effects of improved TDD out-of-band performance

A summary of the 3GPP-RAN TDD out of band emission requirements are given below.

TABLE 4

Summary of the 3GPP-RAN TDD out-of-band emission requirements

TDD BS class	**Adjacent Carrier spacing of 5 MHz**	**Alternate Carrier spacing of 10 MHz**	**Other Carrier spacing of ?15 MHz**
Local Area (LA)	ACLR, –23 dBm	ACLR, –36 dBm	Spurious, –40 dBm
Wide Area (WA)	ACLR, –36 dBm	ACLR, –33 dBm	Spurious, –43 dBm

Given the allowed external interference levels in [3], the following MCL is required.

Editor’s note: Numbers in TABLE 5 below need to be updated according to changes in TABLE 4 above.

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TABLE 5

Required MCL

Scenario	**Allowed Iext, dBm**	**TDD BS class**	**Carrier Spacing, MHz**	**MCL range**	
				From	**To**
Macro, rural	–114 to –106	WA	5	81	73
		WA, LA	10	78	70
		WA, LA	? 15	74	66
Macro, downtown	–100 to –95 dBm	WA	5	67	62
		LA	5	77	72
		WA, LA	10	64	59
		WA, LA	? 15	60	55
Outdoor micro	–97 to –90 dBm	WA	5	64	57
		LA	5	74	67
		WA, LA	10	61	54
		WA, LA	? 15	57	50
In building pico	–85 dBm	LA	5	62	62
		LA	10	49	49
		LA	? 15	45	45

As can be seen, an MCL of 72 dB in adjacent carriers is sufficient for all deployment in scenarios except for macro rural.

5.3.1.2 Effect of tightened TDD specifications on required coupling

In the following we have considered the effects of power amplifier (PA) linearization techniques and filtering techniques on TDD out of band emissions in adjacent band and the resulting required coupling. The baseline is considered the 45dBc of the general-purpose base station.

Using these techniques the required MCL can be much reduced as listed in the table below. In many cases the required adjacent channel MCL will be below 30dB. The required MCL for alternate (10MHz) or greater spectral distance is for further study but is expected to be generally lower. Alternatively simpler filters may be used.

TABLE 6

Case	TX power	Inherent ACLR	Linearisation	6-section	8-section	ACP	Iext	MCL	Iext	MCL
Rural	43	45	18		58	-78	-114	36	-106	28
Downtown	34	45			58	-69	-100	31	-95	26
Downtown	34	45	18	30		-59	-100	41	-95	36
Outdoor Micro	34	45	18	30		-59	-97	38	-90	31
Outdoor Micro	34	45			58	-69	-97	28	-90	21
Pico	27	45	18			-36	-85	49	-85	49
Pico	24	45		30		-51	-85	34	-85	34

NOTE - Empty entries in the “Linearisation”, “6-section” or “8-section” columns signify that the technique is not used in the specific configuration.

5.3.1.3 Effects of FDD receiver filtering on allowed TDD base station TX power deployed in the same geographical area

Based on the specified FDD ACS and blocking performance of 25.105 the allowable interference levels for interference equal to Iext has been calculated.

The FDD ACS and blocking performance will dictate the allowed TDD Tx power when operating in same geographic area with MCL of 72dB. The following table summarizes the TDD power limitations with and without additional input filters:

TABLE 7

Allowed TDD TX Power for deployment in the same geographical area

			TDD TX power, dBm		
	TDD Band, MHz	FDD ACS/Blocker dBm	WG4 Specified FDD RX (no external filter)	With low Cost filter	With typical filter
Macro, Rural	Adjacent (5 MHz)	-61 – -69	12 – 3	NA	13 – 4
(Iext = -114 to -106dBm)	10 MHz	-44.5 – -48.5	27.5 – -23.5	NA	37.5 – 33.5
	15 MHz	-44.5 – -48.5	27.5 – -23.5	NA	>43
	20 MHz	-44.5 – -48.5	27.5 – -23.5	NA	>43
Macro, Downtown	Adjacent (5 MHz)	-51 – -55	21 – 17	NA	22 – 18
(Iext = -100 to -95dBm)	10 MHz	-40 – -41.5	32 – 30.5	NA	42 – 40.5
	15 MHz	-40 – -41.5	32 – 30.5	NA	>43
	20 MHz	-40 – -41.5	32 – 30.5	NA	>43
Outdoor micro	Adjacent (5 MHz)	-45 – -50	27 – 22	28 – 23	28 – 23
(Iext = -97 to -90dBm)	10 MHz	-36 – -39	36 –33	42 – 39	>43
	15 MHz	-36 – -39	36 – 33	>43	> 43
	20 MHz	-36 – -39	36 – 33	>43	>43
In building pico	Adjacent (5 MHz)	-40	32	33	33
(Iext = -85dBm)	10 MHz	-34	39	> 43	> 43
	15 MHz	-34	39	> 43	> 43
	20 MHz	-34	39	> 43	> 43

As can be seen, where the TDD TX power is limited by blocker requirements (which is everywhere except for the adjacent band) the TDD TX power is greater than 33.5 dB for a Typical filter and not limited (>43 dBm) for a High Performance filter. In the adjacent band TDD TX power is limited by requirements of the FDD receiver. For in building pico the TX power is limited to 32 dBm, with no additional filtering. All TDD deployments are practical when High Performance filters are used to protect the FDD receiver, with TDD TX power >43 dB for all deployments except for Macro, Rural.

In many cases the allowed TX power exceeds the requirements and can be traded off against reduced coupling loss requirements.

5.3.2 Effects of MS filtering and linearization

Editor's note: Text required.

5.4 Effects of other techniques

5.4.1 Effects of using power control

Section 4.4.1 describes the benefits of using DL power control in TDD systems. In addition to increasing system capacity, power control also provides added immunity to DL interference as the BS can flexibly allocate power to a victim MS. In particular the interference of an FDD MS (UL) to an adjacent TDD MS (DL) can be mitigated using the power control.

Editor's note: In the following sentence referring to [3], mention of the related section number in [3] is required for clarity.

In previous work [3] the worst-case scenario has been found to be that of the pico TDD deployment (indoor) in the presence of FDD mobiles serviced by a macro, over the rooftop BS. This section brings the results and conclusion of Monte Carlo analysis that has been run for the scenario with and without power control.

The assumptions, methodology and path loss rules used to evaluate the effects of power control are described in appendices E and F.

5.4.1.1 Results

Table 8 shows the average outage rate and other relevant statistics for the four simulation cases.

TABLE 8

Global statistics

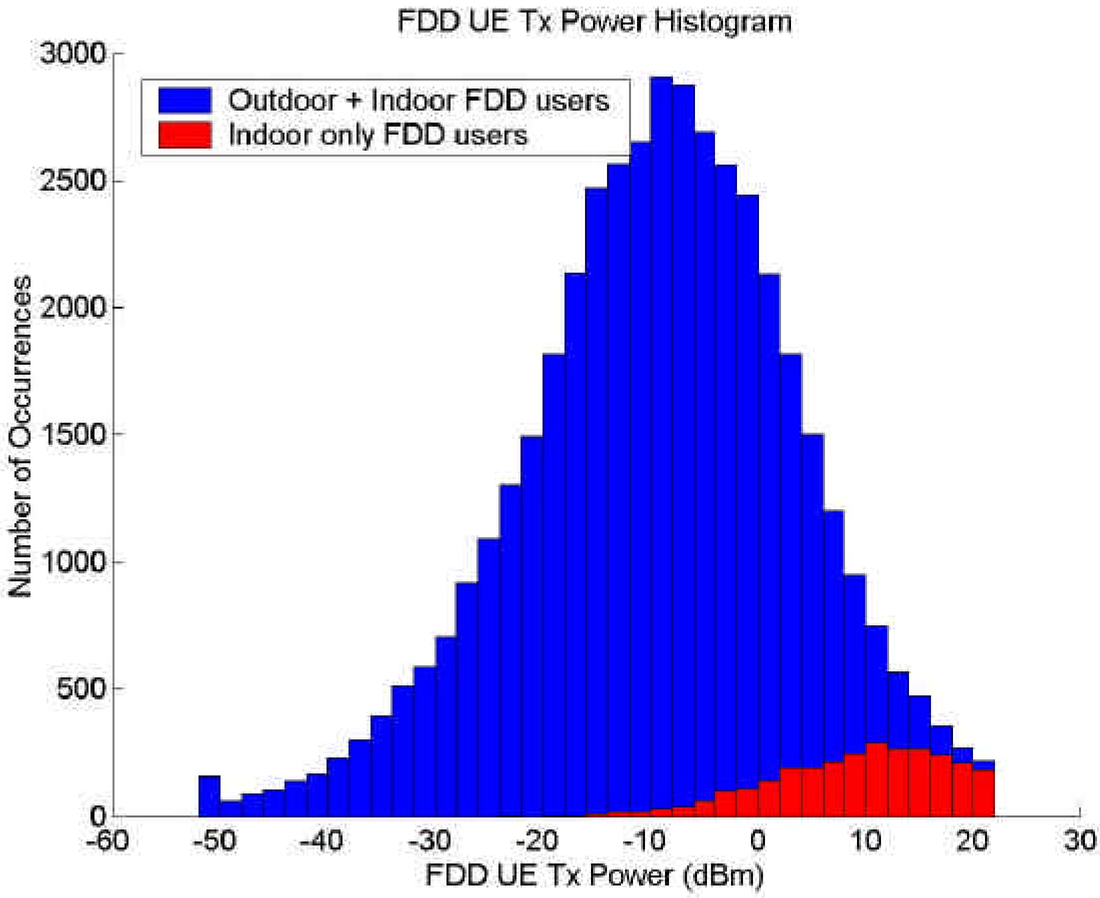
Case	TDD power control	FDD MS ACLR (dB)	TDD MS ACS (dB)	TDD load	FDD load	FDD BS average noise rise (dB)	Indoor FDD outage (%)	TDD outage (%)
1	OFF	? ?	? ?	72	? ?	? ?	? ?	**1.80**
2	OFF	33	33	72	110	6.3	11.8	**2.04**
3	ON	? ?	? ?	160	? ?	? ?	? ?	**2.28**
4	ON	33	33	160	110	6.3	11.8	**2.33**

It is apparent that the overall impact of the FDD users on the TDD system is weak, even when the TDD system does not use power control. This conclusion is in line with previous results that show negligible effect on capacity and outage as a whole. Note that the TDD load under power control has been adjusted to yield the same outage as without PC.

Figure 23 shows the distribution of the transmission powers of the active (i.e. not dropped) FDD users as well as of the indoor FDD mobiles only. It can be seen from the graph that these indoor mobiles transmit at high power close or near to their maximum, which causes the high FDD outage indoor. Had the fixed penetration loss of the building been increased to higher values, the percentage of indoor FDD users in outage (and thus non-active) would have increased and the impact to the TDD system would not have been worse. Note also that as another worst-case assumption it has been assumed that the time average of the MS power over time can equal its maximum power. In fact this cannot be true due to the fading margin.

FIGURE 23

Distribution of transmission powers of active indoor FDD mobiles



Editor's note: The above graph to be provided in greyscale to make it readable in black and white printing.

5.4.1.2 Statistics as a function of distance from the closest FDD mobile

In order to assess if this is a problem, statistics of the probability of outage as a function of the distance to the closest active indoor FDD mobile are collected for cases 2 and 4 where FDD mobiles were aggressing the TDD mobiles. The result is shown graphically in Figure 24.

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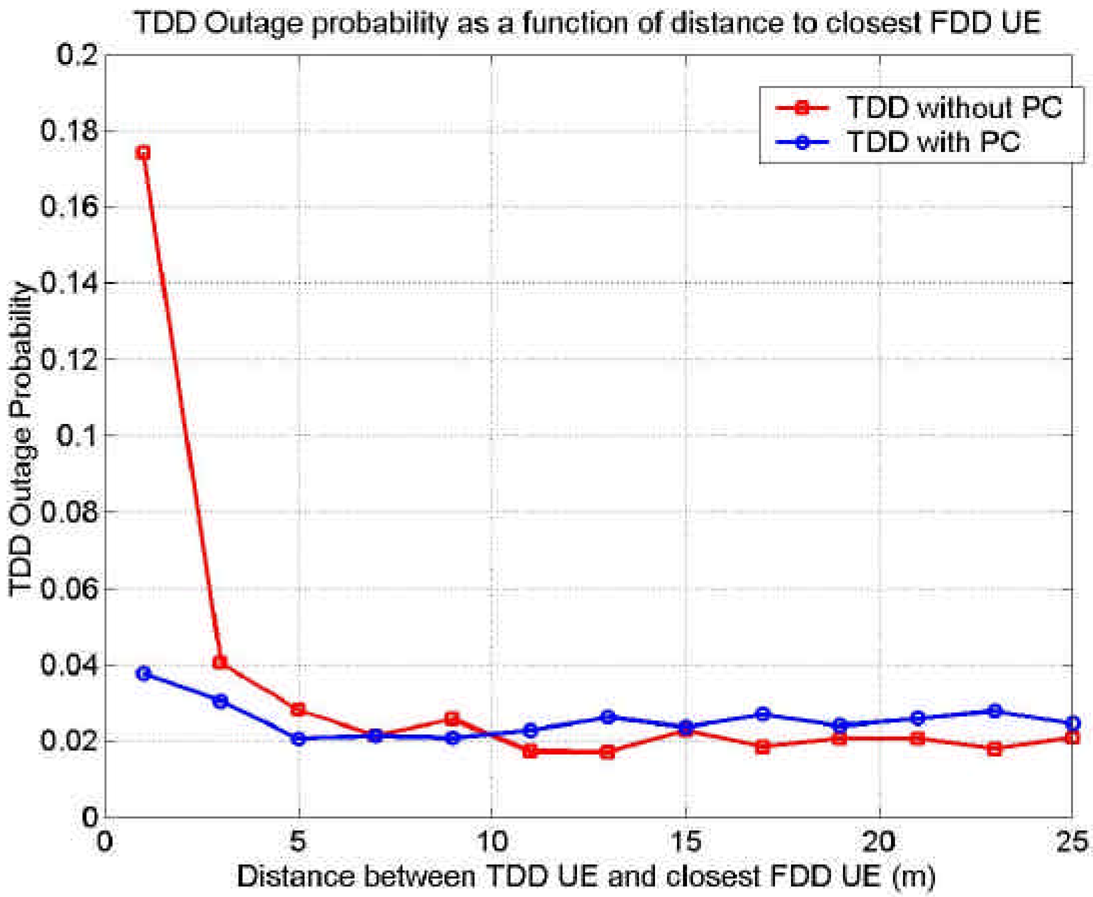
FIGURE 24

TDD outage probability as a function of distance from the closest indoor FDD mobile



Editor's note: The above graph to be provided in greyscale to make it readable in black and white printing. Also, UE be changed to MS in the figure.

The graph shows that when power control is not used in the TDD system, the outage probability of TDD mobiles becomes significantly larger for distances of 2 meters or less (although the likelihood of failure is still below 20%). When power control is activated, the phenomenon almost disappears. The outage probability becomes practically independent of the distance from an active FDD mobile.

This behavior should not be surprising. The power control of TDD, by allowing the users aggressed by an interferer (such as an FDD mobile) to use more power, spreads the effect of this interference to the whole system (since the power used to compensate for the additional interference is no longer available for other users). As a result, the individual user performance is spared at the price of an insignificant system capacity degradation.

Therefore, we can say that power control is an efficient technique for mitigating the effects of mobile-to-mobile interference.

5.4.1.3 Conclusion

This work has shown that FDD mobiles operating in an area covered by a TDD system do not significantly degrade the individual performance of TDD users served by this system under realistic conditions. There is no knock-out effect from the FDD users even if they are transmitting at high power at short distance from TDD users.

Editor's note: The following two paragraphs in square brackets are not finalized.

[Specifically, no impact on the overall capacity or outage could be measured in a pessimistic scenario where a higher-than-normal density of FDD mobiles would transmit at a high power in the band adjacent to the TDD band when the TDD system was using ordinary power control. In terms of individual performance of TDD users, the impact was found to be negligible even for small separation (1 meter) between the TDD and FDD mobiles.

In addition, the work has shown that TDD power control proves to act as an effective mitigation technique with respect to potential aggressions from FDD mobiles to TDD mobiles.]

6 Considerations for combining mitigation techniques

Editor's Note: This section discusses the issues related to using certain mitigation techniques in combination with others, for one specific scenario, e.g. MS-MS or BS-BS, or a combination of mitigation techniques applied collectively.

7 Conclusions

8 References

[1] ETSI TR 125 942 V4.0.0 (2001-09), Technical Report, "Universal Mobile Telecommunications Systems (UMTS); RF System Scenarios".

[2] 3GPP TR 25-952.

[3] "Draft New Report ITU-R M.[IMT.COXT] on the Coexistence between IMT-2000 TDD and FDD Radio Interface Technologies Operating in Adjacent Bands and in the Same Geographical Area", ITU-R WP 8F, Attachment 7.12 to chairman's report of the 7th meeting of the Working Party 8F, 27 February to 5 March 2002, Queenstown, New Zealand.

[4] "Antenna-to-Antenna Isolation Measurements", TSGR4#8(99)631, 26 October 1999.

[5] Polarization in Electromagnetic Systems, Warren L. Stutzman, Chapter 7 Dual-Polarized Systems, Artech House, 1993.

[6] "Electronic Isolation of Collocated Horizontally and Vertically Stacked Antennas", EMS Wireless, 1999.

[7] TS 25.104.

[8] UMTS 30-03 "UMTS 30.03, "Selection procedures for the choice of radio transmission technologies of the UMTS", v. 3.2.0".

[9] ETSI TS 25 104 V4.2.0 (2001-9).

[10] Rappaport, T S, Wireless Communications – Principles and Practice, Prentice Hall, 1996.

[11] 3GPP TS 25.221 V3.10.0 (2002-03), "Physical Channels and Mapping of Transport Channels onto Physical Channels (TDD)", Release 99.

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Appendix A

Local Area (LA) and Wide Area (WA) base station performance requirements

(From 25.105 v5.1.0, reproduced here for the convenience of the reader)

6.6.2.2.2.1 3,84 Mcps TDD Option

6.6.2.2.2.1.2 Additional requirement for operation in the same geographic area with FDD on adjacent channels

In case the equipment is operated in the same geographic area with a FDD BS operating on the first or second adjacent channel, the adjacent channel leakage power shall not exceed the limits specified in Table 6.8AA.

TABLE 6.8AA

Adjacent channel leakage power limits for operation in the same geographic area with FDD on adjacent channels

BS Class	BS Adjacent Channel Offset	Maximum Level	Measurement Bandwidth
Wide Area BS	± 5 MHz	–36 dBm	3,84 MHz
Wide Area BS	± 10 MHz	–36 dBm	3,84 MHz
Local Area BS	± 5 MHz	–23 dBm	3,84 MHz
Local Area BS	± 10 MHz	–33 dBm	3,84 MHz

NOTE – The requirements in Table 6.8AA for the Wide Area BS are based on a coupling loss of 74 dB between the FDD and TDD base stations. The requirements in Table 6.8AA for the Local Area BS ACLR1 (± 5 MHz channel offset) are based on a relaxed coupling loss of 87 dB between TDD and FDD base stations. The requirement for the Local Area BS ACLR2 (± 10 MHz channel offset) are based on a relaxed coupling loss of 77 dB between TDD and FDD base stations. The scenarios leading to these requirements are addressed in TR 25.942 [4].

If a BS provides multiple non-contiguous single carriers or multiple non-contiguous groups of contiguous single carriers, the above requirements shall be applied to those adjacent channels of the single carriers or group of single channels which are used by the FDD BS in the same geographic area.

6.6.2.2.3 Additional requirement in case of co-siting with nsynchronized TDD BS or FDD BS operating on an adjacent channel

6.6.2.2.3.1 3,84 Mcps TDD Option

6.6.2.2.3.1.2 Additional requirement in case of co-siting with FDD BS operating on an adjacent channel

In case the equipment is co-sited to a FDD BS operating on the first or second adjacent channel, the adjacent channel leakage power shall not exceed the limits specified in Table 6.9AA.

TABLE 6.9AA

Adjacent channel leakage power limits in case of co-siting with FDD on an adjacent channel

BS Class	BS Adjacent Channel Offset	Maximum Level	Measurement Bandwidth
Wide Area BS	± 5 MHz	–80 dBm	3,84 MHz
Wide Area BS	± 10 MHz	–80 dBm	3,84 MHz

NOTE – The requirements in Table 6.9AA are based on a minimum coupling loss of 30 dB between base stations. The co-location of different base station classes is not considered. A co-location requirement for the Local Area TDD BS is intended to be part of a later release.

If a BS provides multiple non-contiguous single carriers or multiple non-contiguous groups of contiguous single carriers, the above requirements shall be applied to those adjacent channels of the single carriers or group of single channels which are used by the co-sited FDD BS.

Co-existence with UTRA-FDD

6.6.3.4.1 Operation in the same geographic area

This requirement may be applied to geographic areas in which both UTRA-TDD and UTRA-FDD are deployed.

6.6.3.4.1.1 Minimum requirement

For TDD base stations which use carrier frequencies within the band 2 010-2 025 MHz the requirements applies at all frequencies within the specified frequency bands in Table 6.16.
For 3.84 Mcps TDD option base stations which use a carrier frequency within the band 1 900-1 920 MHz, the requirement applies at frequencies within the specified frequency range which are more than 12,5 MHz above the last carrier used in the frequency band 1 900-1 920 MHz.
For 1.28 Mcps TDD option base stations which use carrier frequencies within the band 1 900-1 920 MHz, the requirement applies at frequencies within the specified frequency range which are more than 4 MHz above the last carrier used in the frequency band 1 900-1 920 MHz.

The power of any spurious emission shall not exceed.

TABLE 6.16

BS Spurious emissions limits for BS in geographic coverage area of UTRA-FDD

BS Class	Band	Maximum Level	Measurement Bandwidth
Wide Area BS	1 920-1 980 MHz	–43 dBm (*)	3,84 MHz
Wide Area BS	2 110-2 170 MHz	–52 dBm	1 MHz
Local Area BS	1 920-1 980 MHz	–40 dBm (*)	3,84 MHz
Local Area BS	2 110-2 170 MHz	–52 dBm	1 MHz

(*) For 3.84 Mcps TDD option base stations, the requirement shall be measured with the lowest center frequency of measurement at 1 922.6 MHz or 15 MHz above the last TDD carrier used, whichever is higher. For 1.28 Mcps TDD option base stations, the requirement shall be measured with the lowest center frequency of measurement at 1 922.6 MHz or 6.6 MHz above the last TDD carrier used, whichever is higher.

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NOTE – The requirements for Wide Area BS in Table 6.16 are based on a coupling loss of 67 dB between the TDD and FDD base stations. The requirements for Local Area BS in Table 6.16 are based on a coupling loss of 70 dB between TDD and FDD Wide Area base stations. The scenarios leading to these requirements are addressed in TR 25.942 [4].

6.6.3.4.2 Co-located base stations

This requirement may be applied for the protection of UTRA-FDD BS receivers when UTRA-TDD BS and UTRA FDD BS are co-located.

6.6.3.4.2.1 Minimum requirement

For TDD base stations which use carrier frequencies within the band 2 010-2 025 MHz the requirements applies at all frequencies within the specified frequency bands in Table 6.17.
For 3.84 Mcps TDD option base stations which use a carrier frequency within the band 1 900-1 920 MHz, the requirement applies at frequencies within the specified frequency range which are more than 12,5 MHz above the last carrier used in the frequency band 1 900-1 920 MHz.
For 1.28 Mcps TDD option base stations which use carrier frequencies within the band 1 900-1 920 MHz, the requirement applies at frequencies within the specified frequency range which are more than 4 MHz above the last carrier used in the frequency band 1 900-1 920 MHz.

The power of any spurious emission shall not exceed.

TABLE 6.17

BS Spurious emissions limits for BS co-located with UTRA-FDD

BS Class	Band	Maximum Level	Measurement Bandwidth
Wide Area BS	1 920-1 980 MHz	–80 dBm (*)	3,84 MHz
Wide Area BS	2 110-2 170 MHz	–52 dBm	1 MHz

(*) For 3.84 Mcps TDD option base stations, the requirement shall be measured with the lowest center frequency of measurement at 1 922.6 MHz or 15 MHz above the last TDD carrier used, whichever is higher. For 1.28 Mcps TDD option base stations, the requirement shall be measured with the lowest center frequency of measurement at 1 922.6 MHz or 6.6 MHz above the last TDD carrier used, whichever is higher.

NOTE – The requirements in Table 6.17 are based on a minimum coupling loss of 30 dB between base stations. The co-location of different base station classes is not considered. A co-location requirement for the Local Area TDD BS is intended to be part of a later release

Appendix B

Deployment based MCL calculations

Introduction

The following presents the results of an investigation aiming at determining the appropriate value for the minimum coupling loss between a macro BS and a micro or pico BS in different scenarios:

a) Macro, downtown BS in proximity of in building pico BS.

b) Macro, downtown BS in proximity of outdoor micro BS.

General approach

For the purpose of determining the ACLR requirement of the micro or pico BS, the minimum coupling loss between a macro, downtown BS and a micro or pico BS may be defined as the value that is exceeded with a probability of 90%, recognizing that the remaining cases (where the coupling loss is lower) should be addressed by operator coordination. This probability must take into account the generally higher density of micro or pico BSs compared to macro BSs.

To take this fact into account it is assumed that a Macro, downtown BS is surrounded by a larger number of micro or pico BSs placed at typical distance from each other. The position of the macro BS relative to the arrangement of micro or pico BSs is random. For each position of the macro BS, the smallest coupling loss to any of the surrounding micro or pico BSs is recorded, and a distribution of coupling loss is obtained by varying the position of the macro BS.

Macro, downtown BS and in building pico BS

Scenario

This scenario is depicted in the Figure B-1. In building pico BSs are located inside blocks arranged according to a Manhattan grid where the road width is 15 m and the block size is 110 m. The macro, downtown BS is assumed to be located on top of the center block at a random location within the green (shaded) area. In building pico BSs can potentially be present in every building, and up to the highest floor. There are up to four in building pico BSs per floor, and the height difference between the in building pico BSs on the highest floor and the macro, downtown BS is assumed to be 15 m. It is also assumed that there is another grid of in building pico BS at a lower floor with a height difference of 23 m.

In the calculations there may not be an in building pico BS at every location of the grids.
The number of in building pico BS's that are actually present (density) is a parameter. For each trial a subset of locations for the in building pico BS's is randomly selected along with a position for the macro, downtown BS within the green area shown below.

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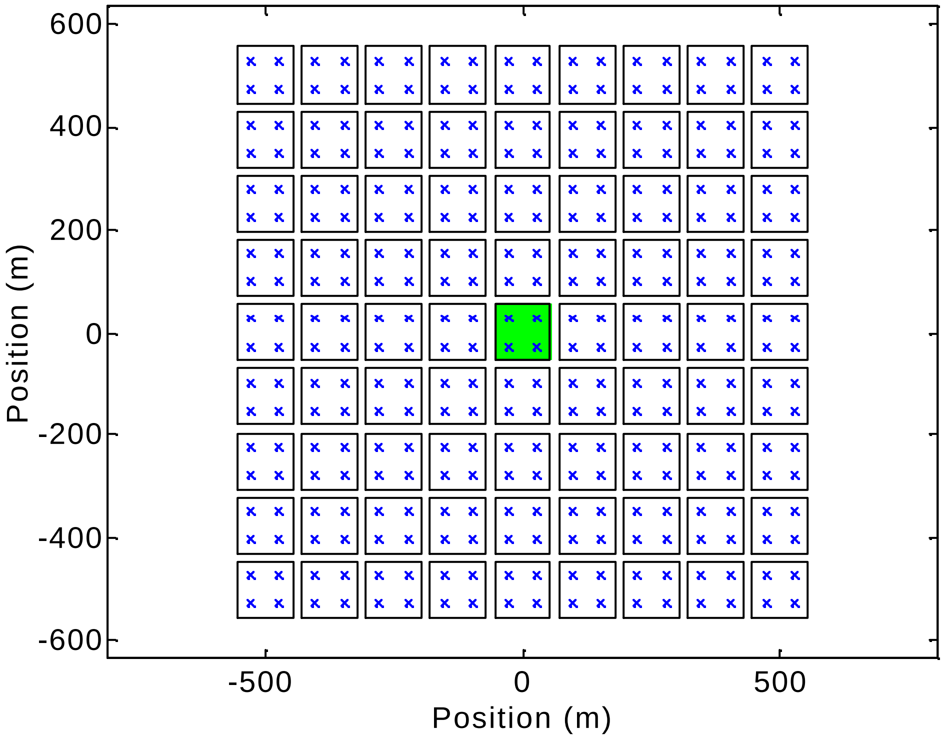
FIGURE B-1

Assumed deployment scenario for Macro, downtown BS and in building pico BS in proximity. The crosses are possible locations for the in building pico BS's. The macro, downtown BS may be anywhere within the green area



Propagation model

Free space propagation loss added to building penetration loss of 10 dB is assumed between the macro, downtown and the in building pico BSs. Frequency is 2.6 GHz.

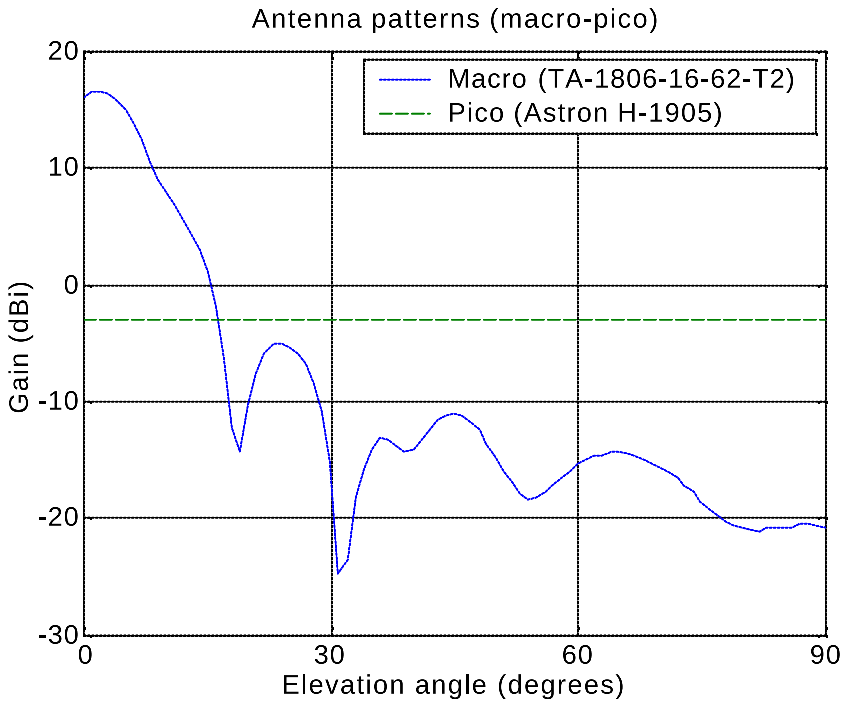
$$PL(d) = 38.1 + 20 \log10(d \text{ in meters}) + 10 \text{ dB}$$

Antenna patterns

Figure B-2 shows the antenna patterns assumed for the analysis. The macro antenna (Tiltek) has a downtilt of 2 degrees and a gain of 16.5 dBi. The pico antenna (Astron H-1905) has a gain of less than –3 dBi for the relevant elevation angles. These data are available from the Internet site of the manufacturers.

FIGURE B-2

Assumed antenna patterns for the Macro, downtown BS/in building pico BS



Coupling loss results

Coupling loss between a pair of BSs is obtained by subtracting the gains of the antennas from the feeder losses and propagation loss. Variations in azimuth of the gain of the macro, downtown BS are ignored (i.e. it is assumed that the in building pico BS is always in the direction of the maximum gain in azimuth). Feeder losses are assumed to be 3 dB for both BSs combined. The distribution of the coupling loss between the macro, downtown BS and the most coupled in building pico BS is shown in Figure B-3 below.

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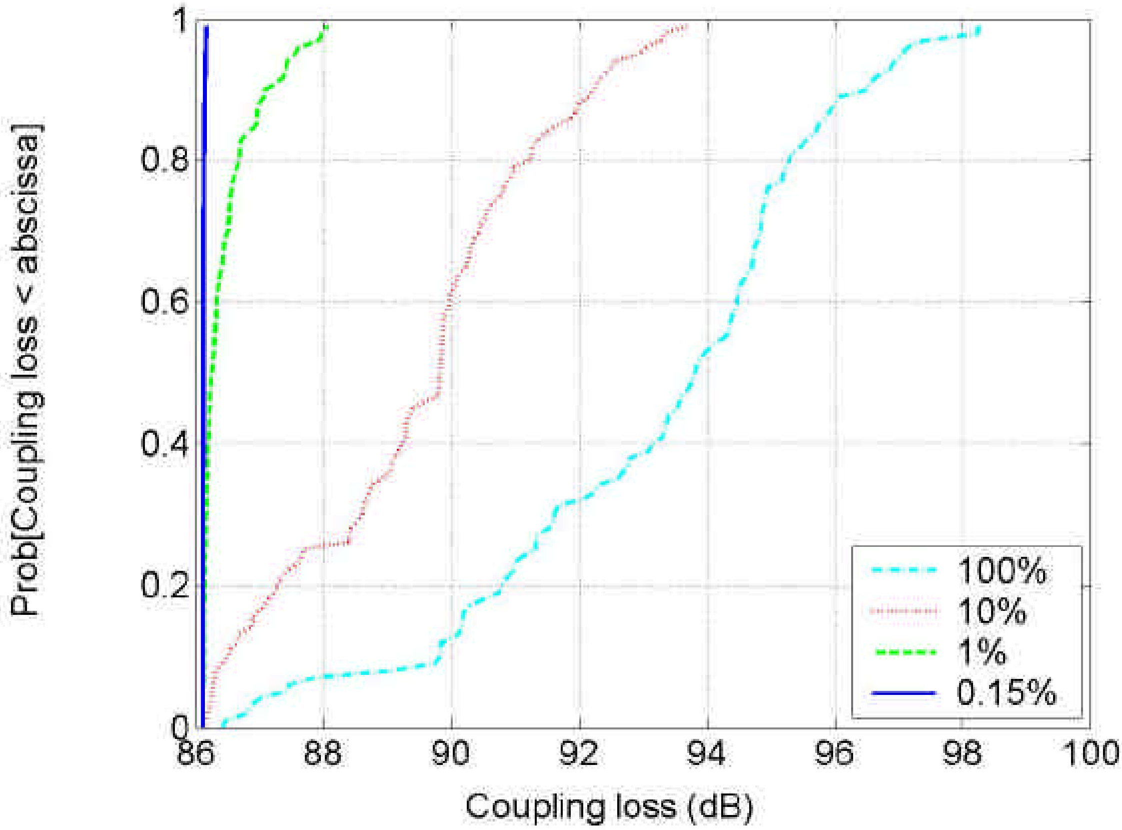
FIGURE B-3

Distribution of the coupling loss between the macro, downtown BS and the most coupled in building pico BS, for different densities of in building pico BS's (100% corresponds to a full grid)



The obtained minimum coupling loss is around 86 dB. Assuming feeder losses of 4 dB (instead of 3 dB) would increase that figure by 1 dB.

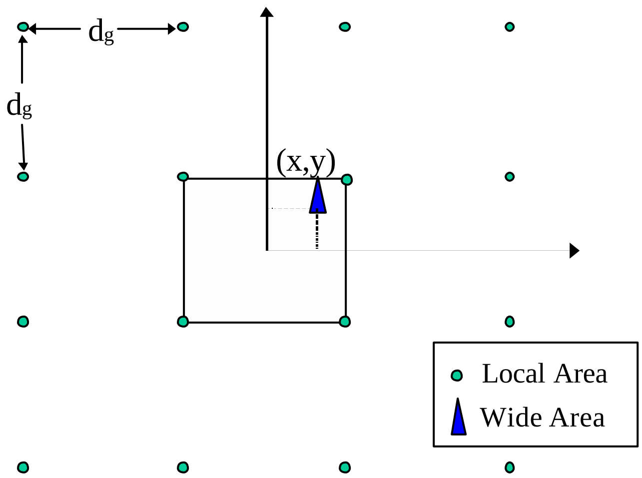
Macro, downtown BS and outdoor micro BS

Scenario

This scenario is represented in Figure B-4 below, where (without loss of generality) the outdoor micro BSs are deployed along a square grid of spacing d_g = 200 m. The macro, downtown BS is located in a certain position (x, y) with respect to the center of this arrangement.

FIGURE B-4

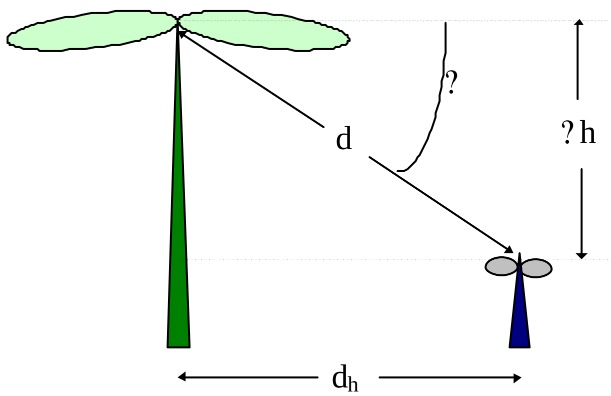
Assumed deployment scenario for Macro, downtown BS and outdoor micro BS in proximity



The situation in the vertical plane is illustrated in Figure B-5. The height difference between the outdoor micro BS and macro, downtown BS antennas is ? h = 25 m, and these antennas see each other at an elevation angle of ? = arctan(? h / d_h) where d_h = ? $[(x-x_l)^2+?y-y_l)^2]$ and (x_l, y_l) are the coordinates of the outdoor micro BS.

FIGURE B-5

Illustration of the scenario in the vertical plane



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Propagation model

Two path loss models may be considered for this scenario. The simplest model is the free space path loss as in the macro/pico scenario (without penetration loss):

$$PL(d) = 38.1 + 20 \log10(d \text{ in meters})$$

However, it should be recognized that this model might give overly pessimistic results since there is a high probability that the two antennas are not in line-of-sight in an urban environment, even for short distances. For this reason the vehicular test environment path loss model should also be considered:

$$PL(d) = 130.5 + 37.6 \log10(d \text{ in meters}),$$

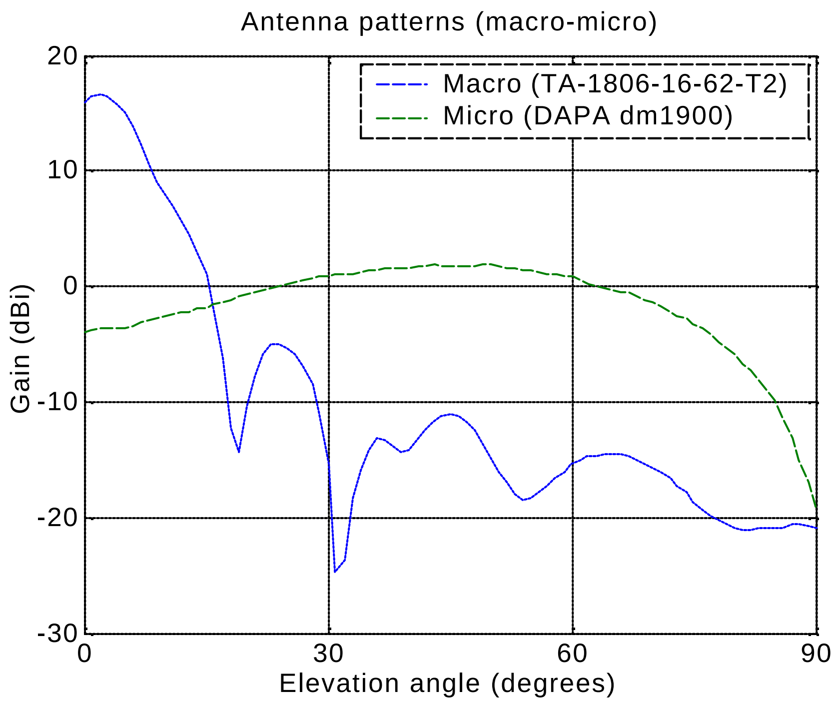
Where it is assumed that the macro antenna is at 15 meters above the average rooftop level, and the frequency is 2.6 GHz.

Antenna patterns

Figure B-6 shows the antenna patterns assumed for the analysis. The macro antenna (Tiltek) is the same as in the previous scenario. The micro antenna (DAPA dm19-00) is omnidirectional.
The pattern is available from the Internet site of the manufacturer (www.dapacom.com).

FIGURE B-6

Assumed antenna patterns for the Macro, downtown BS/outdoor micro BS

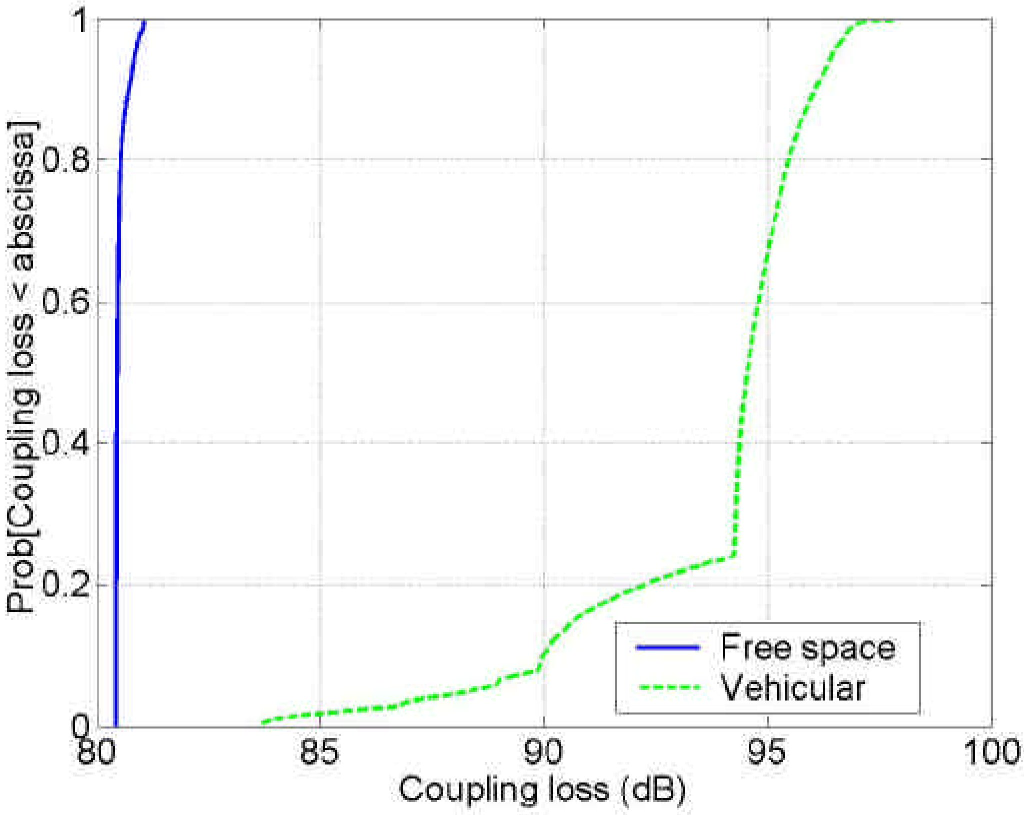


Results

Coupling loss between a pair of BSs is obtained by subtracting the gains of the antennas from the feeder losses and propagation loss. Variations in azimuth of the gain of the macro, downtown BS are ignored (i.e. it is assumed that the outdoor micro BS is always in the direction of the maximum gain in azimuth). Feeder losses are assumed to be 3 dB for both BSs combined. The distribution of the coupling loss between the macro, downtown BS and the most coupled outdoor micro BS is shown in Figure B-7 below for the two considered path loss models.

FIGRE B-7

Distribution of coupling loss between a macro, downtown BS and the most coupled outdoor micro BS



The Figure shows that the 10th percentile of the distribution is either 78 dB or 88 dB depending on the propagation model chosen.

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Appendix C

Background Information on Adaptive Antennas and Array Geometry

A wide range of techniques and tradeoffs has been developed for enhancing coverage and capacity over the past 20 years. The most important and widely used include frequency planning, power control, modulation and coding, and sectorization. These “standard” radio techniques are, in essence, exploited in modern cellular systems to a great extent. Further improvements in coverage and spectral efficiency from these techniques will be small and well short of the orders of magnitude needed for next-generation, broadband, wireless multimedia services. For these services, new techniques need to be employed. One such technique is the use of adaptive antennas. Arrays of multiple antennas, combined with digital beam-forming techniques and advanced signal processing open a new area for enhancing wireless communication systems.

A base station utilizing smart antennas employs a small collection (array) of simple, off-the-shelf antennas (typically 4 to 12) coupled with special signal processing to manage the energy radiated and received by the base station. This improves coverage and signal quality and mitigates interference in the network on both the uplink and the downlink.

The Uplink (reception at the base station)

Typically, the received signal from each of the spatially distributed antenna elements is multiplied by a weight, a complex adjustment of amplitude and phase. These signals are combined to yield the array output. As illustrated in Figure C-1, an adaptive algorithm controls the weights according to predefined objectives such as “tuning” into a particular user while “tuning out” interference and noise. This processing is performed independently and simultaneously for each of the users being served by the base station.

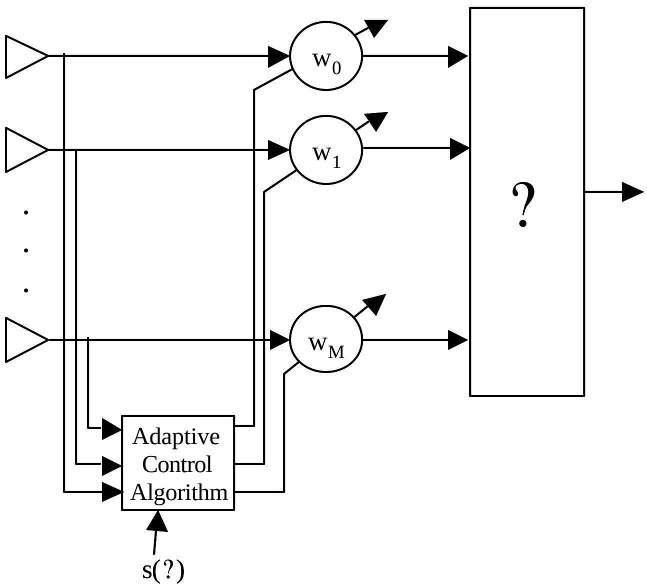


Figure C-1 Uplink Spatial Processing

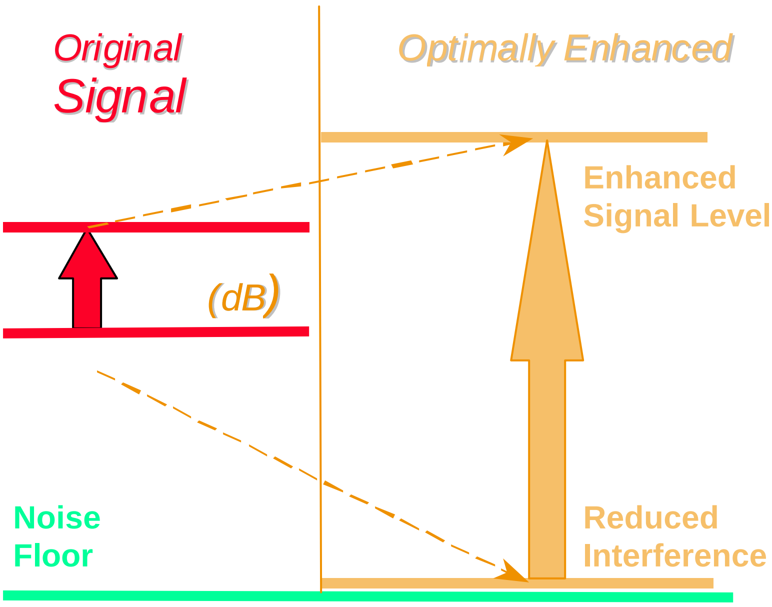
These dynamic calculations enable the system to tune itself for optimized signal reception: The equivalent received signal level is improved by a factor of $10\log_{10}$(number of antennas), which, for example, is 10 dB for a 10-antenna system.

At the same time, interference is rejected by many orders of magnitude, anywhere from 30 to 50 dB if an interfering signal is strong enough to warrant it. This rejection and the analogous suppression on the downlink are high enough that, in TDD/TDMA implementations of smart antennas frequency planning can be done away with completely (for example, the PHS system in Japan).

These gains and how they relate to overall gains in signal quality are summarized in Figure C-2.

FIGURE C-2

Effect of Spatial Processing on S/(I+N)



The Downlink (transmit from the base station)

Similar gains occur on the downlink. The signals to be transmitted are multiplied by weighting factors of different amplitude and phase for each antenna. The weighting factors are chosen dynamically to ensure that the transmitted signals constructively combine and add at the user of interest while at the same time not present interference at other co-channel users. The weight factors are again chosen dynamically based on predefined objectives.

These dynamic calculations enable the system to tune itself for optimized signal transmission: the equivalent transmitted-power signal level is a factor of $20\log_{10}$(number of antennas) over the power emitted by a single antenna at the base station. This is, for example, 20dB, for a 10-antenna system. This is a monumental improvement in equivalent signal level. Because the signals constructively interfere at the targeted user, for example, ten 1-Watt transmitters at the base station produce an equivalent incident radiation as if a 100W transmitter were employed. In addition, the redundancy introduced through the use of multiple transmitting elements, combined with the reduction in power amplifier size, increases the base station reliability. Smaller power amplifiers are more reliable and less expensive than larger ones, and the loss of a single transmitting element from the array has only a small effect on base station downlink performance (as opposed to the case where the base station has only a single radiating element). At the same time, interference is mitigated by 30 to 40 dB if a nearby user (interferer) is close enough to the base station to warrant it.

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Conceptual Presentation

Conceptually, all this works as in the simple model shown in Figure C-3. Imagine a simple, two-antenna base station attempting to communicate to two users, user A and user B, on the same channel. Also imagine that since the signals from these users travel along different paths to the base station they arrive in the following combinations at the antenna array.

User A Signal at the base station: (+A, +A)
User B Signal at the base station: (+B, -B)

Note the difference is these "signatures": In this example, user A's signals arrive in phase between the two antennas and user B's signals arrive out of phase between the two antennas. These "signatures" are commonly referred to as "spatial signatures." In a real-world implementation, these signatures are vectors in an M-dimensional complex space, where M is the number of antennas.

These signals arrive together at the base station and combine to become:

Base Station Received Signal: (+A + B, +A - B)

Now, in order for the base station to extract user A's signal from the interference caused by user B, it simply adds the two signals with weight factors (1,1):

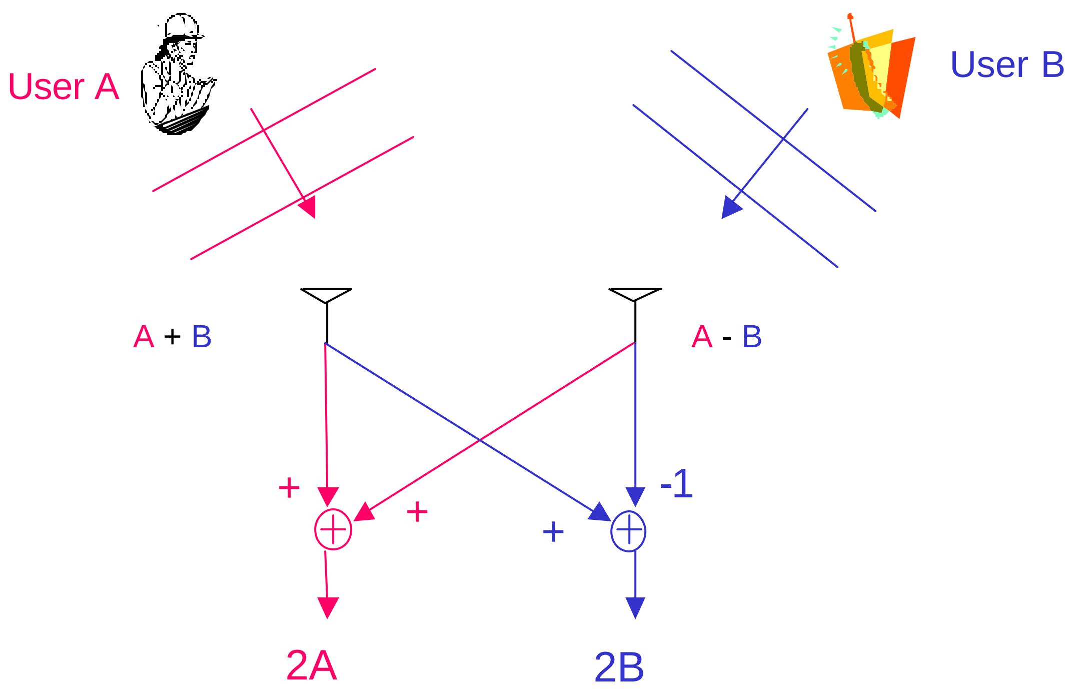
Extract User A: (+1, +1) ? (+A + B, +A - B) = (+A +B) + (+A –B) = 2A

and similarly for user B, the weight vector (+1, -1) is used:

Extract User B: (+1, -1) ? (+A + B, +A - B) = (+A +B) - (+A –B) = 2B

FIGURE C-3

Simple Model of Adaptive Antennas. Users' signals arrive with different relative phases and amplitudes at the array. Weights are applied in order to extract signals for particular users



In each case, by use of an appropriate weight vector, the base station is able to extract and separate the signals of user A and user B from one another while simultaneously providing gain for each.

In contrast, let's consider a base station with only a single antenna. In this case, the received signals would be modeled as:

Single Antenna Received Signal = (+A +B)

and the base station is left with unusable signals from user A and user B intermixed with one another.

An important point here is that the type and performance of the downlink processing used depends on whether the communication system uses time division duplex (TDD) schemes, which transmit and receive on the same frequency or frequency division duplex (FDD) schemes, which use separate frequencies for transmit and receiving. In most FDD systems, fading and other propagation characteristics are uncorrelated from the uplink radio channel to the downlink one, whereas in TDD systems the uplink and downlink channels can be considered reciprocal. Hence, in TDD systems, uplink channel information may be used to achieve spatially selective transmission. In FDD systems, the uplink channel information cannot be used directly, and other types of downlink processing must be considered.

In real-world implementations of smart antennas, there are multiple complications that must be handled: There are more co-channel users to decipher, there are multiple other sources of interference, there are many more antennas, signal levels and phases vary across the array, and so on. With any given technology, however, addition of spatial processing will increase the spectral efficiency of that system.

Spectral Efficiency

Spectral efficiency is defined as the amount of information that is carried by a communication system per unit of used spectrum. Since the information carried is expressed in bits per second (b/s), then spectral efficiency has takes the unit of b/s/Hz. Capacity of wireless base stations, however, are affected by network-level factors including multiple access method and frequency reuse. Normalizing the spectral efficiency to a cell, therefore, would provide a fair baseline for comparing technologies. This leads to the definition of spectral efficiency in b/s/Hz/cell. The importance of increase in spectral efficiency becomes clear by observing the following formula.

$$Cells/km^2 \;?\; \frac{Demand\ (b/s/km^2)}{BW\ (Hz)\ ?\ Spectral\ \ Efficiency\ (b/s/Hz/cell)}$$

From the above equation, one can observe the following.

a) For a given demand in a given bandwidth, the higher the spectral efficiency the less the number of base stations required to cope with that demand.

b) For an existing network operating in a given bandwidth, increase in spectral efficiency enables the system to provide more capacity to users.

c) In order to cope with a given demand, higher spectral efficiency allows operation in a smaller bandwidth with the same number of cells.

Decrease in the number of base stations, increase in the capacity, and decrease in the required spectrum directly translate to cost of deployment in both capital and operating expenditure.

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Immunity to Fading

The intrinsic diversity of the array provides significant immunity to fading. This effect is calculated for the link budget using a formula according to Jakes. In an environment where all elements of the array are fading independently, e.g., as in a dense urban setting, an array with 12 elements reduces the required fast fading margin by a factor of roughly 8-17 dB, for fading outage probabilities of from ten to one percent. Table C-1 displays the fading margin as a function of desired outage probability and number of array elements.

TABLE C-1

Fade Margin as a Function of Desired Outage Probability

No. of Array Elements	**Outage Probability**			
	1%	**2%**	**5%**	**10%**
1	*20.00 dB*	*17.10 dB*	*13.00 dB*	*9.80 dB*
2	*11.50 dB*	*9.70 dB*	*7.50 dB*	*5.80 dB*
3	*8.40 dB*	*7.30 dB*	*5.70 dB*	*4.40 dB*
4	*6.90 dB*	*6.00 dB*	*4.70 dB*	*3.70 dB*
5	*5.90 dB*	*5.20 dB*	*4.10 dB*	*3.20 dB*
6	*5.30 dB*	*4.60 dB*	*3.60 dB*	*2.80 dB*
7	*4.90 dB*	*4.20 dB*	*3.30 dB*	*2.60 dB*
8	*4.40 dB*	*3.90 dB*	*3.10 dB*	*2.40 dB*
9	*4.10 dB*	*3.60 dB*	*2.90 dB*	*2.20 dB*
10	*3.90 dB*	*3.40 dB*	*2.70 dB*	*2.10 dB*
11	*3.60 dB*	*3.20 dB*	*2.50 dB*	*2.00 dB*
12	*3.50 dB*	*3.00 dB*	*2.40 dB*	*1.90 dB*

Adaptive Array Geometry

The adaptive arrays are implemented in many ways depending on the deployment constraints. The geometry may be linear, circular, or a combination thereof. The coverage area may be the whole cell (omnidirectional) or part of a cell (sectorized). Figure C-6 shows three different adaptive array arrangements. While the picture of left is a 10 element circular array, the other two present combinational arrangements of linear and circular arrays with 12 and 10 elements.

FIGURE C-6

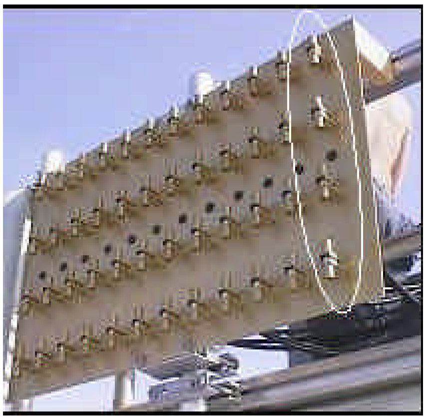
Three different adaptive array geometries

In Figure C-6, the GPS antennas are also marked to give a feeling of the size of the array. The elements used are off-the-shelf elements made by antenna manufacturers similar to the ones used in non-array cases. Each antenna element, therefore, consists of multiple small dipoles that collectively make the antenna element.

Figure C-7 shows a non-omnidirectional adaptive array with 12 elements covering a section of the cell. In this figure, every four vertical dipoles make an array element.

FIGURE C-7

A non-omnidirectional adaptive Array



Appendix D

Adaptive Antennas Cost Analysis

In order to quantify the impact of the cost of AA on deployment of IMT-2000 systems, a scenario involving adaptation of a typical AA implementation for a WCDMA system was considered. The deployment area was San Francisco Bay Area comprising of both dense and light urban morphologies. Table D-1 shows some information about the deployment market.

TABLE D-1

Market data

Parameter	Value
Population	5,000,000
Subscribers	200,000
Coverage Area – Dense/Light Urban (km^2)	700/4,300
Traffic Distribution Dense/Light Urban	40%/60%
Peak Hour Throughput Requirements Dense/Light Urban (Mbps)[1]	100.053 / 180.6

[1] Voice demand is based on existing operators' statistics. Data demands is based on "Economics of Mobile Wireless Data" by Qualcomm, Inc.

Three-sectored sites were considered with each sector having two 10 MHz carriers (5 MHz up, 5 MHz down) available to it. Table D-2 shows some of the information required to perform a capacity/coverage/cost analysis.

TABLE D-2

Analysis data

Parameter	Baseline	With AA[1]
Range, Dense/Light Urban (km)	2/4	2.68/5.80
Voice Channels per Carrier, Dense/Light Urban	18/18	38/59
Data Capacity per Carrier, Dense/Light Urban (kbps)	400/400	864/1332
Number of sites in Dense/Light Urban	56/86	31/41

[1] The results presented in this column assume ArrayComm's Intellicell adaptive antenna technology.

In the above table, the number of sites is calculated based on the maximum of the number of sites required for coverage and the number of sites required for capacity.

The total cost of deployment includes base station as well as other costs such as installation. While the cost of the base stations and installation will increase for AA, the total cost is more than offset by the significantly less number of base stations required to provide service. This is shown in Table D-3.

TABLE D-3

Relative Cost

Parameter	Dense Urban	Light Urban
Relative Base Station Cost	150%	150%
Relative Other Costs	150%	150%
Total Relative Market Cost	83%	72%

As a result, combining both dense and light urban data, total reduction in the number of base stations for the market and in the cost of deployment could be calculated. The results are tabulated below.

TABLE D-4

Savings

Parameter	Reduction % with implementation of AA
Total Cost	24%
Total Number of Required Sites	49%

The results presented in the above table are for the coverage limited case, which is the likely scenario for the initial deployments. As networks grow and become capacity limited, the amount of reduction is expected to increase even further.

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Appendix E

Assumptions and methodology used to evaluate the effects of power control

Assumptions

Deployment scenario

The scenario is depicted in Figure E-1. A group of 4 TDD pico cells are deployed inside a building of dimensions 110 m x 110 m (shown enlarged in Figure E-2). This building is situated at a distance of 740 m from the macro FDD base station. The macro FDD base station is tri-sectored, and the radius of each cell (sector) is 500 m. It is further assumed that 20% of the FDD users in the sector serving the building (cell 1) are operating inside the building.

It should be understood that this scenario was designed in a way that makes the TDD system as much vulnerable as possible to the interference from the FDD mobiles. First, the FDD mobiles located inside the building will transmit at a high power level compared to the general FDD mobile population. This is because the indoor mobiles have to overcome the penetration loss of the building and also the building is located near the edge of the FDD cell. Furthermore, the density of FDD mobiles in the building is much higher than if they were uniformly distributed throughout the cell (13 times denser).

Specific parameters pertaining to the scenarios of the TDD and FDD systems are listed in tables E-3 and E-4 respectively.

FIGURE E-1

Deployment scenario used for the simulations to evaluate power control

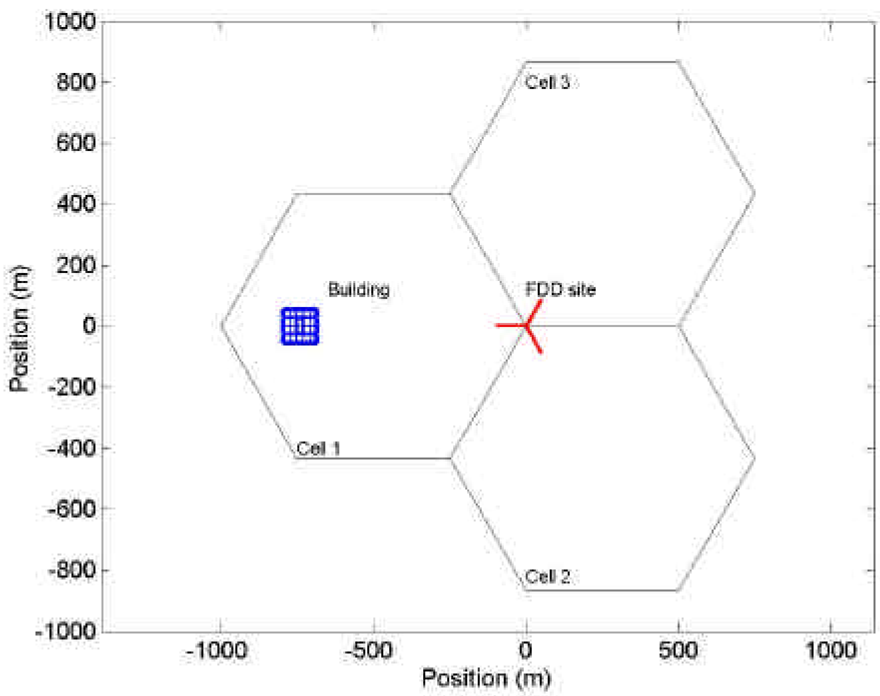

FIGURE E-2

Effects of power control: Detail of the building containing the TDD pico-cells for evaluation

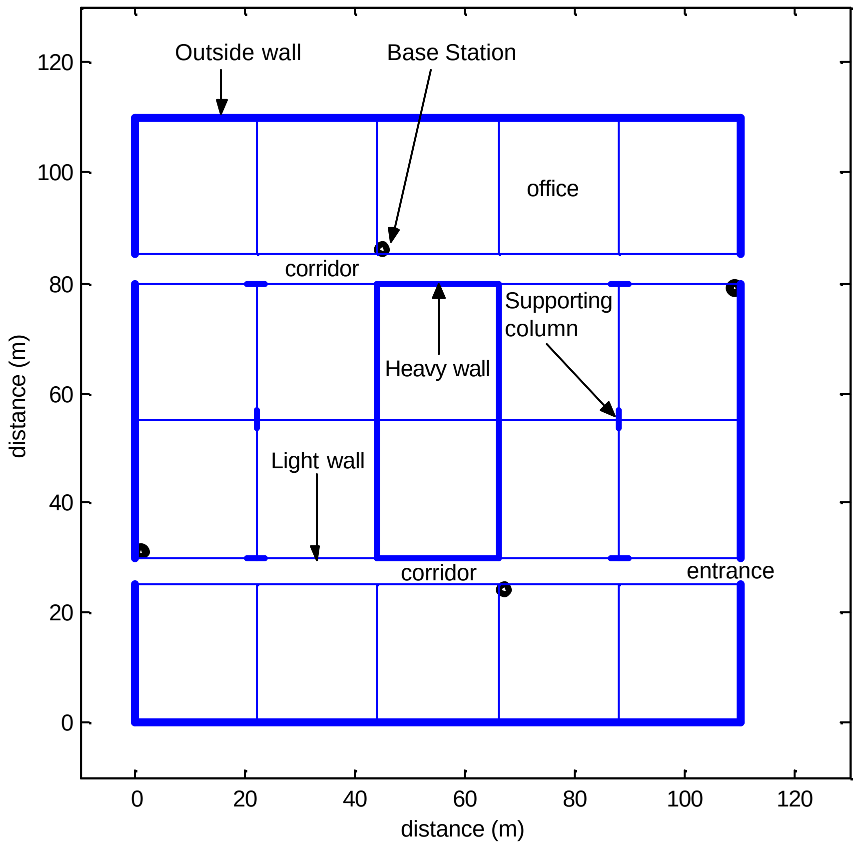

TABLE E-1

Effects of power control: Assumptions for TDD pico deployment

Building size	110 x 110 meters
Number of rooms	20 rooms in 4 rows
Room size	22 x 25 meters
Length of supporting columns	3 m
Number of corridors	2
Corridor size	110 x 5 meters
Size of entrance point	5 m
Number of penetrated floors	None
Outside wall loss	10 dB
Inside wall loss	6.9 dB (heavy), 3.4 dB (light)
Supporting column loss	6.9 dB
Users distribution	85% in the offices, 15% in the corridors

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TABLE E-2

Effects of power control: Assumptions for FDD deployment.

Number of cells	3
Cell (Sector) radius	500 m
Users distribution	Cell 1: 20 % placed in the building and the rest uniformly distributed across the hexagons' surface Cells 2 and 3: uniform density across the hexagons' surface

Note that in spite of the fact that only 3 FDD cells were simulated, the FDD UL noise rise has been observed to be approximately 6dB which is reasonable for a downtown deployment. Simulating more cells (maintaining the 6 dB noise rise criterion) would have reduced the number of FDD users per cell, which would have helped the TDD system.

System characteristics

The system characteristics of the TDD and FDD systems are shown in E-3 and E-4 respectively. Only the downlink of TDD and the uplink of FDD were simulated. No soft or softer handover was modeled for the FDD system. This assumption again is a worst case as generally SHO will reduce the MS transmit power. The power control of TDD can be enabled or disabled.

TABLE E-3

Effects of power control: System characteristics of TDD pico system

BS antenna gain		4 dBi (omni directional)
BS antenna coupling losses		2 dB
BS maximum Tx power		22 dBm
MS antenna gain		0 dBi
MS antenna coupling losses		0 dB
MS ACS		33 dB
MS receiver noise figure		9 dB
User bit rate		12.2 kbps (2 codes of spreading factor 16)
Required C/I per code		-4.3 dB
MUD efficiency		95%
Dynamic channel allocation (slot-to-cell)		8 downlink slots
Dynamic channel allocation (user-to-slot)		User's codes preferably assigned to slot(s) with least interference
Power control	OFF	Fixed 13 dBm per user
	ON	Variable between –8 dBm and 22 dBm

TABLE E-4

Effects of power control: System characteristics of FDD macro system

BS antenna gain	17 dBi (Standard tri-sectored antenna)
BS antenna coupling losses	2 dB
BS receiver noise figure	5 dB
MS antenna gain	0 dBi
MS antenna coupling losses	0 dB
MS maximum Tx power	22 dBm
MS ACLR	33 dB
Bit rate	12.2 kbps
Required C/I	-17.4 dB
Power control	Enabled

Simulation plan

In order to analyze the effect of FDD interference to the TDD system with and without power control, four simulations are performed.

1) The power control of TDD is OFF and the no FDD system exists.

2) The power control of TDD is OFF and the TDD system is interfered by the FDD system

3) The power control of TDD is ON and no FDD system exists.

4) The power control of TDD is ON and the TDD system is interfered by the FDD system.

Comparison of the performance of the TDD system between cases 1 and 2 will show the impact of FDD interference when TDD does not use power control. Comparison of the performance of the TDD system between cases 3 and 4 will show the impact when TDD uses power control. If there is any benefit of power control with respect to robustness to FDD interference, this impact should be less than when TDD does not use power control. The impact is measured in terms of the increase in the overall outage rate of TDD users and also in terms of the outage rate as a function of the distance to the closest FDD interferer.

When executing those simulations the load of each system should be selected carefully. The load of the TDD system is set so that the outage rate is around 2% when there is no FDD interference. Note that the load (in terms of number of users) has to be higher when the power control of TDD is ON since there is an important capacity benefit obtained by enabling power control. When setting the load of the FDD system one should be careful that it is not high to the point that most of the indoor FDD users are dropped due to lack of sufficient transmission power, as this would defeat the purpose of the simulations. Accordingly the load of the FDD system is set so that the average noise-plus-interference level at the FDD base station is around 6 dB above the thermal noise.

Therefore the load of the TDD system is set to 72 users (in 4 cells) when power control is OFF and 160 users when power control is ON. The load of the FDD system is set to 110 users (in 3 sectors). A higher load of the FDD system would have resulted in a higher percentage of outages for FDD users located inside the building.

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Appendix F

Path loss models used for the effects of power control

Indoor test environment

This model is used to compute the path loss between:

– An indoor FDD mobile and a TDD mobile (note that all TDD mobiles are indoors).

– A TDD mobile and a TDD base station.

It is available in xxx and consists of using the following formula [2]:

$$L = 37 + 20\,Log_{10}(R) + \sum_i k_{wi}\,L_{wi} + 18.3\,n^{\left(\frac{n+2}{n+1} - 0.46\right)}$$

where

R	transmitter-receiver separation given in metres
k_{wi}	number of penetrated walls of type i
L_{wi}	loss of wall type i (dB) (light and heavy walls)
n	number of penetrated floors.

Two types of internal walls are considered. Light internal walls with a loss of 3.4 dB and heavy (weight bearing) internal walls with a loss of 6.9 dB. The model treats supporting columns as walls with loss of 6.9 dB.

A log-normal shadowing component of standard deviation of 6 dB is added to the result.

Outdoor to indoor test environment

This model is used to compute the path loss between an outdoor FDD mobile and a TDD mobile

The model is described in [2] and repeated here for convenience.

The indoor node is projected to virtual positions at the sides of the building. Attenuation is calculated between the outdoor node of interest and each of the virtual positions using the vehicular propagation model. Attenuation is also calculated between the indoor node and each of the virtual positions as:

$$L_{iv}^{j} = \sum_i k_{wi}\,L_{wi} + a\,R$$

where

k_{wi}	number of penetrated walls of type i,
L_{wi}	loss of wall type i (dB),
R	virtual position-indoor node separation in metres,
a	is attenuation of 0.8 dB/meter.

The indoor losses, outdoor losses and the outer wall penetration losses are added. as:

$$L^j \; ? \; L^j_{ov} \; ? \; L_{ow} \; ? \; L^j_{iv}$$

where

L^j_{ov} pathloss between the outdoor node and the virtual position j (dB),

L^j_{iv} pathloss between the indoor node and the virtual position j (dB),

L_{ow} loss of the building's outside wall (dB).

Finally, the lowest pathloss through all the virtual positions is selected.

The propagation model described in this section applies to both directions, i.e. Indoor to Outdoor and Outdoor to Indoor. The outside wall of the building has 10 dB loss.
A log-normal shadowing component of standard deviation of 6 dB is added to the result.

Vehicular test environment

This model is used to compute the path loss between the following nodes:

– An FDD base station and an outdoor FDD mobile.

– An FDD base station and an indoor FDD mobile, after the addition of a fixed penetration loss of 15 dB.

It is available in section B.1.4.1.3 of [8].

A log-normal shadowing component of standard deviation of 10 dB is added to the result.

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