REPORT ITU-R M.2045

Mitigating techniques to address coexistence between IMT-2000 time division duplex and frequency division duplex radio interface technologies within the frequency range 2 500-2 690 MHz operating in adjacent bands and in the same geographical area

(2004)

1 Scope

This Report considers techniques to improve compatibility between IMT-2000 time division duplex (TDD) and frequency division duplex (FDD) radio interface technologies operating in adjacent frequency bands and in the same geographic area. Report ITU-R M.2030 analyzed and presented results of the consequences of adjacent channel interference on FDD and TDD compatibility within the 2 500-2 690 MHz band, for a range of scenarios. It identified several scenarios where co-existence between TDD and FDD networks was problematic due to base station to base station (BS-to-BS) or mobile station to mobile station (MS-to-MS) interference. This Report considers techniques, within specified classifications, to mitigate this interference, and hence to improve coexistence between TDD and FDD mobile networks in adjacent frequency bands and in the same geographic area. In so doing, this Report describes the degree of improvement they offer.

The analysis in this Report considers the following IMT-2000 radio interfaces operating within the 2 500-2 690 MHz band:

FDD: IMT-2000 CDMA Direct Spread: (WCDMA or UTRA FDD)

TDD: IMT-2000 CDMA TDD: (UTRA TDD) with its two modes:

- high chip rate (HCR, 3.84 Mchip/s) TDD and
- low chip rate (LCR, 1.28 Mchip/s) TDD, known also as TD-SCDMA.

However, the mitigation techniques described in this Report may be also more generally applicable to other frequency bands and to other TDD and FDD radio interfaces. The mitigation techniques described in this Report address the issues identified in Report ITU-R M.2030 and use assumptions consistent with those made in Report ITU-R M.2030. When these assumptions do not hold for a particular deployment the improvement obtained may be more or less. This study is not fully exhaustive and there may be other techniques not analysed and reported herein that may assist in achieving compatible deployment of TDD and FDD systems in adjacent frequency bands.

2 Introduction and summary

Previous studies have found that significant interference can be experienced in some base station to base station (BS-to-BS) scenarios (whether they be co-located or operate in the same geographical area) as well as in mobile station to mobile station (MS-to-MS) scenarios, where outages would impact user service levels. These studies have considered time division duplex (TDD) and frequency division duplex (FDD) systems operating on adjacent frequencies within the 2.5 GHz band using representative parameters for each scenario, in which no specific measures had been deployed to mitigate this interference. These studies are described in Report ITU-R M.2030 - Coexistence between IMT-2000 time division duplex and frequency division duplex terrestrial radio interface technologies around 2600 MHz operating in adjacent bands and in the same geographical area.

This Report identifies a number of techniques that may be applied to mitigate interference between TDD and FDD systems operating on adjacent frequencies. It identifies the applicability of these techniques to the scenarios identified in Report ITU-R M.2030 where interference might occur, and analyses the potential benefits of the techniques. The evaluation criteria used in this Report are the same as those presented in Report ITU-R M.2030, e.g. required separation distances and/or isolation requirements or supported cell range, capacity loss and probability of interference.

The Report also indicates the manner in which any particular mitigation technique can be applied, who would apply it (e.g. the vendor or operator), and whether or not coordinated action is required in both the TDD and FDD networks.

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 the BS-BS or MS-MS interference scenarios that may be relevant. This Report also identifies potential constraints that any mitigation technique may impose on deployment and what effect, if any, they may have on system complexity and/or network performance.

Some of the characteristics of operational IMT-2000 networks within the 2 500-2 690 MHz frequency range are likely to differ from the assumptions made in the analysis of this Report and in Report ITU-R M.2030. This Report provides information to assist in assessing and optimizing, for the scenarios identified in Report ITU-R M.2030, the trade-off between the benefits of each mitigation technique and its drawbacks, versus the use of guardbands and/or increased geographic cell separation.

This Report identifies a set of interference mitigation techniques that are useful in facilitating coexistence between TDD and FDD systems. Each technique described will mitigate interference problems but may not entirely eliminate the problem. It is likely, that in order to obtain satisfactory performance several of the mitigation techniques will have to be applied simultaneously.

The evaluation of the impact of a particular mitigation technique in this Report is done in the context of and benchmarked against the scenarios identified and described in Report ITU-R M.2030. These scenarios may not always correspond to actual deployment scenarios in the field and care needs to be taken when extrapolating these results to different scenarios. Additionally, given the nature of RF propagation in the real-world the analysis relies heavily on simulation and statistical analysis rather than relying solely either on worst case or best case deterministic analysis.

As well as mitigation techniques, this Report also describes mechanisms included in the IMT-2000 TDD and FDD specifications that also provide mitigation of interference.

3 Review of previous related work

Report ITU-R M.2030 addresses 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. Specifically, the interference properties between IMT-2000 Direct Spread (WCDMA or UTRA FDD) and IMT-2000 CDMA TDD (UTRA TDD) with its two modes high chip rate (HCR, 3.84 Mchip/s) TDD and low chip rate (LCR, 1.28 Mchip/s) TDD are studied. For the purposes of the analysis it is assumed that TDD and FDD systems at 2.5 GHz have similar characteristics to those of WCDMA and HCR/LCR TDD as defined in [5, 6, 7 and 8].

Report ITU-R M.2030 provides an analysis and presents results of the consequences of adjacent channel interference on FDD and TDD compatibility for a number of scenarios. That study is based on deterministic calculations for BS-BS scenarios leading to required separation distance and/or isolation requirements or supported cell range. The interference from MSs into MSs and BSs is analysed both with deterministic and statistical calculations leading to capacity loss and/or probability of interference. The conclusions of the Report reflect only the studies made in that Report.

Report ITU-R M.2030 does not address potential improvement brought about by mitigation techniques such as site engineering, equipment improvement, adaptive antenna, etc. These mitigation techniques are the subject of this Report.

4 Subjects considered in this document

4.1 List of scenarios

– BS-to-BS, WCDMA-TDD
  – Macro-to-macro line-of-sight (LoS)
  – Macro-to-micro (vehicular)
  – Micro-to-micro (LoS)
  – Micro-to-micro (pedestrian)
– MS-to-MS.

4.2 List of mitigation techniques classes

– Methods related to specifications
– Equipment performance (supplier improving the equipment performance)
– Site engineering on single site
– Deployment relationship between sites.

4.3 Parameters for IMT-2000 assumed in this Report

The analysis in Report ITU-R M.2030 and in this Report has been based on the specifications for FDD and TDD as defined in [5, 6, 7 and 8]. These specifications do not include requirements for the frequency range 2 500-2 690 MHz. However for the analysis, the requirements for the frequency range 1 900-2 170 MHz have been assumed.

It is possible that the requirements for the 2 500-2 690 MHz band for the parameters related to coexistence between FDD and TDD will be different to those for the frequency range 1 900-2 170 MHz, as the result of advances in technology and the impact of the higher operating frequency.

5 Mitigation techniques: A short description of their characteristics and improvement potential

5.1 Site placement

5.1.1 Brief description

Site placement as a mitigation technique is only applicable to the micro to macro scenarios that assumes rooftop and street level deployment respectively with a significant antenna height differential. As a result, the coupling between micro BSs that are close to a macro BS will be reduced. The benefits are provided by the vertical antenna patterns of the macro and micro BS antennas. However, in non-LoS conditions the improvements may be reduced.

5.1.2 Integration into an IMT-2000 technology

This is a deployment technique, which is technology independent.

5.1.3 Indication of who should apply the technique

The technique should be applied by the operator of the micro BS.

5.1.4 Implications and trade offs

The technique is available due to the different placement characteristics (on rooftop vs. at street level) between the BS types. The full benefit is only available for each nearby macro BS (approximately within 50 m of the micro BS) and the amount of additional isolation would be expected to decrease for larger macro-micro BS separation.

5.2 Antenna separation

5.2.1 Brief description

Coupling between two antennas located in the same site can be reduced by separating the antennas vertically, horizontally or back-to-back by a few metres.

For network planning purposes the widely accepted figure of the coupling loss for co-located antennas that are not coordinated is 30 dB. Higher values of coupling loss are achievable where the three types of separations described above are available (see § 5.2.2). The improvement is achievable using the antenna patterns only, without the use of any additional screening or absorption material.

5.2.2 Integration into an IMT-2000 technology

This is a deployment technique, which is technology independent.

5.2.3 Indication of who should apply the technique

Coordination is needed between the two networks deployed in the cell site and operating in adjacent frequencies.

5.2.4 Implications and trade-offs

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

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

5.3 Antenna polarization

5.3.1 Brief description

It is possible to get additional isolation between two linearly polarized BS antennas by having them orthogonally polarized to each other. As an example, using vertical polarization on one antenna and horizontal polarization on the other can reduce the degree of coupling between the two. The coupling effect is quantified in terms of an antenna characteristic know as cross polar discrimination (XPD).

One possible scenario for implementing this technique would be the case of two BS antennas at close proximity, potentially in LoS of 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 LoS, where isolation is needed most.

5.3.2 Integration into an IMT-2000 technology

This is a deployment technique, which is technology independent.

5.3.3 Indication of who should apply the technique

A coordinated decision needs to be made for the two networks operating in adjacent frequencies.

5.3.4 Implications and trade-offs

This technique cannot be used if either network uses polarization diversity.

5.4 Adaptive antennas

5.4.1 Brief description

Adaptive antennas may be defined as "an array of antennas that is able to change its antenna pattern dynamically to adjust to noise, interference and multipath" [9]. Adaptive antennas are used to enhance received signals and may also be used to form beams for transmission. The direct benefit from the use of adaptive antennas on the coexistence, however, is due to the fact that the RF energy radiated by antenna arrays is both lower than that from conventional antennas for the same e.i.r.p. and focused in limited, specific regions of a cell rather than wide sectors.

5.4.2 Integration into an IMT-2000 technology

Adaptive antennas are included in the TD-SCDMA IMT-2000 standard and can also be applied to other IMT-2000 technologies.

5.4.3 Indication of who should apply the technique

This technique may be integrated into the BS hardware and software or could be added on to an otherwise conventional BS. For the integrated case, the BS would have had to have been developed with the use of adaptive antenna arrays and spatial processing as an integral system capability. Otherwise, it will require the joint support of both the BS and the adaptive antenna system vendors.

5.4.4 Implications and trade-offs

The typical reason for the deployment of systems using adaptive antennas is to increase the network capacity and coverage thus making better use of available spectrum. Adaptive antennas can also be used to perform null steering, which is not analysed in this Report, to reduce a BS's susceptibility to interference from other systems' BSs. In either case, using adaptive antennas to address coexistence problems is likely to limit the availability of the capacity and coverage benefits they typically provide.

5.5 Transmitter/receiver improvements

5.5.1 Brief description

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

5.5.2 Integration into an IMT-2000 technology

As described in § 4.3.6, the specifications of IMT-2000 CDMA Direct Spread and IMT-2000 CDMA TDD for the frequency range 2 500-2 690 MHz may define tighter limits that have been assumed in the analysis in Report ITU-R M.2030 and in this Report. They may also include optional requirements for the situation when FDD and TDD BSs are co-located.

The BS could also be designed to exceed the performance defined in the specifications.

5.5.3 Indication of who should apply the technique

If the implementation uses additional filtering, it will be specific to the frequencies used by the two networks, but can be implemented by the operators or their vendors.

Depending on the status of the standards requirements at the time of the deployment, the effect of mitigation may benefit from coordinated implementation in both the transmitters of the interfering network and the receivers of the other.

5.5.4 Implications and trade-offs

This technique can be deployed at all sites within a network (without the deployment constraints of placement of antennas) but requires some extra complexity (amplifier linearity and/or filters) in the BSs. For a given degree of complexity and filter insertion loss, a greater mitigation will be achieved for a single carrier than for a multicarrier network.

5.6 TDD power control

5.6.1 Brief description

TDD DL (downlink) power control is an integral part of the TDD standard and is used to increase system capacity. In addition to increasing system capacity, power control also provides added immunity to DL interference as the BS can adapt the power it transmits to a victim MS. In particular, using the power control, the signal to the TDD MS can be raised to counter the interference of an FDD MS uplink (UL) on an adjacent frequency. Power control is applicable to all cell types (pico, micro and macro).

5.6.2 Integration into an IMT-2000 technology

The technique is integral to all IMT-2000 technologies.

5.6.3 Indication of who should apply the technique

Technique is applied by the vendor.

5.6.4 Implications and trade offs

Simulations have shown that this technique can provide a sufficient solution to MS-to-MS interference in many scenarios. However, when TDD and FDD terminals come very close to each other (less than a few metres) the benefit may not always be sufficient to prevent outage in some parts of the cell (e.g. at the cell edge or indoors) or when the FDD mobile terminal suddenly starts transmitting. Usage of power control, in addition to mitigating MS-to-MS interference, also reduces the general inter-cell interference created in CDMA systems. Therefore there is no additional cost associated with usage of power control.

5.7 Mobile handover

5.7.1 Brief description

Handover has been incorporated into cellular type mobile systems mainly to facilitate mobility; however as a by-product it maintains system performance in the presence of RF channel impairments. By handing off the mobile station, a change is introduced (different RF channel, time slot, frequency band, etc.) consistent with the capabilities, design, and deployment rules for the system, and in the process the system has the ability to choose a better channel.

Handover, while not designed to mitigate interference, may function in some cases as a work around to interference. This unintended benefit of handover might be useful in some cases but should not be considered as the predominant means or method of interference control, particularly for externally imposed interference. In any event, the efficacy of handover in interference situations and how it might be utilized is a balance between the benefit achieved and the adverse system impacts that accrue.

5.7.2 Integration into an IMT-2000 technology

TDD inter-carrier handover is mandatory to MSs. It is an integral part of any IMT-2000 TDD LCR deployment and may be used by operators in IMT-2000 TDD HCR when the operator operates more than a single carrier or when handover between radio access technologies (radio access technology (RAT): FDD or TDD) is possible. The control of the mode of escape can be configured by network operators in the construction of the cell neighbour lists.

5.7.3 Indication of who should apply the technique

Support for the mechanism is standard for the MS for the case of inter-channel handover and optional for inter-RAT. The latter therefore requires implementation by the MS vendor. In addition the technique needs to me implemented by the operator.

5.7.4 Implications and trade-offs

The efficacy of handover in interference situations and how it might be utilized is a balance between the benefit achieved and the adverse system impacts that accrue. For example, handover to avoid a channel that has a continued adverse interference situation may moderate the impact of interference to the end user, but does nothing to eliminate the interference from the system and restore that channel back to traffic carrying service. Therefore system capacity is degraded in the course of mitigating the impact/effect of the interference. The amount of capacity degradation depends on the intensity of the interference and the area that is affected. There may also be cases where the handover cannot be completed due to inability to receive network commands.

Consequently, handover should be considered as a means for a system to continue to operate at some acceptable level of functionality in the presence of interference, but with other impacts in the system.

Handover between different types of networks (utilizing different RATs) is dependant on availability of dual mode terminals, compatible multimedia applications and spectrum availability. While handover is not an interference elimination technique, it nonetheless should be considered in the context of an interference mitigation capability.

5.8 Antenna downtilt

Antenna downtilt is not addressed as a stand alone mitigation technique in this Report.

5.8.1 Brief description

Two macro (over the rooftop) BS antennas that are pointed towards each other can exhibit a tight coupling to each other. In cell planning, the main beam of antennas are frequently down tilted to improve network performance. This increases the isolation between the two antennas by typically a few dB.

5.9 FDD power control

FDD power control is not addressed as a stand alone mitigation technique in this Report.

5.9.1 Brief description

FDD DL power control is an integral part of the FDD standard and is used to increase system capacity. In addition to increasing system capacity, power control also provides added immunity to DL interference as the BS can adapt the power it transmits to a victim MS. In particular, using the power control, the signal to the FDD MS can be raised to counter the interference of a TDD MS (UL) on an adjacent frequency at the expense of some capacity decrease. Power control is applicable to pico, micro and macro deployments. The effects of the FDD power control have not been considered in this Report.

6 Tabular classification of mitigation techniques and methods

	Technique name	Methods related to specifications	Equipment performance (supplier improving the equipment performance)	Site engineering on single site	Deployment relationship between sites
BS-to-BS scenarios					
1	Separation: Site placement			X	X
2	Separation: Separation of antennas			X	
3	Separation: Antenna polarization				X
4	Adaptive antennas:	X for TD-SCDMA	X for TDD		
5	Transmitter/ receiver improvements: Additional filtering		X	X	
6	Transmitter/ receiver improvements: Linearization techniques		X		
MS-MS scenarios					
7	TDD power control and dynamic channel allocation:	X (already integral to the standard)	X		
8	Use of handover:	X (already integral to the standard)			

7 Tabular assessment of improvement potential and applicability

	Technique name	Macro-to-macro (LoS)	Macro-to-micro (vehicular)	Micro-to-micro (LoS)	Micro-to-micro (pedestrian)	MS-to-MS
1	Separation: Site placement	Not applicable	<17 dB improvement for vehicular Benefit achieved at 50 m is likely to be up to 17 dB, equal to the peak macro antenna gain	Not applicable	Not applicable	Not applicable
2	Separation: Antenna separation: (1) – Vertical – Horizontal – Back-to-back	The reference value for coupling loss when antennas share a site or mast is 30 dB(2). While it is not always possible to coordinate the co-location process between competing operators, doing so could lead to between 15-40 dB of additional isolation for two adjacent antennas. In real deployment conditions, where there may be multiple antennas causing interference, a mitigation of 10-15 dB above the standard 30 dB reference value may be achievable	Not applicable	Not applicable	Not applicable	Not applicable
3	Separation: Antenna polarization	The applicability is limited to particular cases, achievable improvement is in the range of a few dB	Not applicable	Not applicable	Not applicable	Not applicable

	Technique name	Macro-to-macro (LoS)			Macro-to-micro (vehicular)			Micro-to-micro (LoS)			Micro-to-micro (pedestrian)			MS-to-MS
4	Adaptive antennas:	Adaptive antennas reduce the average level of interference at the victim BS by a factor related to the number of elements in the array (e.g. 10 dB for a 10-element array). While they do not necessarily reduce the peak level of interference experienced at the victim BS, they substantially reduce the probability of that event occurring and the overall probability of outage			Adaptive antennas reduce the average level of interference at the victim BS by a factor related to the number of elements in the array (e.g. 10 dB for a 10-element array). While they do not necessarily reduce the peak level of interference experienced at the victim BS, they substantially reduce the probability of that event occurring and the overall probability of outage			Adaptive antennas reduce the average level of interference at the victim BS by a factor related to the number of elements in the array (e.g. 10 dB for a 10-element array). While they do not necessarily reduce the peak level of interference experienced at the victim BS, they substantially reduce the probability of that event occurring and the overall probability of outage			Adaptive antennas reduce the average level of interference at the victim BS by a factor related to the number of elements in the array (e.g. 10 dB for a 10-element array). While they do not necessarily reduce the peak level of interference experienced at the victim BS, they substantially reduce the probability of that event occurring and the overall probability of outage			Not applicable
5	Transmitter/receiver improvements: Additional filtering(3) (results for single carrier BS)	Adjacent channel leakage ratio (ACLR)/adjacent channel selectivity (ACS) improvement provided by additional filter			ACLR/ACS improvement provided by additional filter			ACLR/ACS improvement provided by additional filter			ACLR/ACS improvement provided by additional filter			Not applicable
		Frequency offset			Frequency offset			Frequency offset			Frequency offset			
		5 MHz	6 MHz	7 MHz	5 MHz	6 MHz	7 MHz	5 MHz	6 MHz	7 MHz	5 MHz	6 MHz	7 MHz	
	Adjacent ACLR(4) (dB)	9	35	71	9	35	71	9	35	71	9	35	71	
	Adjacent ACS(4) (dB)	9-15	>35	>71	9-15	>35	>71	9-15	>35	>71	9-15	>35	>71	
	1st alternate ACLR(4) (dB)	68	68	68	68	68	68	68	68	68	68	68	68	
	1st alternate ACS(4) (dB)	>68	>68	>68	>68	>68	>68	>68	>68	>68	>68	>68	>68	

	Technique name	Macro-to-macro (LoS)	Macro-to-micro (vehicular)	Micro-to-micro (LoS)	Micro-to-micro (pedestrian)	MS-to-MS
6	Transmitter/receiver improvements(4): Power amplifier linearization techniques (results for single carrier BS) Adjacent (dB) 1st alternate (dB)	ACLR 18 13	ACLR 18 13	ACLR 18 13	ACLR 18 13	Not applicable
7	TDD power control: – TDD pico – TDD macro	Not applicable	Not applicable	Not applicable	Not applicable	This can provide a sufficient solution to MS-to-MS interference in many scenarios. However, when TDD and FDD terminals come very close to each other (less than a few metres) the benefit may not always be sufficient to prevent outage in some parts of the cell (e.g. at the cell edge or indoors) or when the FDD mobile terminal suddenly starts transmitting

	Technique name	Macro-to-macro (LoS)	Macro-to-micro (vehicular)	Micro-to-micro (LoS)	Micro-to-micro (pedestrian)	MS-to-MS
8	Use of inter-channel or inter-network handover	Not applicable	Not applicable	Not applicable	Not applicable	When available, reduces the likelihood or eliminates the possibility of MS-to-MS interference for both TDD on FDD and FDD on TDD. However, there may be cases where the handover cannot be completed due to inability to receive network commands

(1) An minimum coupling loss (MCL) of 30 dB is generally used for network planning but these higher values are achievable were adequate space and conditions exist. The parameters considered in deriving the values in the Table are:

– vertical separation: two 16 dBi vertically polarized, 90° sector antennas with approximately 2 m of vertical separation;

– side-by-side separation: two 16 dBi vertically polarized, 90° sector antennas at approximately 4 to 6 m of horizontal separation;

– back-to-back separation: two 16 dBi vertically polarized, 90° sector antennas at horizontal back-to-back separation distances in the range of 1 to 1.5 m.

(2) The rationale for this particular value is described in 3GPP TR 25.942.

(3) Example for an eight section cavity filter at 2.6 GHz, this filter was scaled from a commercially available filter at 1.9 GHz with a pass-band of nominally 5 MHz and insertion loss of ≈2 dB.

(4) These values are relative to the 3GPP baseline values of 45 dBc and 55 dBc for adjacent and alternate channels, respectively.

8 Conclusions

Report ITU-R M.2030 investigated the coexistence between IMT-2000 TDD and FDD radio interfaces operating in adjacent bands and in the same geographical area, within the frequency band 2 500-2 690 MHz. It identified several BS-to-BS and MS-to-MS scenarios where interference was a severe problem.

This Report investigates techniques to improve compatibility between the two radio interfaces for the problematic scenarios identified in Report ITU-R M.2030. Application of these mechanisms would reduce the size of, and may in some cases eliminate, the guardband and/or isolation distances that might otherwise be required.

This Report has identified a number of techniques that can provide significant mitigation of interference between TDD and FDD networks in the scenarios investigated. A single technique will not provide full mitigation in all scenarios. However, a combination of techniques can provide a solution to mitigate TDD/FDD interference in many situations. Some of the techniques need to be implemented through coordination of network deployments. Some techniques are only applicable to specific scenarios, and/or require the technique to be implemented by the manufacturer of BSs. Nonetheless, these mitigation techniques could be considered in determining if there are guardband requirements between the two systems.

The results in this Report are based on existing 3GPP specifications for the 2 GHz band. This Report may assist in the development of the specifications for the 2 500-2 690 MHz band.

Annex 1

Support material for site placement

1 Discussion

This Annex describes the assumptions that lead to the determination of the mitigation benefits of placing antennas at different heights above ground. This antenna placement strategy is typical of a multi-layer hierarchical deployment in urban areas with macro cells placed on rooftops and micro cells placed a few metres above ground (at "street level").

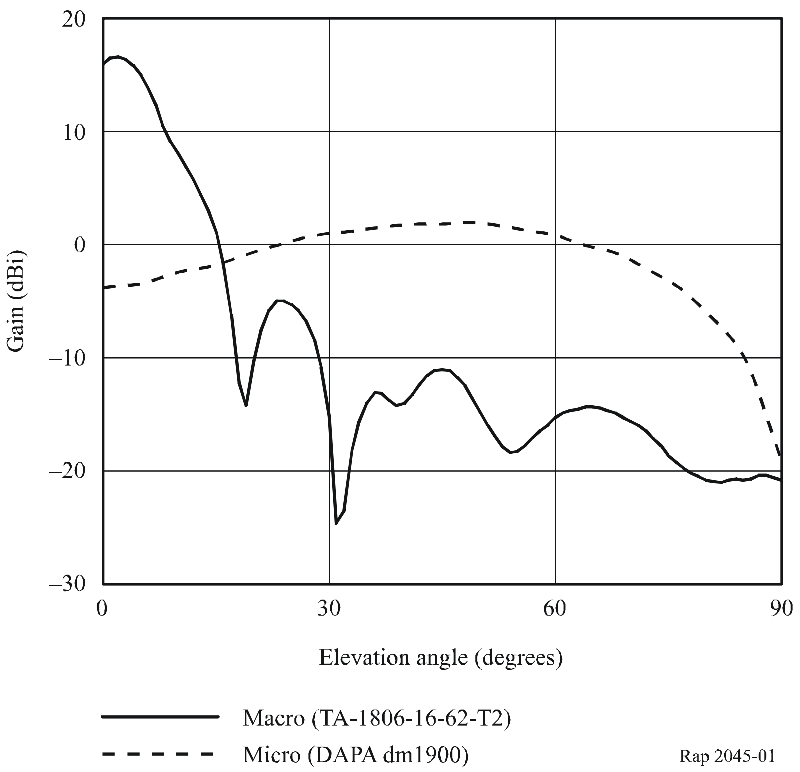
The benefits depend on the antenna patterns of the macro and micro antennas and the propagation regime between them, i.e. LoS or non-LoS. While both are possible, non-LoS is much more likely and therefore Report ITU-R M.2030 has focused on the vehicular propagation model with an antenna separation of 50 m. Both macro and micro antennas are directive in the vertical plane. However the low gain of the micro antenna and its closeness to other objects renders it practically omnidirectional and can be ignored.

For LoS propagation the benefits are assumed to depend on the precise antenna pattern of the macro as well as the exact relative location of the antennas (vertically and horizontally). A specific commercially available antenna with a 2-3^{o} down tilt (see Fig. 1) has been used as an example that provides a coupling loss (CL) reduction (relative to beam centre) of approximately 23 dB at 50 m with 25 m height differential between the antennas. While not monotonic, this benefit is generally reduced as the distance grows and becomes essentially zero at or close to the down tilt angle of the antenna.

For non-LoS propagation it is safer to assume that the nulls in the antenna pattern will be "filled in" with reflections and to use therefore the envelope of the antenna pattern. With similar assumptions as for LoS, the non-LoS benefit in CL reduction have been agreed to be 17 dB.

FIGURE 1

Example antenna patterns (macro-micro)



2 Propagation model

Free space:

$$PL_{dB} = 38.1 + 20 \log_{10}(d \text{ (m)})$$

Vehicular: (adjusted for 2.6 GHz and antenna 15 m above the average rooftop level)

$$PL_{dB} = 130.5 + 37.6 \log_{10}(d \text{ (km)})$$

Annex 2

Support material for antenna separation

1 Effect of antenna separation

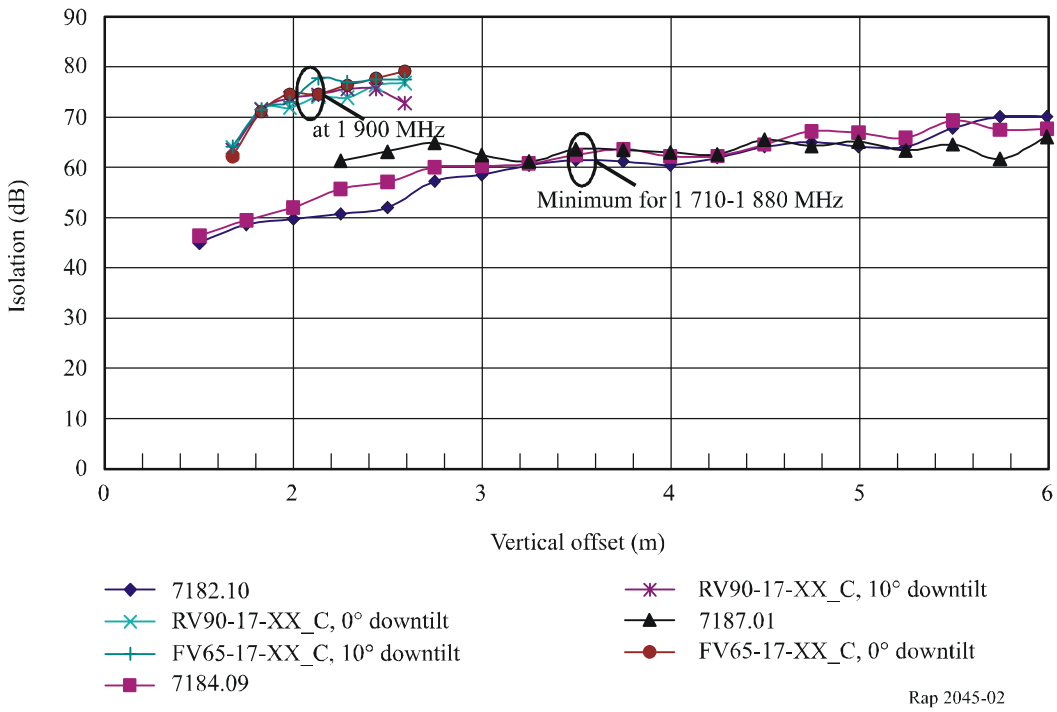
The value of MCL of 30 dB that has been generally agreed for uncoordinated deployment has been derived from the case of two antennas mounted on separate poles within 10 m of each other. This value has also been used in Report ITU-R M.2030. Mounting the antennas on the same pole can increase the coupling loss. The amount of increase depends on the relative orientation of the antennas and their separation. Vertical, horizontal and back to back placements have been considered and provide significant increase. Back to back placement is not considered practical for realistic deployment. In various measurements between two antennas, reported by several companies, the improvement has been found to be 15-40 dB above the uncoordinated MCL for separation (measured from antenna centres) of a few metres. For compiled measurements with vertical separation see Fig. 2.

In many cases however multiple antennas (e.g. for sectorized deployment) are to be deployed on the same height restricted pole which will reduce the improvement over the uncoordinated MCL to 10-15 dB.

FIGURE 2

Examples of antenna isolation with vertical offset

(Figure 2 shows performance of commercially available antennas at around 2 GHz)



Annex 3

Effects of using adaptive antenna technology

Since the macro TDD BS - macro FDD BS interference was identified as the most problematic case in Report ITU-R M.2030, 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, ACLR, ACS, channel bandwidths, receiver sensitivity, etc. are consistent with [1]. The adaptive antenna array's 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 Report ITU-R M.2030.

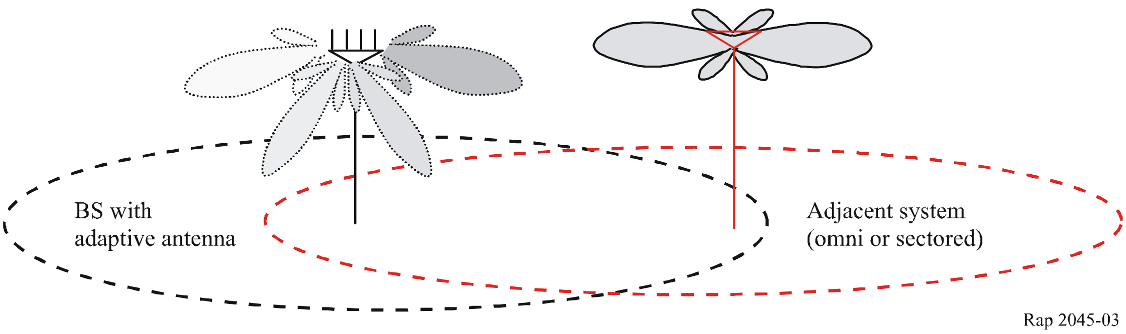
1 General information

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. 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. Additional background information on adaptive antenna systems can be found in Report ITU-R M.2040 - Adaptive antennas concepts and key technical aspects.

The direct benefit from the use of adaptive antennas on the coexistence, however, is due to the fact that the RF energy radiated by antenna arrays is both lower than that from conventional antennas for the same e.i.r.p. and user density, and focused in limited, specific regions of a cell rather than wide sectors. Since users are distributed within the cell area, the adaptive antenna array is likely to point its beams at user locations, thus lowering the likelihood of creating/accepting interference to/from other stations, as depicted in Fig. 3.

FIGURE 3

Distribution of adaptative antenna array's beams in time and space lowers the likelihood of interference



In general, 3GPP specifications allow for the use of adaptive antenna systems, which may be implemented differently by each equipment vendor. The results presented here assume that beamforming is implemented on the dedicated channels for the communication between the TDD BS and the mobiles within the coverage area of its cell and omnidirectional transmission of the broadcast channel. There may be techniques, not described herein, that will provide for better performance.

2 Propagation models

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

$$L = 40(1 - 4\times10^{-3}\Delta h_b)\log_{10}(R) - 18\log_{10}(\Delta h_b) + 21\log_{10}(f) + 80 + FM \quad (1)$$

where:

- FM: log-normally distributed shadowing margin with standard deviation of 10 dB
- f: frequency (MHz)
- Δh_b: BS antenna height above average rooftop
- R: distance (km).

Several propagation models are used in Report ITU-R M.2030 for the purpose of coexistence simulations. However, Report ITU-R M.2030 uses a dual-slope model from [3] for the case of macro-cell BS-to-BS interference. This model is formulated by equation (2) for 2.6 GHz.

$$L_{LoS} = \begin{cases} 40.7 + 20\log_{10}(d) & \text{for } 1 \le d \le d_{break} \\ 0.7 - 20\log_{10}(d_{break}) + 40\log_{10}(d) & \text{for } d \ge d_{break} \end{cases}$$
$$d_{break} = \frac{4h_{tx}h_{rx}}{\lambda} \qquad (2)$$

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 metres. 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.

3 Deterministic analysis without adaptive antennas

Given the adjacent channel interference ratio (ACIR), it is possible to calculate the required separation distance from the following of a TDD BS interfering with an FDD BS without the benefit of adaptive antennas.

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

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

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

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

Given the ACLR and ACS values in Table 1:

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

The required path loss, assuming tolerable adjacent channel interference of –114 dBm is found as follows:

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

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.

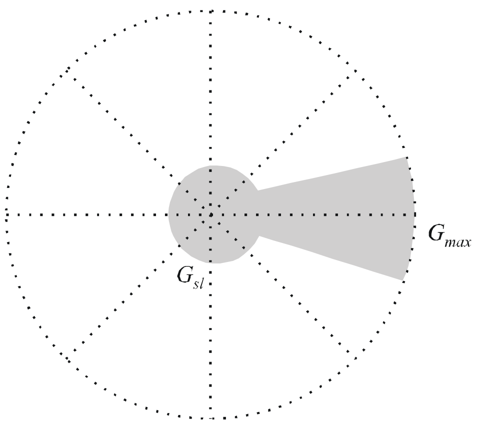
4 Statistical analysis with adaptive antennas

As described above, demonstrating the effect of implementing an adaptive antenna system at the BS requires statistical analysis, as discussed in [3] and in Report ITU-R M.2030. This analysis would take into consideration variations in the relative locations of the BSs and their separation distances, and the time-varying direction and adaptive antenna gain in the adjacent channel toward the victim BS. Such an analysis would yield a more accurate determination of the percentage of time that the victim BS is in outage due to interference from the adjacent band system. These values would then allow for determining the additional isolation required to achieve the acceptable level of degradation as described in Report ITU-R M.2030 and ETSI 25.942 [1].

A simplified model of an adaptive antennas' beam pattern is shown in Fig. 4.

FIGURE 4

Simplified model for the E-plane and H-plane of the adaptive antenna array's beam



The maximum gain of an adaptive antenna array's beam, G_{max}, is generally related to the array parameters as follows:

$$G_{max} = G_{element} + 10\log_{10} M \quad (4)$$

In the above formula, M is the number of array elements, $G_{element}$ is the gain of a single array element. 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 $G_{element}$ could be assumed to be 5 $\log_{10}(M)$ in main beam coupling throughout the analyses. The random direction of the adaptive antenna array's 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. If the victim and interferer share only the vertical plane (but not the horizontal plane), the gain of the array is given by equation (5).

$$G = G_{element} - 10\log_{10} M \quad (5)$$

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

$$G = G_{element} - 20\log_{10} M \quad (6)$$

Annex 4

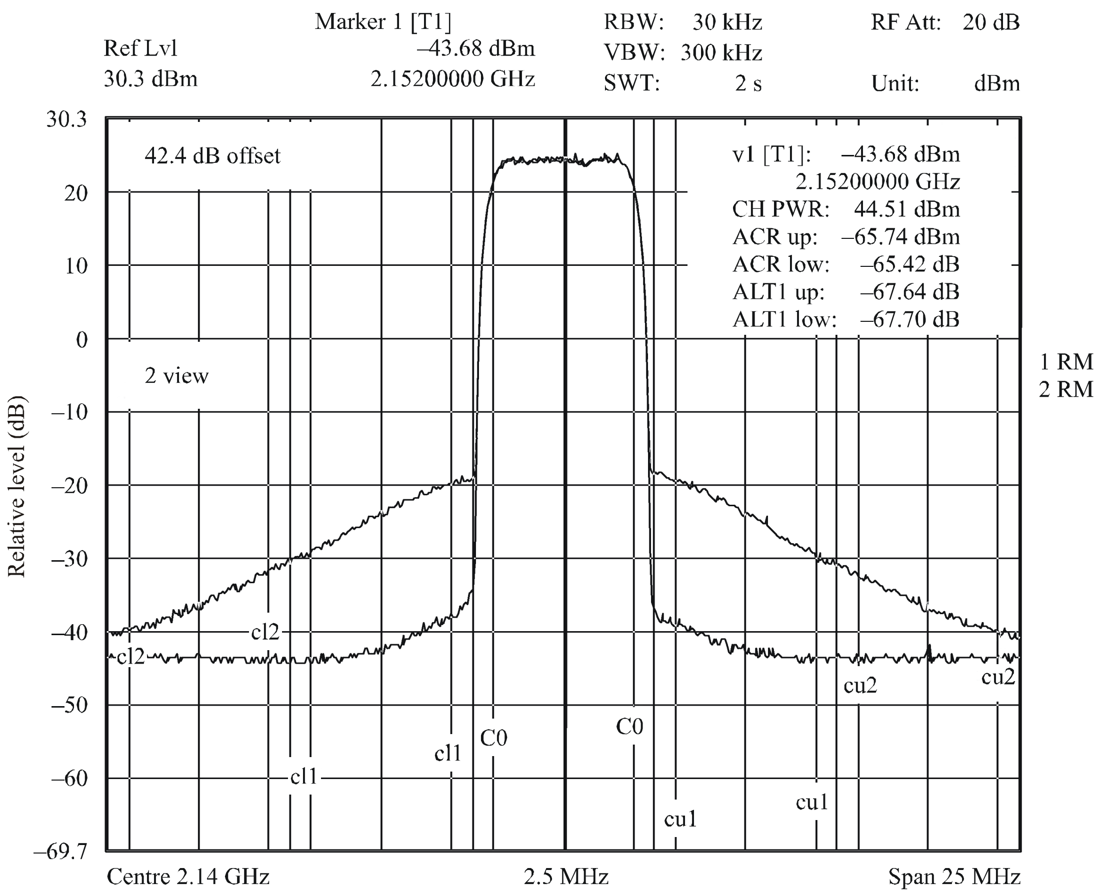
Support material for power amplifier linearization

The emissions requirements of a general purpose BS have been written such that they can be implemented with a multi-carrier power amplifier without filter and with standard linearization techniques. Subsequent versions of the standard that have not been considered in Report ITU-R M.2030 have imposed stricter requirements on TDD BSs designated for operation proximity to FDD BSs.

This Annex shows an example (see Fig. 5) of a commercial power amplifier that can enhance ACLR1 from its baseline of –45 dBc by approximately 18 dB, to –63 dBc and ACLR2 (adjacent channel leakage ratio in the second alternate channel) by approximately 13 dB from its baseline of –55 dBc to approximately –68 dBc, for a single carrier. Moreover this is achieved without substantially degrading the efficiency of the power amplifier.

FIGURE 5

Example of improvement in ACLR1 and ACLR2



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Annex 5

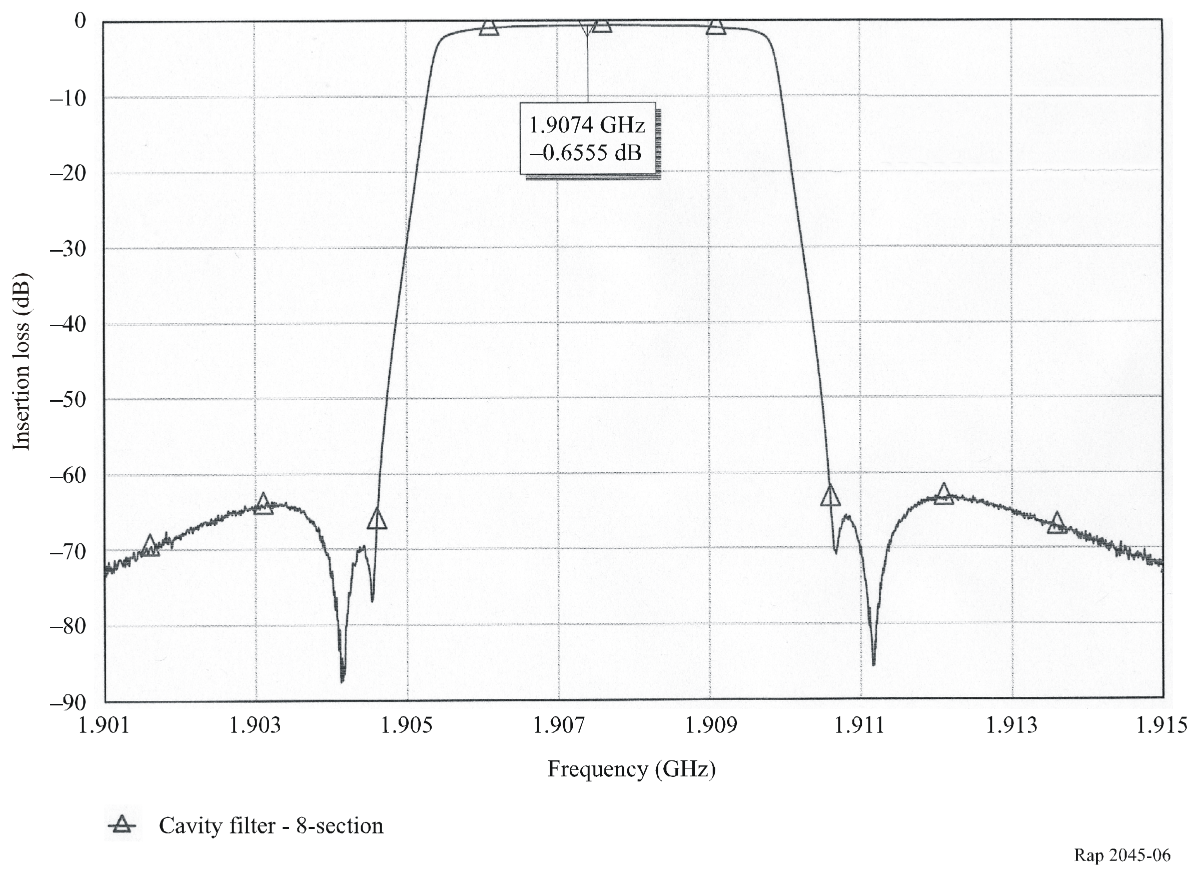
Support material for BS equipment improvement - Filtering

An example of the possible improvements that may be achieved by filtering is taken from a commercially available single carrier 8-section filter at 1.9 GHz. The filter response is shown in Fig. 6. This filter has been scaled to 2.6 GHz without any attempt to optimize the design.

To compute the improvement in unwanted emissions, the filter response is weighted by the BS emissions mask and the receiver root raised cosine filter response. Computing the improvement in receiver selectivity requires exact knowledge of the receiver filter that is not defined by the standard. The improvement however can be assumed to lie between the value obtained from assuming a rectangular (uniform) response and that obtained with a root raised cosine filter.

FIGURE 6

Example of filter insertion loss and rejections



Annex 6

Assumptions and methodology used to evaluate the effects of power control

1 TDD pico BS

TABLE 1

Effects of power control: assumptions for TDD pico deployment

Building size	110 × 110 m
Building distance from FDD macro	740 m
Number of rooms	20 rooms in 4 rows
Number of TDD pico cells	4
Room size	22 × 25 m
Length of supporting columns	3 m
Number of corridors	2
Corridor size	110 × 5 m
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

TABLE 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 hexagon's surface *Cells 2 and 3:* uniform density across the hexagon's surface

TABLE 3

Effects of power control: system characteristics of TDD pico system

BS antenna gain		4 dBi (omnidirectional)
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 kbit/s (2 codes of spreading factor 16)
Required *C*/*I* per code		–4.3 dB
Multiple user detection 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 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 kbit/s
Required *C*/*I*	–17.4 dB
Power control	Enabled
Soft handoff	Disabled

1.1 Simulation plan

Simulations were run with and without power control and with and without the interfering FDD MS.

The load of the TDD system is set so that the outage rate is around 2% when there is no FDD interference. The load of the FDD system is set so that the average noise-plus-interference level at the FDD BS is around 6 dB above the thermal noise.

2 TDD macro BS

TABLE 5

System and deployment characteristics of FDD and TDD macro system

	FDD	TDD
Building type	Same as that used for the TDD pico deployment	
Building distance from macro BS	320 m (centre of building)	
FDD and TDD deployment	Co-located	
User distribution	20% in building	
BS antenna gain	17 dBi (standard tri-sectored antenna)	
Grid size	Based on corner-centric sector deployment with 600 m site-site distance	
BS antenna coupling losses	2 dB	
MS antenna gain	0 dBi	
MS antenna coupling losses	0 dB	
BS receiver noise figure	5 dB	–
MS receiver noise figure	–	9 dB
MS maximum Tx power	22 dBm	–
BS maximum Tx Power	–	39 dBm
MS ACLR	33 dB	–
MS ACS	–	33 dB
Bit rate	12.2 kbit/s	64 kbit/s
Required *C*/*I* per code	–17.4 dB	–4.8 dB
Number of slots	–	8 downlink timeslots
Fast dynamic channel allocation	–	Enabled
Power control	Enabled	

2.1 Simulation plan

The load of the TDD system is set so that the outage rate is around 2% when there is no FDD interference. The load of the FDD system is set so that the average noise-plus-interference level at the FDD BS is around 6 dB above the thermal noise.

3 Path loss models used for the effects of power control

3.1 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 BS.

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 (m)

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.

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

3.2 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:

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

where:

k_{wi}: number of penetrated walls of type i

L_{wi}: loss of wall type i (dB)

α: is attenuation of 0.8 dB/m.

R: virtual position-indoor node separation (m)

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

$$L^{j} = L_{ov}^{j} + L_{ow} + L_{iv}^{j}$$

where:

L_{ov}^{j}: pathloss between the outdoor node and the virtual position j (dB)

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

L_{iv}^{j}: pathloss between the indoor node and the virtual position j (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.

3.3 Vehicular test environment

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

– an FDD BS and an outdoor FDD mobile

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

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

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

Annex 7

Handover

This Annex discusses the usage, availability and implications of handover as a tool to reduce effects of MS-to-MS interference. Two types of handover are considered, inter-channel and inter-RAT (FDD or TDD) (or in other words: inter-mode between FDD and TDD).

Availability: All mobiles are capable of inter-frequency handover. The ability of the operator to hand over to a different carrier depends also on the availability to the operator of multiple carriers. This technique is therefore likely to be available to FDD (with typically 2-3 pairs per operator) and to LCR TDD (with 3 subcarriers) and may become available to HCR TDD operators.

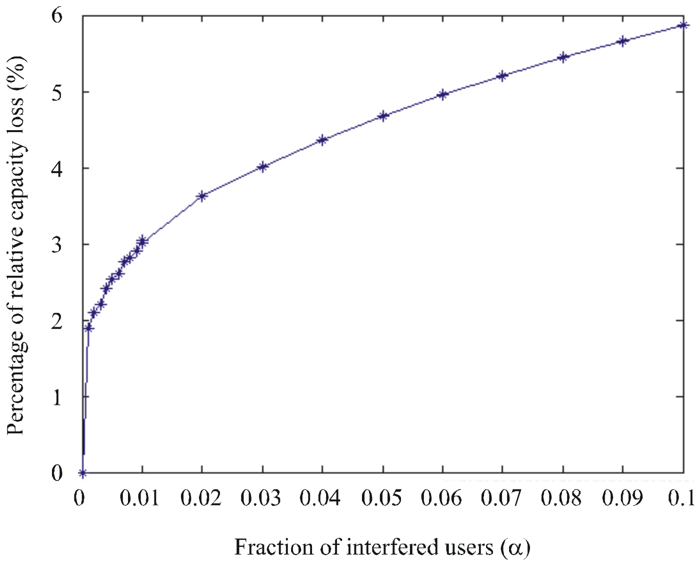
In addition, dual-mode (or dual-RAT) mobiles are also capable of handing over to the other RAT provided the operator deploys both RATs and that the service can be provided on both. For example, hand over to GSM/GPRS/EDGE can be done for medium data rate packet services and the capacity sized such that the latency is unchanged. This technique is suitable where the primary mode (e.g. TDD) is expected to have low market penetration.

Usage: Handover is executed by network commands and would operate best when interference rises gradually (e.g. as a result of moving closer to the source of interference). There would be however times when the interference rises abruptly (e.g. as a result of interfering mobile being switched on) where network commands may not be received. The mobile in this case would execute an independent registration to another carrier or RAT (if has been detected before). This process is termed cell reselection in IMT-2000 TDD and FDD and directed retry in GSM. It is short (on the order of 300-400 ms for IMT-2000 TDD and FDD) and therefore will not be noticeable in packet mode or slightly noticeable for voice mode.

Capacity implications: The fact that some of the mobiles (i.e. those that are affected by interference from another mobile) cannot be freely assigned to any cell causes some losses in trunking efficiency which will somewhat reduce the number of subscribers that can be served by the combined network (composed of the two carriers or two RATs). An example of this capacity loss for inter-frequency handover of circuit switch service (e.g. voice) is shown in Fig. 7.

FIGURE 7

Capacity loss for inter-frequency handover



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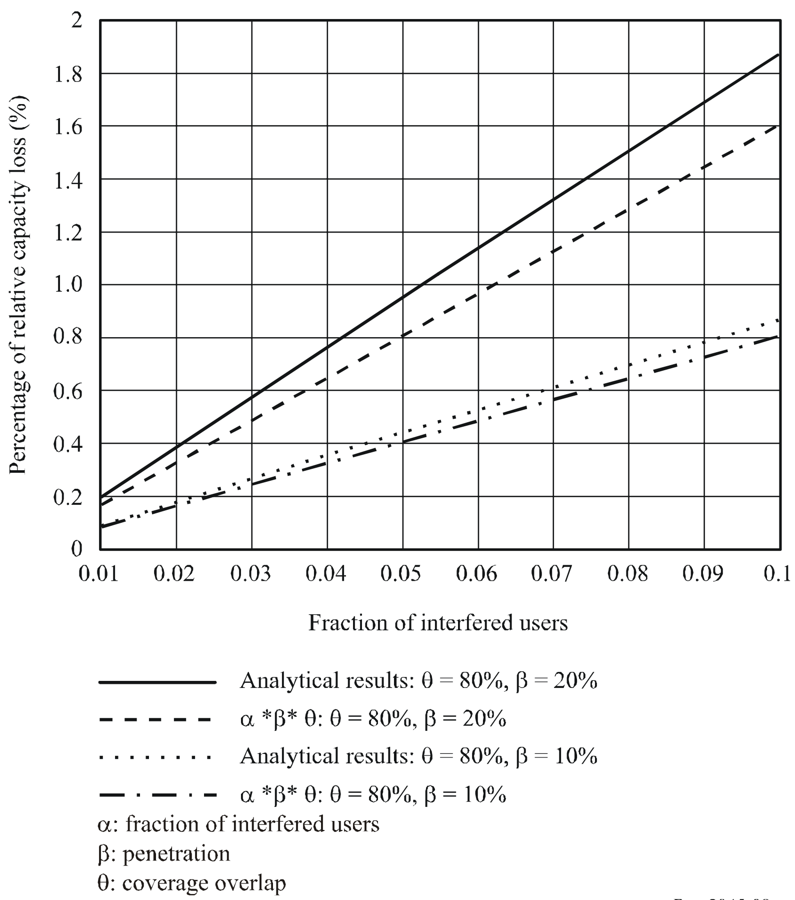
In the case of inter-RAT handover the loss depends also on the market penetration of the primary mode and the overlap in coverage. An example of the capacity loss for the cases of 10% and 20% penetration with 80% coverage overlap is provided in Fig. 8. Note that as explained before the queuing delay requirements in the GSM system are tightened to account for the lower data rate.

FIGURE 8

Capacity loss for inter-RAT handover



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