

REPORT ITU-R M.2030

Coexistence between IMT-2000 time division duplex and frequency division duplex terrestrial radio interface technologies around 2 600 MHz operating in adjacent bands and in the same geographical area

(Question ITU-R 229/8)

(2003)

1 Introduction**1.1 Introduction and outline**

In this Report the coexistence between IMT-2000 time division duplex (TDD) and frequency division duplex (FDD) radio interfaces are investigated. Specifically, the interference properties between IMT-2000 CDMA Direct Spread (also called WCDMA or UTRA FDD) and IMT-2000 CDMA TDD (also called 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 a large number of scenarios.

The main part of the Report describes base station to base station (BS-BS) interference for both proximity and co-location scenarios. Also mobile station (MS) to BS, BS-MS and MS-MS scenarios are studied for proximity scenarios.

In § 2.4-2.5, the transmitter and receiver characteristics are described. In § 2.8 the relation between the external interference level, and coverage and capacity is discussed. In § 3.2 the methodology of the deterministic BS-BS and MS-MS scenarios is described. The Monte Carlo methods are described in § 3.3. The results are presented in § 4 and conclusions are made in § 5.

An overview of the results can be obtained by reading § 1, 2.1-2.3 and 5.

1.2 Scope

For the purposes of the analysis in this Report it has been assumed that TDD and FDD systems at 2.5 GHz will have similar characteristics to those of WCDMA and HCR/LCR TDD as given in Recommendation ITU-R M.1457.

1.3 Summary

This Report provides an analysis and present results of the consequences of adjacent channel interference (ACI) on FDD and TDD compatibility for a number of scenarios. This 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 feasibility of certain scenarios is subject to a trade-off between technical, regulatory and economical factors. In this Report, different points of view have been reflected on factors such as propagation conditions, user density and placement, which correspond to different trade-off choices. The above views by no means exclude other points of views. The conclusions below reflect only the studies made in this Report.

It is recognized that any potential improvement brought about by mitigation techniques such as site engineering, adaptive antenna, etc, is not covered in this Report and should be the subject of further study.

Main results

BS-BS interference: General observations

- Several scenarios and parameter settings examined are associated with severe interference problems.
- The separation distances have been calculated over an interval of tolerated external interference where the smaller value for separation distance implies high levels of planned tolerated external interference which in turn implies smaller coverage and/or capacity and higher transmit powers for the MS in the victim system.
- There is no fundamental difference in magnitude of interference when considering FDD downlink (DL) to TDD uplink (UL) interference or when considering TDD DL to FDD UL for any of the examined scenarios.
- Thus, the potential problems come from the basic fact that DL transmitters are geographically and spectrally close to sensitive UL receivers, regardless of the duplex method involved.
- Minimum requirements available in third generation partnership project (3GPP) specifications on transmitter and receiver characteristics are assumed to the maximum extent possible. It could be noted that practical equipment may be better than required in the specifications.
- For several scenarios large values of separation distances or additional isolation are needed to obtain low interference conditions. Some scenarios have low separation distances and do not require additional isolation.
- In some deployment scenarios separation distances or filtering requirements can be traded off against coverage and higher MS transmit powers in the victim system.
- There are a number of basic actions that can be taken alone or in combination in order to combat the BS-BS interference problems. All actions are associated with some kind of cost or other difficulties that must be taken into account as well, as there is always a trade-off to consider.

BS-BS interference in proximity: WCDMA/3.84 Mchip/s TDD

The required separation distances are in a range from 1 m to 15 km depending upon the cell types involved and carrier separation used. They are the lowest for pico-to-pico scenarios and the highest for macro-to-macro scenarios.

BS-BS interference in proximity: WCDMA/1.28 Mchip/s TDD

Based on assumptions for reference separation distances, only the macro-to-macro scenario requires significant additional isolation. For other scenarios, the basic isolation is sufficient.

BS-BS co-location: WCDMA/3.84 Mchip/s

- Co-location of BSs will be prevalent in future systems
- When WCDMA and 3.84 Mchip/s macro BSs are co-located the noise floor of both systems are impacted considerably when considering a 30 dB coupling loss
- Coverage and capacity will be severely affected, if appropriate isolation is not provided between the BSs.
- Based on the existing specifications and minimum coupling loss (MCL) assumptions, even a guardband of 5 MHz and 10 MHz will not remove the problem.
- Continued studies must define needed system specifications and guardbands, as appropriate, considering BS co-location, taking into consideration the fact that some degree of isolation may be achieved in practical systems.

MS-BS, BS-MS interference

- 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.

MS-MS interference

- The Monte Carlo simulations suggest that MS-MS interference will have a small or negligible impact on the capacity when averaged over the system and using uniform user densities (see § 4.2.2.3).
- Deterministic MS-MS calculations suggest that one mobile might create severe interference to another geographically and spectrally close mobile (see § 4.2.3).
- Studies are therefore needed where non-uniform user densities are considered, which are more realistic in real systems in hot spot areas (see § 4.2.3).
- The outage cannot be reduced much even at the cost of BS density or capacity decrease. Instead, the requirements should be set on the service level.

2 Assumptions

2.1 Radio interface technologies considered

In this Report the IMT-2000 technologies considered are the FDD based IMT-2000 CDMA Direct Spread radio specification and the TDD based IMT-2000 CDMA TDD with its two modes HCR TDD (3.84 Mchip/s) and LCR TDD (also known as TD-SCDMA, 1.28 Mchip/s).

They are for simplicity referred to as FDD and TDD, respectively, in the appropriate sequence.

2.2 Interference scenarios

This Report considers the following basic scenarios:

- Interference to FDD BS caused by TDD BS (Deterministic calculations)
- Interference to TDD BS caused by FDD BS (Deterministic calculations)
- Interference to FDD BS caused by TDD user equipment (UE) (Monte Carlo simulations)
- Interference to TDD BS caused by FDD UE (Monte Carlo simulations)
- Interference to FDD UE caused by TDD UE (Monte Carlo simulations)
- Interference to TDD UE caused by FDD UE (Monte Carlo simulations)
- Interference to FDD UE caused by TDD BS (Monte Carlo simulations)
- Interference to TDD UE caused by FDD BS (Monte Carlo simulations)
- Interference to FDD UE caused by TDD UE (Deterministic calculations)
- Interference to TDD UE caused by FDD UE (Deterministic calculations)

The methodology used in the calculations and simulations is described in § 3.

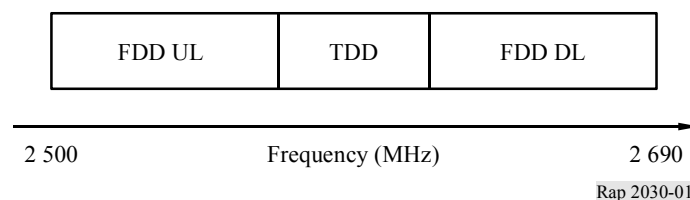
2.3 Involved cell layers

All scenarios should be considered, i.e. macro, micro and pico. However, not all combinations of FDD and TDD cell layers have been investigated since some are considered less likely.

2.3.1 Frequency allocation

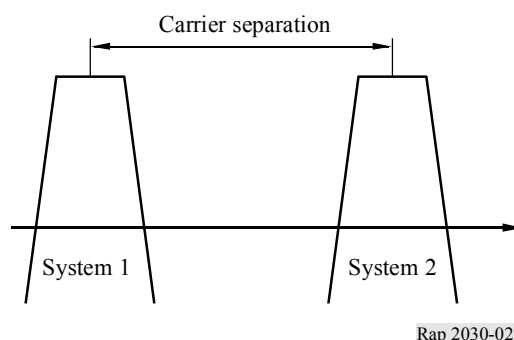
The study focuses on coexistence in the IMT-2000 band between 2 500 MHz and 2 690 MHz. A principle allocation according to Fig. 1 is assumed. This study focuses on interference between TDD and FDD UL as well as TDD and FDD DL. Interference between FDD UL and FDD DL is not considered (because of the frequency separation). No particular assumptions on the sizes of the bands have been made since the focus is on the border effects between FDD UL and TDD, and TDD and FDD DL, respectively.

FIGURE 1
Assumed frequency allocation



It is assumed in the calculations that the TDD and FDD bands are separated with a certain amount of bandwidth (possibly of zero width). The carrier separation is defined as the spectral distance between the centre frequencies of the respective bands, including possible guardbands.

FIGURE 2
Carrier separation



The carrier separation thus consists of half the bandwidth of system 1 plus half the bandwidth of system 2 plus possibly extra guardband. For WCDMA 3.84 Mchip/s TDD the carrier separation is a minimum $2.5 + 2.5 = 5$ MHz and for WCDMA/TD-SCDMA it is minimum $2.5 + 0.8 = 3.3$ MHz.

With 5 MHz extra guardband the carrier separation thus becomes 10 or 8.3 MHz, respectively.

2.3.2 Deployment scenarios and BS position

In this study, different types of BSs (for both FDD and TDD deployment) are considered (macro, micro and pico). A macro BS is assumed to be located above rooftop and to be deployed in areas with both high and low user densities. The main objective of the macro BSs is to achieve coverage over a relatively large area.

A micro BS is assumed to be located outside below rooftop and are deployed in areas with high user densities. The micro BSs are mainly used to enhance the capacity in areas with high user densities.

The pico BS is located indoors and used for indoor coverage only. Typical deployment scenarios are in an office building. The pico BS could in principle be located at any floor within a building. However, it is here assumed that the height of the pico BS is approximately the same as the height of a micro BS.

The assumed heights of the different BSs are summarized in Table 1. Furthermore, the average building height is assumed to be 24 m and thus, the macro BSs are positioned 6 m above the average rooftop.

TABLE 1

Assumed heights of the macro, the micro and the pico BS (both FDD and TDD)

BS type	Height (m)
Macro	30
Micro	6
Pico	6

2.4 Transmitter characteristics

The transmitter characteristic includes output power restrictions and transmitter antenna gain.

2.4.1 Output power and antenna gain

The BS maximum output power and antenna gain for FDD and TDD BSs are found in Table 2.

TABLE 2

Maximum output power and Tx antenna gain for the macro, micro and pico BSs (FDD and TDD)

BS type	Maximum output power (dBm)	Antenna gain (Tx) (dBi)
FDD macro	43	15
FDD micro	30	6
FDD pico	24	0
3.84 Mchip/s TDD macro	43	15
3.84 Mchip/s TDD micro	30	6
3.84 Mchip/s TDD pico	24	0
TD-SCDMA macro	34 ⁽¹⁾	15
TD-SCDMA micro	21 ⁽¹⁾	6
TD-SCDMA pico	12 ⁽¹⁾	3 ⁽¹⁾

⁽¹⁾ The transmitter power of TD-SCDMA BS is assumed lower than for 3.84 Mchip/s because of the use of 8-element smart antenna system employed for TD-SCDMA.

The FDD BS is assumed to transmit continuously whereas the TDD BS is assumed to transmit half of the time (activity factor = 0.5).

The FDD and TDD MS maximum output power and transmission antenna gain are found in Table 3.

TABLE 3

Maximum output power and Tx antenna gain for FDD and TDD MSs

MS type	Maximum output power (dBm)	Antenna gain (Tx) (dBi)
FDD	21	0
TDD	21	0

2.4.2 Spectrum masks and adjacent channel leakage ratio (ACLR) values

The BS ACLR values in Table 4 are from [1] and [2] respectively. For the TDD BS, the ACLR requirement refers to the case of coexistence with other (TDD or FDD) systems.

The below values are valid for 3.84 Mchip/s TDD. For 1.28 Mchip/s TDD, see § 2.6.

TABLE 4

FDD and TDD BS ACLR

Carrier separation (MHz)	FDD BS ACLR (dB)	TDD BS ACLR (dB)
5	45	70
10	50	70
15	67	70

The ACLR values employed for FDD and TDD MSs can be found in Table 5. The values are taken from [3] and [4] except for 15 MHz where an assumption has been made.

TABLE 5

FDD and TDD MS ACLR

Carrier separation (MHz)	FDD MS ACLR (dB)	TDD MS ACLR (dB)
5	33	33
10	43	43

2.5 Receiver characteristics

2.5.1 Receiver noise floor and antenna gain (FDD and TDD)

A noise floor of -103 dBm and -99 dBm supposes a noise figure (NF) of 5 and 9 dB respectively (thermal noise power -174 dBm/Hz $\cdot$ 3.84 MHz = -108 dBm/3.84 MHz).

The receiver noise floor and the receiver antenna gain for FDD and TDD BSs are found in Table 6. The corresponding values for the FDD and TDD MSs are found in Table 7.

TABLE 6

FDD and TDD BS receiver noise floor and antenna gain

BS type	Receiver noise floor (dBm)	Antenna gain (Rx) (dBi)
FDD macro	−103	15
FDD micro	−103	6
FDD pico	−103	0
TDD macro	−103	15
TDD micro	−103	6
TDD pico	−103	0

TABLE 7

FDD and TDD MS receiver noise floor and antenna gain

MS type	Receiver noise floor (dBm)	Antenna gain (Rx) (dBi)
FDD	−99	0
TDD	−99	0

2.5.2 Receiver sensitivity

The BS reference sensitivity levels in Table 8 (specified for a 12.2 kbit/s service, BER must not exceed 0.001) are taken from [1] and [2].

TABLE 8

BS reference sensitivity for FDD and TDD BSs

BS type	BS reference sensitivity level (dBm)
FDD macro	−121
FDD micro	−121
FDD pico	−121
3.84 Mchip/s TDD macro	−109
3.84 Mchip/s TDD micro	−109
3.84 Mchip/s TDD pico	−109

The MS receiver sensitivity values presented in Table 9 are from [3] and [4], respectively.

TABLE 9

FDD and TDD MS receiver sensitivity

MS type	BS reference sensitivity level (dBm)
FDD	−117
TDD	−105

2.5.3 Adjacent channel selectivity (ACS) specifications

The BS ACS values in Table 10 are (indirectly derived) from [1] and [2] except for 15 MHz where an assumption has been made. Furthermore, the FDD and TDD MS ACS are found in Table 11.

The below values are valid for 3.84 Mchip/s TDD. For 1.28 Mchip/s TDD, see § 2.6.

TABLE 10

FDD and TDD BS ACS

Carrier separation (MHz)	FDD BS ACS (dB)	TDD BS ACS (dB)
5	46	46
10	58	58
15	66	66

TABLE 11

FDD and TDD MS ACS

Carrier separation (MHz)	FDD MS ACS (dB)	TDD MS ACS (dB)
5	33	33
10	43	43

2.6 Resulting adjacent channel interference ratios (ACIRs)

The ACS and ACLRs have been taken from the 3GPP specifications for 5 and 10 MHz carrier separation and have been estimated for 15 MHz carrier separation.

The above ACLR and ACS values result in an ACIR value according to the following formula:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \text{ (in linear terms)}$$

The values have been rounded in the ACIR column.

TABLE 12

FDD to 3.84 Mchip/s TDD BS ACIR

Carrier separation (MHz)	FDD BS ACLR (dB)	3.84 Mchip/s TDD BS ACS (dB)	Resulting ACIR (dB)
5	45	46	~42
10	50	58	~49
15	67	66	~63

TABLE 13

3.84 Mchip/s TDD to FDD ACIR

Carrier separation (MHz)	3.84 Mchip/s TDD BS ACLR (dB)	FDD BS ACS (dB)	Resulting ACIR (dB)
5	70	46	~46
10	70	58	~58
15	70	66	~64

TABLE 14

TD-SCDMA to FDD BS ACIR

Carrier separation (MHz)	TD-SCDMA BS ACLR (dB)	FDD BS ACS (dB)	Resulting ACIR (dB)
3.3	50 (in the specification a value of 50 dB for 3.2 MHz carrier separation is used also here)	46	~45
8.3	65 (estimated)	58	~57

Note that the TD-SCDMA ACLR values for 8.3 MHz carrier separation has been estimated since there is no specified value for this separation in the standard specification.

2.7 The practical gain of antennas of the interfering station and the victim

With conventional antenna systems, the practical gain of interfering and victim stations are considered to be the sum of the individual antenna gains in the direction from the interfering to the victim stations, including the effects such as difference in height and downtilt angles. In the special case of the direct boresight coupling, this gain would be the sum of the maximum antenna gains and could result in the worst case coexistence scenario. For detailed derivation of the practical antenna gains, please refer to Appendix 3.

When TDD systems utilize adaptive antenna beam forming, the coexistence situation must be analysed differently and determining the likelihood of interference requires statistical analyses such as Monte Carlo simulations. Any potential improvement brought about by the use of adaptive antenna is not covered in this Report and requires further study.

Reference separation distance

2.8 Relation between acceptable BS degradation and additional interference to the BS

In order to understand the full system impact of a certain interference source (and consequently the required separation distances) it is important to investigate the coverage and capacity losses induced by a certain external interference level.

In this section the impact on coverage and capacity is investigated as a function of the total noise level including both receiver noise and the external interference. Given the acceptable losses this determines the corresponding acceptable interference level. After that the required separation distances can simply be read from the Tables in § 4.

Two different approaches are taken to study the impact of an increased noise floor in the UL of an FDD cell: the impact on coverage and the impact on capacity.

In the first approach, the required number of BSs (or the BS density) is calculated for different values of the total noise floor (BS receiver noise + external interference) and for two different user densities. This to show the effect on the required BS density of an increased noise floor in lightly and heavily loaded macro systems. The method is described in [5].

In the second approach, the impact of an increased noise floor is studied in a network with fixed BS positions. Here, the increased noise floor results in a lower system capacity.

Although only the FDD system impact has been investigated, the same principles apply also for the TDD system and similar losses will be experienced.

2.8.1 Definitions and basic relations

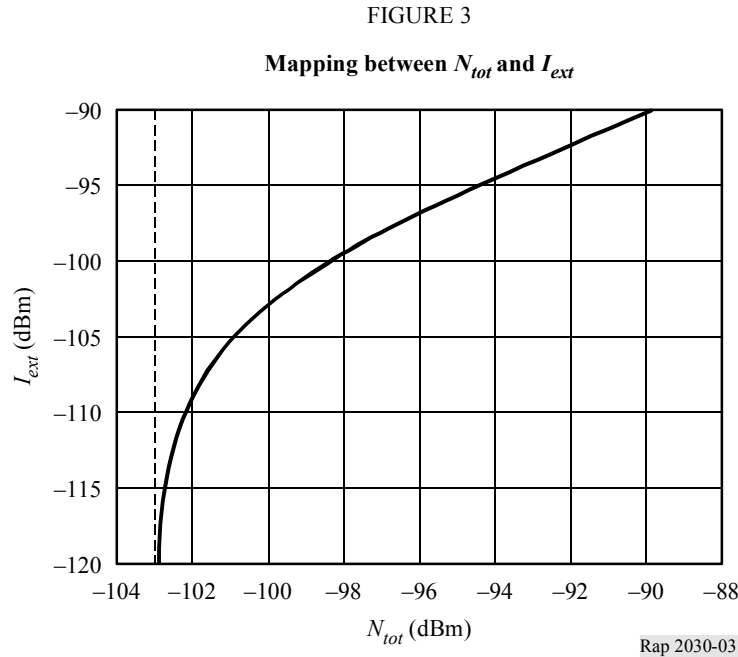
The receiver noise floor due to thermal noise is denoted N_{BS} and is assumed fixed: $N_{BS} = -103$ dBm.

The internal interference in the victim system consists of both intercell and intracell interference and is denoted, I_{int} , while the external interference from the aggressor system is denoted, I_{ext} .

The total noise floor experienced in the victim system is defined as:

$$N_{tot} = N_{BS} + I_{ext}$$

The mapping between N_{tot} and I_{ext} with a fixed $N_{BS} = -103$ dBm is shown in Fig. 3.



In a system without external interference the total receiver noise floor is $N_{tot} = N_{BS} = -103$ dBm.

The total interference, I , consists of three components:

$$I = N_{BS} + I_{ext} + I_{int}$$

2.8.2 Impact on the BS density for a given user population

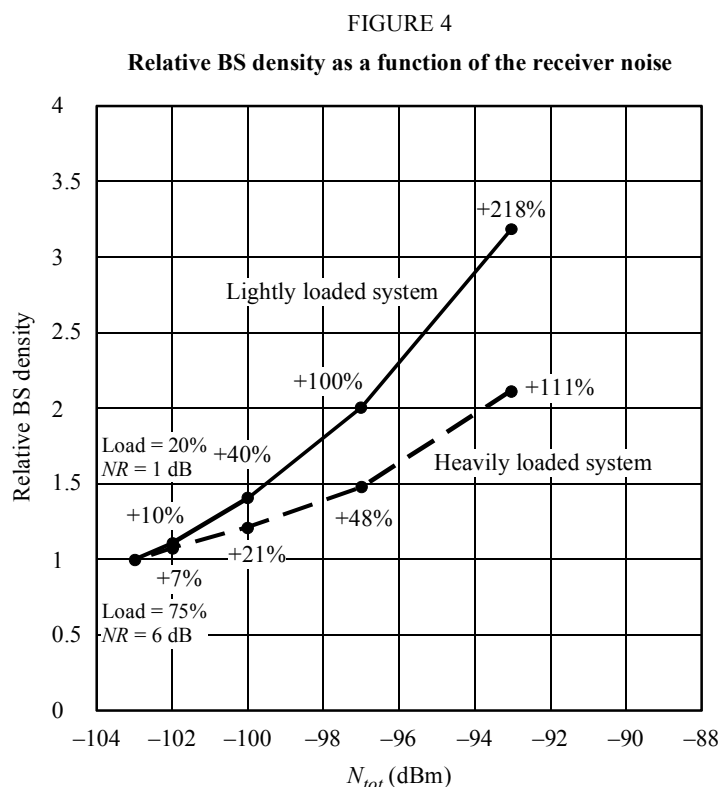
The impact of an increased noise floor (caused e.g. by external interference) on the FDD UL is shown in Fig. 4. The BS density is plotted as a function of the “total noise floor” at the FDD BS receiver.

The reference point is derived for a known area with a known user density. A FDD macro cellular system should cover the area and provide service to the users using a certain QoS criterion. To minimize the costs, as few BSs as possible should be used. Since the users are power limited it is usually the UL that limits the coverage in macro cells.

The leftmost ends of the curves in Fig. 4 correspond to an isolated system where no external interference is present. With the introduction and increase of external interference, N_{tot} rises successively, which leads to tighter required cell plan in order to fulfil the QoS criterion. The relative increase in number of BS compared to the reference case is plotted in Fig. 4.

Two systems are studied, one lightly loaded system where the load is 20% of pole capacity and one heavily loaded system where the load is 75% of pole capacity. This corresponds to a noise rise (NR) of 1 and 6 dB, respectively.

As can be seen, the impact is more severe in the lightly loaded system (planned mainly for coverage) than in the heavily loaded system (planned also for high capacity).



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2.8.3 Impact on the system capacity with a given cell plan

In this scenario it is assumed that the BS density cannot be affected by tighter cell plan. Instead the external interference will have consequences on the system capacity. It will be shown that the UL capacity loss is dependent on the deployment scenario and the system plan.

The system must satisfy the constraints that the UL service must meet a certain C/I target; and that the MS must use a power level less than the peak power limit up until the designed cell border. Thus, the total interference, I , at the BS receiver must not exceed a certain value, I_{acc} , the maximal level of acceptable interference that consequently follows from the cell size criterion.

Thus, $I = N_{BS} + I_{ext} + I_{int} \leq I_{acc}$ must hold.

The noise floor experienced in the victim system is as before:

$$N_{tot} = N_{BS} + I_{ext}$$

In addition to the above inequality there is the further stability constraint that I_{int} cannot be more than 6 dB higher than the total noise floor N_{tot} which corresponds to a load of 75% of the pole capacity.

For macro cells and micro cells planned also for indoor coverage I_{acc} must be fairly small since the BS must be able to detect a weak MS signal at the faraway cell border (or indoor behind walls) with given C/I . For micro cells with street only coverage I_{acc} can be larger. Pico cells are intended for small cells with little or no coverage problems and allows for even larger I_{acc} . In the next paragraphs this is further examined.

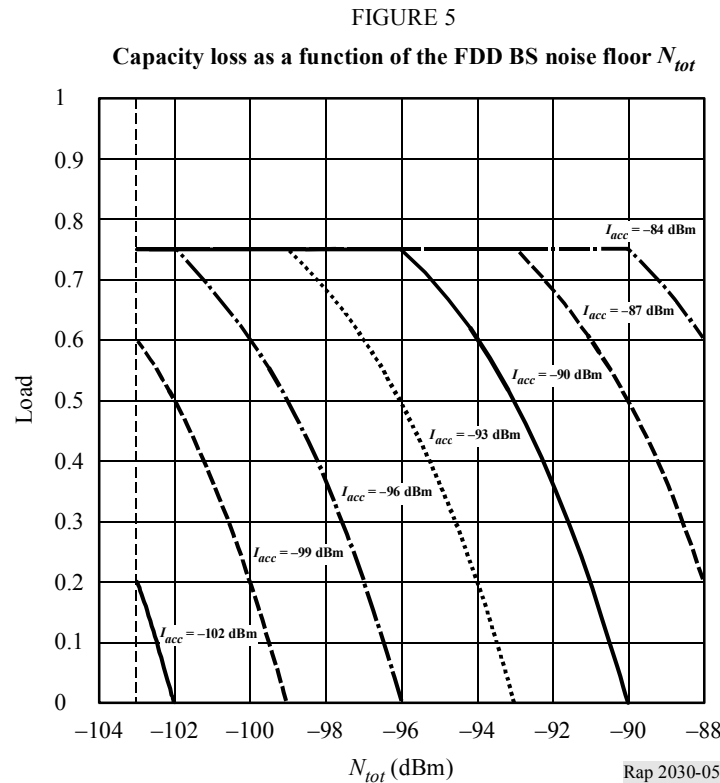
As long as I_{ext} and I_{int} are small enough so that the above inequality holds, I_{ext} and I_{int} can increase without harming either coverage or capacity. When I_{ext} (and thus N_{tot}) increases also I_{int} must increase since the C/I requirements must be fulfilled in the system.

However, when the left-hand side of the inequality equals I_{acc} one of the following must happen when I_{ext} is further increased:

- The left-hand side grows beyond the limit I_{acc} and the inequality is violated.
- Reducing the load I_{int} in the system, compensates the increase of I_{ext} .

The first option reduces the coverage and creates holes in the cell plan and is not investigated further. The second option keeps the cell plan but reduces the capacity. It is the target of the following investigation to quantify this effect.

Figure 5 shows the load that can be handled as a function of the total receiver noise N_{tot} . Since the maximum load is limited to 75% for stability reasons there are horizontal segments of the curves. Each curve is plotted under a certain assumption of I_{acc} and will all share the first part of the horizontal segment.



Note though that for values of $I_{acc} < -97$ dBm the maximum load is below 75% since the system sensitivity is limited by $N_{BS} = -103$ dBm even when there is no external interference present. The leftmost curves are relevant for macro cells while the rightmost curves are relevant for pico cells with the curves relevant for micro cells located in between.

The higher values of I_{acc} , the longer the horizontal segment of the curve becomes, and thus, the more external interference can be tolerated without a capacity degradation. Once the external interference reaches a critical point, the capacity drops since the only way to maintain coverage is to reduce the internal interference in the system by throwing out users.

2.8.4 Acceptable levels of degradation

From the previous paragraphs the following conclusions are drawn on the amount of total interference that can be tolerated for different cell types, and the total amount of noise that can be tolerated in order to suffer acceptable capacity losses.

Table 15 indicates typical ranges of the allowed maximum levels of external interference for different types of cells.

TABLE 15

Maximum tolerated interference levels

	I_{ext} proposal (dBm)	I_{acc}		Resulting increase of BSs density	
		With no capacity loss (dBm)	With 5% relative capacity loss allowance	With no capacity loss (%)	With 5% relative capacity loss allowance (%)
Macro rural	-114 to -106	-101.6 to -100.2	-101.6 to -100.2	3 to 21	3 to 21
Macro downtown	-100 to -95	-95.1 to -91	-95.1 to -91.5	52 to 129	52 to 117
Outdoor micro	-97 to -90	-90.5 to -84.1	-90 to -83.6	60 to 183	46.5 to 170
In-building pico	-85	No result	No result	No result	No result

In the result tables in this Report, the range of I_{ext} values in Table 15 has been used for the corresponding cell type.

It should be noted that the lower value of tolerable I_{ext} , the more accentuated is the potential interference problem while a higher value means that the victim system is more robust against external interference. A low value is necessary in deployment scenarios where high sensitivity is desired, for example in coverage limited systems or micro systems planned for indoor coverage. The system can be planned for a higher value to the price of more BSs and sometimes a lower capacity as is indicated in the above sections. Also, the transmitted powers for all MS in the victim system will increase.

The I_{ext} values in this table are used in § 4 to estimate required separation distances or required ACIR.

2.8.5 Reference separation distances

What separation distance between BSs is acceptable or not depends on the cell types considered but also on what kind of restrictions of deployment or cooperation is possible on the particular market. Below we list distances that have been used to evaluate the effects of performance. They seem reasonable in order to give the two operators as much freedom as possible to deploy the way they want independently of each other, but other distances can be considered as well. Larger separation distance might be possible in markets where co-planning between operators is possible.

Table 16 is used in two ways in this Report. The distance is used as an assumed criterion when the required ACIR is calculated. When a fixed ACIR is assumed, the calculated separation distance can be compared with Table 16 to see if the distance requirement is fulfilled.

TABLE 16

Reference separation distances

Scenario	Reference separation distance (m)
Macro-macro	100
Macro-micro	50
Micro-micro	50
Macro-pico	50
Micro-pico	20
Pico-pico	10

3 Interference evaluation methodologies

3.1 Propagation models

All employed propagation models are according to [6] except the dual-slope line of sight (LoS) propagation model. Furthermore, all models are adapted to a frequency of 2.6 GHz.

The propagation models only take the average behaviour into account. Variations around the mean, due to fading, are not considered in the propagation models. Furthermore, the propagation models are originally used for propagation between BSs and MSs. In this study, however, also BS to BS and MS to MS propagation must be considered. If possible, the same propagation models are deployed as for BS to MS propagation.

The following models are employed:

- path loss model for vehicular test environment (see [6])
- path loss model for outdoor to indoor test environment (see [6])
- path loss model for pedestrian test environment (see [6])
- path loss model for indoor test environment (see [6])
- dual-slope LoS propagation model (see Appendix 2 and [7])

Path loss model for vehicular test environment

$$L = 130.5 + 37.6 \log(R)$$

where:

R : distance (km).