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 TTD (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

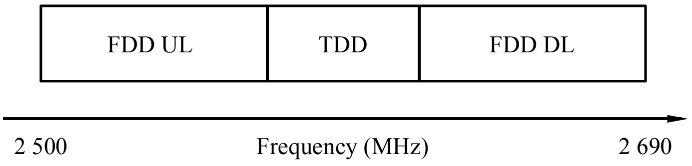
All scenarios should be considered, i.e. macro, micro and pico. However, not all combinations of FDD and TDD cell layers have been investigated since some are considered less likely.

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



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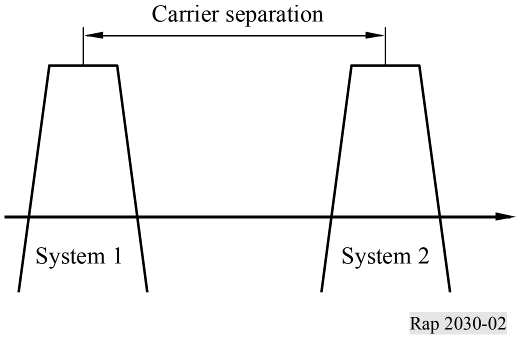
It is assumed in the calculations that the TDD and FDD bands are separated with a certain amount of bandwidth (possibly of zero width). The carrier separation is defined as the spectral distance between the centre frequencies of the respective bands, including possible guardbands.

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 · 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}.

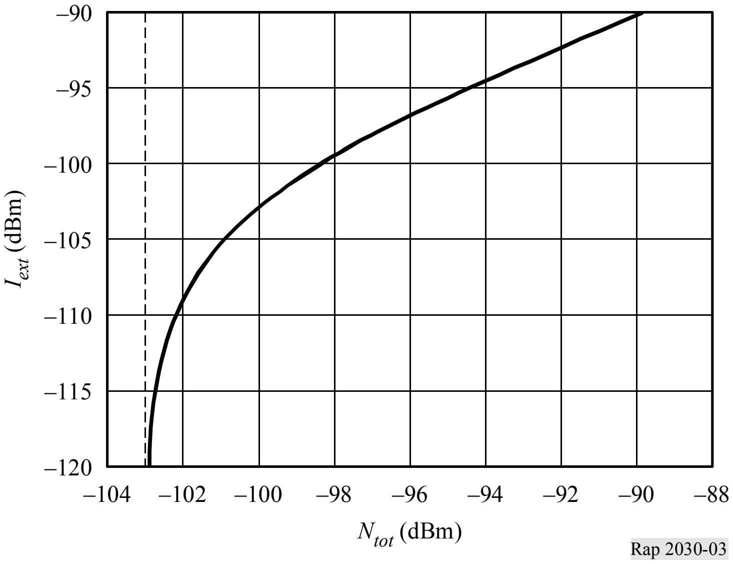
The total noise floor experienced in the victim system is defined as:

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

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

FIGURE 3

Mapping between N_{tot} and I_{ext}



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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.

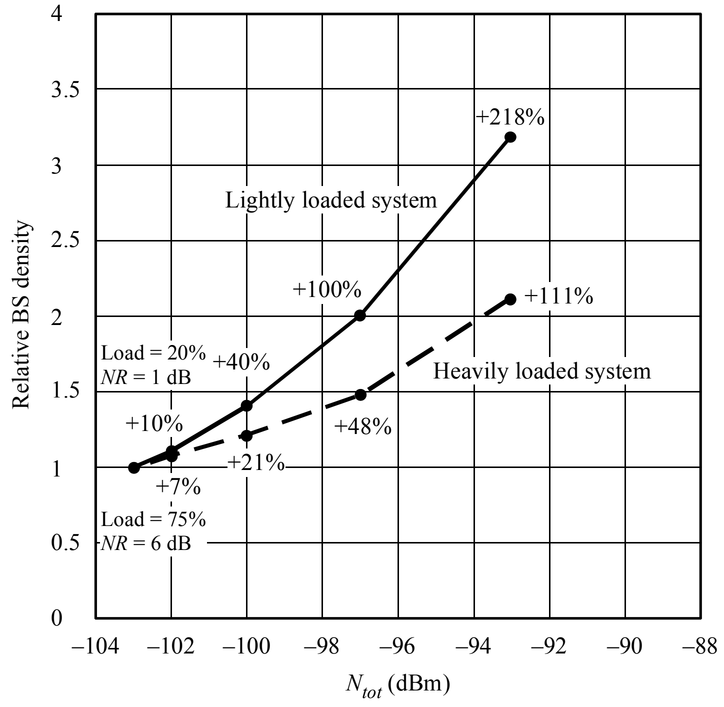
The leftmost ends of the curves in Fig. 4 correspond to an isolated system where no external interference is present. With the introduction and increase of external interference, N_{tot} rises successively, which leads to tighter required cell plan in order to fulfil the QoS criterion. The relative increase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

FIGURE 4

Relative BS density as a function of the receiver noise



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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:

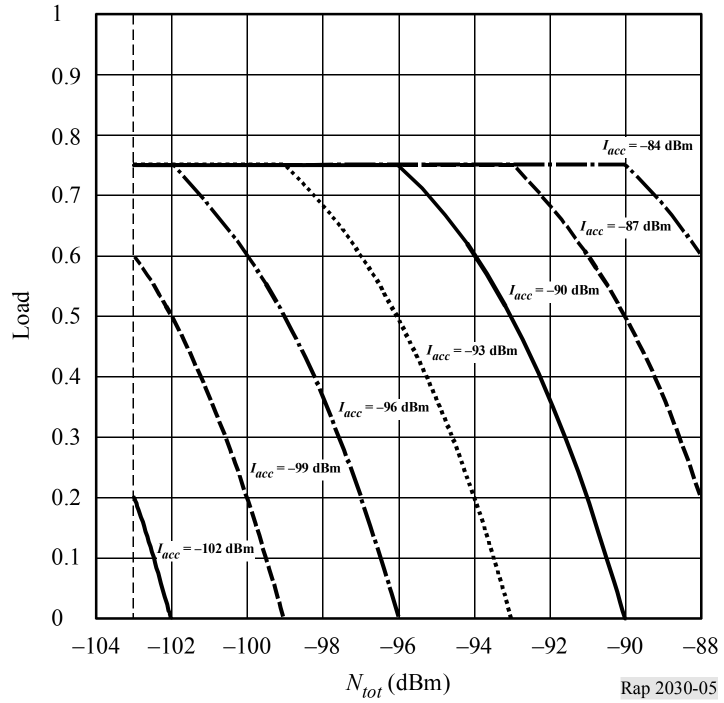
- The left-hand side grows beyond the limit I_{acc} and the inequality is violated.
- Reducing the load I_{int} in the system, compensates the increase of I_{ext}.

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.

FIGURE 5

Capacity loss as a function of the FDD BS noise floor N_{tot}



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).

Path loss model for outdoor to indoor test environment

$$L = 151.4 + 40 \log(R)$$

where:

R: distance (km).

Path loss model for pedestrian test environment

One corner of 90° is assumed to be in-between the transmitter and the receiver. Further, the height of the transmitter and the receiver is assumed to be significantly less than the height of the surrounding buildings.

$$L = 20 \log\left(\frac{4 \pi d_n}{\lambda}\right)$$

$$d_n = \frac{d}{2}\left(2 + d \cdot \frac{q}{2}\right)$$

where:

d: distance (m).

Path loss model for indoor test environment

$$L = 37 + 30 \log(R) + 18.3\, n^{\left(\frac{n+2}{n+1} - 0.46\right)}$$

where:

R: distance (m)

n: number of floors in the path.

Dual-slope LoS propagation

The dual-slope LoS propagation model assumes free-space propagation until the breakpoint, d_{break}. After the breakpoint, the attenuation is increased because of reflections on the ground.

$$L_{LoS} = \begin{cases} 40.7 + 20 \log(d) & \text{for} \quad 1 \le d \le d_{break} \\ 40.7 - 20 \log(d_{break}) + 40 \log(d) & \text{for} \quad d \ge d_{break} \end{cases}$$

where:

d: distance (m).

The breakpoint is calculated as:

$$d_{break} = 4 \frac{h_{tx} \cdot h_{rx}}{\lambda}$$

where:

h_{tx} and h_{rx}: height (over the reflecting surface) of the transmitter and the receiver

λ: wavelength.

The breakpoint is assumed to appear at the distance where the first Fresnel zone is tangent to the ground (reflecting surface). The formula for breakpoint calculation above approximates this.

Example: Assuming a height of 6 m of both the transmitter and the receiver, the breakpoint becomes 1 248 m (a frequency of 2.6 GHz corresponds to a wavelength of 0.1154 m).

See Appendix 2 for more details about this model.

3.2 Deterministic calculations

3.2.1 BS-to-BS interference

FDD macro – TDD macro

In proximity: The dual slope LoS propagation model is employed to calculate the pathloss between a FDD macro and a TDD macro BS.

Co-located: no path loss model is used. A coupling loss of 30 dB is used.

FDD macro – TDD micro

The vehicular pathloss model is employed to model the propagation between a FDD macro BS and a TDD micro BS. This assumes that the height of the FDD BS is above rooftop and that the height of the TDD BS is significantly lower than the surrounding buildings.

FDD macro – TDD pico

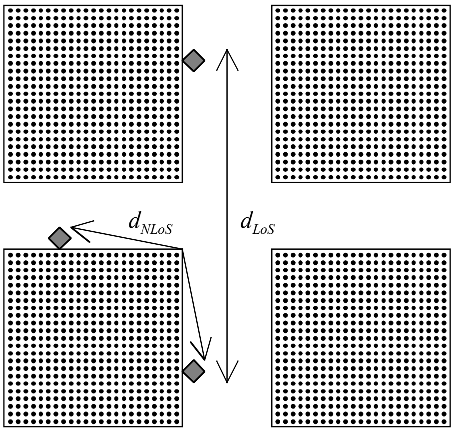
The outdoor to indoor propagation model is employed to calculate the pathloss between a FDD macro BS and a TDD pico BS. The pico BS is assumed to be located inside a building and furthermore, there is no LoS between the two BSs (LoS could, e.g., appear when a pico BS is located high up in the building close to a window that faces the macro BS).

FDD micro – TDD micro

For FDD micro – TDD micro, two scenarios are considered. The BSs are assumed to be located either in the same street or in different streets. Location in the same street implies LoS propagation. If the BSs are located in different streets, it is assumed that there is only one corner (of 90°) between the BSs and that the distance from to the base to the corner is the same for both BSs. The scenarios are depicted in Fig. 6.

FIGURE 6

Propagation between 2 micro BSs in the same and in different streets



NLoS: no LoS

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The dual slope LoS propagation model is employed for the case when the BSs are located in the same street. The pedestrian path loss model is used if the BSs are located in different streets.

FDD micro – TDD pico

The outdoor to indoor path loss model is used in this scenario. NLoS is assumed between the BSs (LoS could e.g. be caused by a window between the BSs).

FDD pico – TDD macro

Not considered.

FDD pico – TDD micro

Outdoor to indoor path loss model (see also FDD micro – TDD pico above).

FDD pico – TDD pico

Both the FDD and the TDD BSs are assumed to be located inside the same building but separated by one floor.

Calculation example, interference to macro FDD BS Rx, caused by macro TDD BS Tx.

First we give an example how the required separation distance is calculated when the ACIR is given, and then how to calculate the required ACIR when the distance is given. In § 2 and Appendix 3, all values of resulting antenna gains and ACIR are tabulated as well as the relevant interval of tolerated external interference.

Input:

TDD BS output power	$P = 43$ dBm
TDD BS activity factor 0.5	$\alpha = -3$ dB
TDD BS Tx antenna gain	$G_{A,Tx} = 15$ dBi
TDD BS ACLR	$ACLR = 70$ dB
FDD BS Rx noise floor	$Rx_{noise} = -103$ dBm
FDD BS Rx antenna gain	$G_{A,Rx} = 15$ dBi
FDD BS ACS	$ACS = 46$ dB

Step 1: Calculate the efficient output power

The efficient output power is the average transmitted power, i.e. the output power plus the activity factor.

$$P_{average} = P + \alpha = 43 + (-3) = 40 \text{ dBm}$$

Step 2: Calculate the resulting antenna gain

Here, 2 macro BSs at the same height are considered. The resulting antenna gain is the sum of the Tx and the Rx antenna gain.

$$G_A = G_{A,Tx} + G_{A,Rx} = 15 + 15 = 30 \text{ dBi}$$

Step 3: Calculate the *ACIR*

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

$(ACLR, ACS) = (70, 46)$ dB implies that $ACIR = 45.98$ dB ≈ 46 dB.

Step 4: Define the maximum tolerable adjacent channel interference

According to Table 15, N_{tot} should be at most –102.7 dBm which for $N_{BS} = -103$ dBm implies that $ACI_{max} = -114$ dBm.

Step 5: Calculate the required path loss

$$L = P + G_A - ACIR - ACI_{max} = 40 + 30 - 46 - (-114) = 138 \text{ dB}$$

Step 6: Convert the path loss to a required separation distance (according to the propagation formula)

$$L_{LoS} = \begin{cases} 40.7 + 20\log(d) & \text{for} \quad 1 \leq d \leq d_{break} \\ 40.7 - 20\log(d_{break}) + 40\log(d) & \text{for} \quad d \geq d_{break} \end{cases}$$

The attenuation at the breakpoint at 1 248 m is 102.6 dB. Thus, the searched distance is after the breakpoint ($d > d_{break}$). The required separation distance $d_{sep} = 9\,541$ m.

When the separation distance is given instead, and the required *ACIR* is the sought value, instead Steps 5 and 6 are slightly changed into:

Step 7: Calculate the required *ACIR*

$$ACIR = P + G_A - L - ACI_{max}$$

where (according to the propagation formula) L is a function of the propagation model (LoS in the example) and given distance d:

$$L_{LoS} = \begin{cases} 40.7 + 20\log(d) & \text{for} \quad 1 \leq d \leq d_{break} \\ 40.7 - 20\log(d_{break}) + 40\log(d) & \text{for} \quad d \geq d_{break} \end{cases}$$

If $d = 100$ m

$$ACIR = 40 + 30 - (40.7 + 20\log(100)) - (-114) = 103.3 \text{ dB}.$$

3.2.2 BS-BS interference, alternative evaluation

The methodology used in the evaluation of the BS-BS interference above can be used to establish a trade-off between the transmit power that is needed for coverage and the power that is available for overcoming external interference. Thus the supportable path loss at cell edge is determined assuming the fulfillment of *C*/*I* requirements and a 6 dB cell noise rise over the external interference.

Three cases are considered:

- TDD and FDD in micro deployment, NLoS between BSs.
- TDD and FDD in micro deployment, LoS between BSs.
- TDD in micro and FDD in macro deployment.

Two cases are considered for the combined antenna gain for macro-micro combination. Under the worst-case assumption, the results are calculated assuming that the antennas of the victim BS and the aggressor BS were looking at each other in the direction of their maximum gain. In that case the combined gain of the two antennas is 21 dB since we assume a macro BS with 15 dBi gain and a micro BS with a 6 dBi gain.

However, as shown in Appendix 3, the combined gain of the transmitting and receiving antennas, when they are close to each other, is less than (or equal to) 8 dB.

The difference in the level of interference between the two assumptions is 21 – 8 dB = 13 dB. Consequently, the supportable cell range difference is the same amount (slightly less than 13 dB, because of the contribution of thermal noise).

In most cases the parameters assumed for the analysis above were kept. Changed parameters are listed in Table 17. Regarding the ACLR parameters of the TDD BS, two sets of values are used. The first set corresponds to the minimum requirements defined in [2], while the second set corresponds to the values shown in Table 4. The increase of the ACLR (at 5 MHz and 10 MHz) to 70 dB decreases the level of interference from the aggressing BS to the victim BS, hence the supportable cell range increases.

TABLE 17

Assumptions for alternative evaluation of BS-BS interference

Parameter		Micro-micro, NLoS	Micro-micro, LoS	Micro-macro
BS transmit duty ratio		1		
Voice activity factor (dB)		–2.8		
TDD BS (Set 1)	ACLR1	45		
	ACLR2	55		
	ACLR3	70		
TDD BS (Set 2)	ACLR1	70		
	ACLR2	70		
	ACLR3	70		
ACLR1 (FDD BS)		45		
ACLR2 (FDD BS)		55		
ACLR3 (FDD BS)		67		
Coupling distance (m)		50		
Coupling (dB)		89	72	79

3.3 Monte Carlo simulation

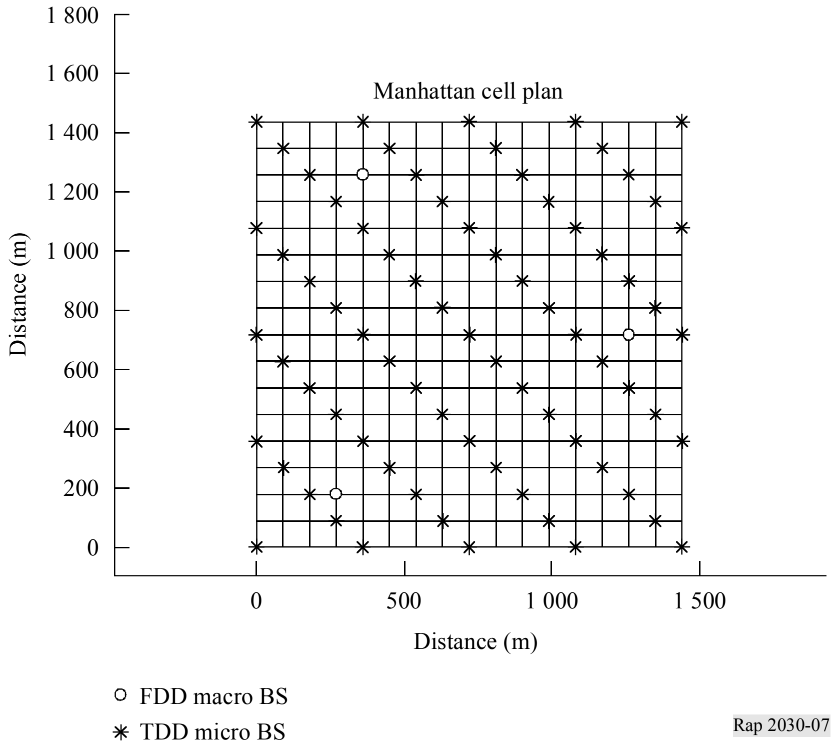
3.3.1 Capacity consequences of MS-BS, BS-MS, MS-MS interference in FDD macro/ 3.84 Mchip/s TDD micro scenarios

Environment and propagation models

The used cell plan is a regular Manhattan environment, see Fig. 7. The environment configuration is similar to what is proposed in [6, § 6.1.5]. The block size is 75 × 75 m and the street width is 15 m. TDD is only modelled as a micro system, comprising 73 BSs. The FDD system is assumed to be either a macro (above rooftop) or a micro system. 12 macro systems are modelled, however, as shown in Fig. 7, only 3 are used in the performance evaluation. The surrounding 9 BSs are used only to avoid border effects. FDD micro BSs are modelled in the same way as TDD micro BS. The TDD and the FDD micro BSs are however not co-sited, instead always located one block away from each other.

FIGURE 7

The employed cell pattern



Users are located outside in the street and randomly distributed in the area.

The vehicular pathloss model is applied to describe the radio propagation between a macro BS and a user. Between a micro BS and a user and between two users, the pedestrian pathloss model is used.

Table 18 presents the most important simulation parameters.

TABLE 18

Required *C*/*I* and assumed asymmetry

	Power control type	**Required *C*/*I***	**Number of time slots per frame (TDD only)**
FDD DL	*C*/*I*-based	–21	–
FDD UL	*C*/*I*-based	–21	–
TDD DL	*C*/*I*-based	–3	8
TDD UL	*C*/*I*-based	–5	7

Performance measures

Outage and blocking are used as performance measures. Outage occurs when a user cannot reach the *C*/*I* target (and is expressed in relation to the total number of users). Blocking occurs when a user cannot enter the system because there are not enough resources at the BSs (e.g. when all channels are busy).

The capacity is defined as the maximum traffic load at which the outage is below 5% and the blocking rate is below 2%.

All evaluations are performed for 5 and 10 MHz carrier separation.

MS-BS interference

Here, the case when TDD terminals interfere with an FDD BS is described. The opposite case, FDD terminals interfering with TDD BSs, is set-up equivalently.

The TDD users are randomly distributed within the system area. Based on this, the pathloss, including shadow fading, can be calculated to the TDD and the FDD BSs. The TDD users connect to the closest TDD BS (in terms of path loss) and are randomly allocated to one of the uplink channels (time slot/code combination).

Furthermore, the required TDD MS output power is calculated such that, if possible, the required *C*/*I* is achieved at the receiver side. According to the output power of all TDD terminals, the ACI can be calculated at the FDD BS receivers. The ACI is calculated for each TDD UL time slot and averaged over the radio frame.

The ACI at each BS, which causes a rise of the FDD BS receiver noise floor, is input to the evaluation of the quality in the FDD system and a similar procedure to what has been described above is now performed in the FDD system. The users are randomly distributed in the system, the pathloss to the FDD BSs is calculated and each user connects to one or several BSs (according to the soft handover criteria). Furthermore, the FDD uplink power is set such that, if possible, the required *C*/*I* at the FDD receiver side is achieved. Finally, the system performance is evaluated by means of outage (and blocking) calculations.

BS-MS interference

Evaluated equivalently to the MS-BS interference scenario described above, however, here the aggressor is a BS (TDD or FDD) and the victim is a MS (FDD or TDD).

MS-MS interference

Evaluated equivalently to the MS-BS interference scenario described above, however, here the aggressor is a MS (TDD or FDD) interfering with another MS (FDD or TDD).

3.3.2 Consequences of MS-BS and MS-MS interference in FDD/3.84 Mchips/s TDD, FDD/1.28 Mchip/s TDD scenarios

The pathloss models and methodology used are very similar to the ones used by Ericsson (see previous paragraph), so only a brief description is given here. The focus of the simulations is on co-existence of macro cells considering a vehicular environment (case 3: 120 km/h) with 8 kbit/s speech users only.

The simulation is a Monte-Carlo based snapshot method calculating cumulative distribution functions for C/I for large numbers (trials) of stochastic mobile distributions over cells (including power control).

No kind of synchronization or coordination between the different systems is assumed.

The goal of simulation procedure is to determine the relative capacity loss of a victim system for a considered link (uplink or downlink) due to the presence of a second system – the interfering system. The reference for the capacity loss is the capacity of the victim system alone without the interfering system.

3.3.3 Outage consequences due to MS-MS interference in FDD/3.84 Mchip/s TDD scenarios

To evaluate a particular frequency arrangement in a band, it is necessary to determine what guardbands between the two systems are necessary, and what effects remain on the channels near the border.

If there is a reduction in capacity in channels near the border, this need not necessarily be a reason to preclude this arrangement. However, this is different for changes to existing bands as opposed to planning for new bands. If a band is already in use, capacity reduction due to the changed use of an adjacent band is more of a problem than when a new band comes into use with two coexisting systems. This is because in the second case it is known from the start that capacity reduction will occur.

The choice of radio access technology in a particular spectrum band depends on the outage probability that is achievable in the band and surrounding channels using a realistic deployment. If the frequency arrangement does not allow for satisfactory minimum outage in a practical deployment, the arrangement should not be used.

For the purpose of choosing frequency arrangements it is usual to perform coexistence studies. The result from such a study will be how effectively the spectrum can be used. There are two measures for expressing the merits of a spectrum arrangement. One is minimum outage and the other is loss of capacity.

Problems with unsatisfactory minimum outage can be avoided by using guardbands between different systems. Adding and/or planning sufficient BSs can deal with the problem of capacity reduction.

Frequency arrangements for FDD (WCDMA) and TDD (3.84 Mchip/s) in adjacent bands can result in interference problems due to the fact that TDD employs both uplink and downlink direction in the same band. On the border between TDD and FDD, it may be necessary to use a guardband and the overall capacity of the TDD and FDD systems may be reduced due to interference.

3.3.3.1 Monte Carlo simulation based on minimum outage

Outage occurs when a user cannot reach the $C/(I + N)$ target, resulting in a connection with the network that cannot be set up or maintained. The outage in general will depend on the combined effects of noise, co-channel interference and adjacent channel interference.

If there is no interference, lack of signal strength will limit the coverage. Interference due to other co-channel users can also cause outage if so many users are present that the interference is too high, so that the number of users accessing the network needs to be limited. Interference from adjacent frequencies can also cause outage that can be resolved for certain scenarios, e.g. BS-BS. Of particular importance is the effect of the ACI for MS-MS interference, where outage can occur that cannot be avoided in planning. Therefore it will be necessary to determine the appropriate size of the guardband in order to prevent an unacceptable outage occurring.

As a measure of the level of interference the term interference probability is often used in this context, and is the same as the outage percentage, i.e. the percentage of users for whom the interference (+ noise) level is too high.

The objective of these simulations is to determine outage due to adjacent channel interference. The focus is on outage that cannot be avoided by appropriate planning of the network.

3.3.3.2 Methodology of simulation

The methodology and tool used to calculate outage is essentially the same as used for Monte Carlo simulation of capacity reduction. The level of the desired signal and the interfering signals are evaluated for each configuration (based on the random distributions) to determine whether the $C/(I+N)$ target is reached or not. The results presented differ from capacity reduction in that the outage is calculated as opposed to assuming an acceptable outage to calculate the level of capacity reduction.

The calculations make use of a victim link and an interfering link (or possible multiple interfering links) that are between a mobile terminal and a BS. The relative positions of the mobile terminals and BSs are defined using distributions.

The effect of co-channel interference is not included. As a result of this, the interference probability in this simulation will be lower than for a loaded system. However, as it is difficult to obtain a good estimate of the load, choosing to model only the adjacent channel interference is an appropriate decision.

In the simulations, users do not move around and no connections are added or removed. Therefore, the point at which a connection is lost is at set up, because the environment will not change. As a result of this, a connection that is set up successfully will be completed successfully. In a realistic network users will move around, therefore a user who does not suffer from outage at the start of a call, may come into an area with high interference, where the call will be dropped.

3.3.3.3 MS-MS interference, FDD macro-TDD macro/pico

The MS-MS interference is evaluated by Monte Carlo simulation for 5 MHz and 10 MHz carrier separation. The simulation assumes that the spectrum below 2 550 MHz is FDD uplink, and the spectrum above 2 550 MHz is TDD. The FDD system is macro only, for TDD both macro and pico deployment are considered. Note that the macro and pico deployments are considered in separate simulations.

The service considered is 8 kbit/s speech for both TDD and FDD.

3.3.3.4 Victim system

The victim system is either a TDD macro-cell or a TDD pico-cell. These two possibilities are considered as two different scenarios. In this scenario the downlink is considered, as it is the mobile terminal that receives interference.

For the macro-cell scenario, all TDD mobiles are assumed to be outdoor. For the pico-cell scenario, the TDD BS and mobile terminal are both indoor.

The specifications are given in Table 19, Table 20 (macro) and Table 21 (pico). These correspond with the specifications given in § 2. ACS values for a TDD mobile terminal are given in Table 22. The TDD BS is not power controlled and transmits using a fixed power.

The total transmit power of the BS is shared between users. A maximum number of 12 users per timeslot is assumed, resulting in the transmit power available per user as given in Table 20 and Table 21.

TABLE 19

CDMA TDD MS (receive)

C/I	–5 dB
Noise floor	–99 dBm
Sensitivity	–105 dBm
Antenna height	1.5 m
Antenna gain	0 dBi

TABLE 20

CDMA TDD macro BS (transmit)

Transmit power, total for BS	43 dBm
Transmit power, available for one user	32.2 dBm
Fixed coverage radius	0.5 km
Antenna height	30 m
Antenna gain	15 dBi

TABLE 21

CDMA TDD pico BS (transmit)

Transmit power, total for BS	24 dBm
Transmit power, available for one user	13.2 dBm
Fixed coverage radius	0.05 km
Antenna height	6 m
Antenna gain	0 dBi

TABLE 22

ACLR and ACS values

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

3.3.3.5 Interfering system

The interfering system is an FDD macro-cell. In this scenario the uplink is considered (mobile terminal transmit). The mobile uses power control, and the power control is modelled as ideal. The power control adjusts the received power to a fixed pre-set receiver sensitivity value (C-based power control).

For the case that the victim system is TDD macro, all FDD mobiles are assumed to be outdoors. For the TDD pico case, all FDD mobiles are assumed to be indoor. The specifications are as given in § 2, and an overview is given in Table 23 and Table 24. ACLR values for a FDD mobile terminal are given in Table 22.

TABLE 23

WCDMA FDD mobile terminal (transmit)

Transmit power	21 dBm
Antenna height	1.5 m
Antenna gain	0 dBi
Power control step	1 dB
Power control: minimum received power	–121 dBm
Power control dynamic range	70 dB

TABLE 24

WCDMA FDD BS (receive)

Antenna height	30 m
Antenna gain	15 dBi
Receiver sensitivity	–121 dBm
Fixed coverage radius	0.5 km

3.3.3.6 Path loss models

Path loss is modelled using mean path loss and slow fading (log-normal). For the macrocell outdoor environment, the model used depends on the separation distance between the two mobiles. Free space path loss is used for distances up to 40 m and the Hata model (with modifications) is used for distances above 100 m. Between these limits an interpolation of free space and Hata is used. The Hata model is adapted for use at frequencies up to 3 GHz, and for situations with both transmit and receive antenna below rooftops.

The outdoor-indoor propagation model is the same as the outdoor only model with an extra loss factor added for attenuation due to external walls. The indoor only propagation model uses free space path loss, to which extra loss is added for attenuation due to internal walls and floors.

It is also possible that propagation occurs from inside one building to inside another. If both the transmitter and receiver are in an indoor environment, but their separation distance is large, it is assumed that the transmitter and receiver are in different buildings. A different propagation model than for the "pure" indoor case is then used. The path loss is then the sum of:

– the attenuation due to an external wall for the transmission out of the building;

– the Hata model as described above for path loss between the buildings;

– the attenuation due to an external wall for the transmission into the other building. The total path loss is therefore the Hata path loss plus two times the penetration loss of an external wall.

3.4 MS-MS (deterministic)

The same methodology is used as for BS-BS interference (see § 3.2) but with the MS transmitter and receiver parameters as defined in § 2. Only the LoS condition is investigated.

4 Calculation examples and results

4.1 Calculation examples

See § 3.3.1.

4.2 Calculation results

4.2.1 Results from deterministic BS-BS interference calculation

4.2.1.1 Required separation distances for TDD/FDD interference

TABLE 25

TDD to FDD interference

Description of scenario (+propagation model)	Carrier separation (MHz)	Tx power (including activity factor) (dBm)	Effective antenna gain (dBi)	ACIR (dB)	Accepted level of I_{ext} low/high (dBm)	Required pathloss (dB)	Required separation distance (m)
TDD macro to FDD macro (LoS)	5	40	30	46	–114/–106	138/130	9 541/6 020
	10	40	30	58	–114/–106	126/118	4 782/3 017
	15	40	30	64	–114/–106	120/112	3 385/2 136
TDD macro to FDD macro (vehicular)	5	40	15	46	–97/–90	106/99	222/145
	10	40	15	58	–97/–90	94/87	107/69
	15	40	15	64	–97/–90	88/81	74/48
TDD macro to FDD pico (outdoor to indoor)	5	40	15	46	–85	94	37
	10	40	15	58	–85	82	18
	15	40	15	64	–85	76	13
TDD micro to FDD macro (vehicular)	5	27	15	46	–114/–106	110/102	284/174
	10	27	15	58	–114/–106	98/90	136/83
	15	27	15	64	–114/–106	92/84	94/58
TDD pico to FDD macro (outdoor to indoor)	5	21	15	46	–114/–106	104/96	65/41
	10	21	15	58	–114/–106	92/84	33/21
	15	21	15	64	–114/–106	86/78	23/15
TDD micro to FDD micro (LoS)	5	27	12	46	–97/–90	90/83	290/130
	10	27	12	58	–97/–90	78/71	73/33
	15	27	12	64	–97/–90	72/65	37/16
TDD micro to FDD micro (pedestrian)	5	27	12	46	–97/–90	90/83	52/33
	10	27	12	58	–97/–90	78/71	24/14
	15	27	12	64	–97/–90	72/65	15/9
TDD pico to FDD micro (outdoor to indoor)	5	21	6	46	–97/–90	78/71	15/10
	10	21	6	58	–97/–90	66/59	7/5
	15	21	6	64	–97/–90	60/53	5/3
TDD micro to FDD pico (outdoor to indoor)	5	27	6	46	–85	72	10
	10	27	6	58	–85	60	5
	15	27	6	64	–85	54	4
TDD pico to FDD pico (LoS)	5	21	0	46	–85	60	9
	10	21	0	58	–85	48	2
	15	21	0	64	–85	42	1
TDD pico to FDD pico (indoor)	5	21	0	46	–85	60	1
	10	21	0	58	–85	48	1
	15	21	0	64	–85	42	<1

TABLE 26

FDD to TDD interference

Description of scenario (+propagation model)	Carrier separation (MHz)	Tx power (including activity factor) (dBm)	Effective antenna gain (dBi)	ACIR (dB)	Accepted level of I_{ext} (dBm)	Required pathloss (dB)	Required separation distance (m)
FDD macro to TDD macro (LoS)	5	43	30	42	–114/–106	145/137	14 275/9 007
	10	43	30	49	–114/–106	138/130	9 541/6 020
	15	43	30	63	–114/–106	124/116	4 262/2 689
FDD macro to TDD micro (vehicular)	5	43	15	42	–97/–90	113/106	341/222
	10	43	15	49	–97/–90	106/99	222/145
	15	43	15	63	–97/–90	92/84	94/61
FDD macro to TDD pico (outdoor to indoor)	5	43	15	42	–85	101	55
	10	43	15	49	–85	94	37
	15	43	15	63	–85	80	16
FDD micro to TDD macro (vehicular)	5	30	15	42	–114/–106	117/109	436/267
	10	30	15	49	–114/–106	110/102	284/174
	15	30	15	63	–114/–106	96/88	121/74
FDD micro to TDD micro (LoS)	5	30	12	42	–97/–90	97/90	650/290
	10	30	12	49	–97/–90	90/83	290/130
	15	30	12	63	–97/–90	76/69	60/26
FDD micro to TDD micro (pedestrian)	5	30	12	42	–97/–90	97/90	80/52
	10	30	12	49	–97/–90	90/83	52/33
	15	30	12	63	–97/–90	76/69	21/12
FDD micro to TDD pico (outdoor to indoor)	5	30	6	42	–85	79	25
	10	30	6	49	–85	72	10
	15	30	6	63	–85	58	5
FDD pico to TDD macro (outdoor to indoor)	5	24	6	42	–114/–106	102/94	58/37
	10	24	6	49	–114/–106	95/87	39/25
	15	24	6	63	–114/–106	81/73	17/11
FDD pico to TDD micro (outdoor to indoor)	5	30	6	42	–97/–90	91/84	31/21
	10	30	6	49	–97/–90	84/77	21/14
	15	30	6	63	–97/–90	70/63	9/6
FDD pico to TDD pico (LoS)	5	24	0	42	–85	64	7
	10	24	0	49	–85	57	4
	15	24	0	63	–85	43	2
FDD pico to TDD pico (indoor)	5	24	0	42	–85	64	2
	10	24	0	49	–85	57	1
	15	24	0	63	–85	43	<1

4.2.1.2 Required ACIR for 3.84 Mchip/s TDD/FDD interference

The required ACIR is independent of the carrier separation. However, the missing isolation compared to the reference cases are not. In the last column the missing isolation is compared to the assumed ACIR from Table 13 in the TDD to FDD case, and from Table 12 in the FDD-to-TDD case. For simplicity only the figures for 5 MHz carrier separation are given.

TABLE 27

TDD to FDD interference

Description of scenario (+propagation model)	**Tx power (including activity factor) (dBm)**	**Effective antenna gain (dBi)**	**Reference separation distance (m)**	**Pathloss (dB)**	**Accepted level of I_{ext} at Rx (dBm)**	**Required ACIR (dB)**	**Missing isolation 5 MHz carrier separation (dB)**
TDD macro to FDD macro (LoS)	40	30	100	80.7	–114/–106	103.3/95.3	57.3/49.3
TDD micro to FDD macro (vehicular)	27	15	50	81.6	–114/–106	74.4/66.4	28.8/20.4
TDD pico to FDD macro (outdoor to indoor)	21	15	50	99.4	–114/–106	50.6/42.6	4.6/–3.4
TDD micro to FDD micro (LoS)	27	12	50	74.7	–97/–90	61.3/54.3	15.3/8.3
TDD micro to FDD micro (pedestrian)	27	12	50	91.9	–97/–90	44.1/37.1	–1.9/–8.9
TDD pico to FDD micro (outdoor to indoor)	21	6	20	83.4	–97/–90	40.6/33.6	–5.4/–12.4
TDD micro to FDD pico (outdoor to indoor)	27	6	20	83.4	–85	34.6	–11.4
TDD pico to FDD pico (LoS)	21	0	10	60.7	–85	45.3	–0.7
TDD pico to FDD pico (indoor)	21	0	10	85.3	–85	20.7	–25.3

TABLE 28

FDD to TDD interference

Description of scenario (+propagation model)	Tx power (including activity factor) (dBm)	Effective antenna gain (dBi)	Reference separation distance (m)	Pathloss (dB)	Accepted level of I_{ext} at Rx (dBm)	Required ACIR (dB)	Missing isolation 5 MHz carrier separation (dB)
FDD macro to TDD macro (LoS)	43	30	100	80.7	–114/–106	106.3/98.3	64.3/56.3
FDD macro to TDD micro (vehicular)	43	15	50	81.6	–97/–90	73.4/66.4	31.4/24.4
FDD macro to TDD pico (outdoor to indoor)	43	15	50	99.4	–85	43.6	1.6
FDD micro to TDD micro (LoS)	30	12	50	74.7	–97/–90	64.3/57.3	22.3/15.3
FDD micro to TDD micro (pedestrian)	30	12	50	91.9	–97/–90	47.1/40.1	5.1/–1.9
FDD micro to TDD pico (outdoor to indoor)	30	6	20	83.4	–85	37.6	–4.4
FDD pico to TDD micro (outdoor to indoor)	21	6	20	83.4	–97/–90	40.6/33.6	–1.4/–8.4
FDD pico to TDD pico (LoS)	21	0	10	60.7	–85	45.3	3.3
FDD pico to TDD pico (indoor)	21	0	10	85.3	–85	20.7	–21.3

4.2.1.3 Required separation distances for TD-SCDMA/FDD interference

TABLE 29

TDD to FDD interference

Description of scenario (+propagation model)	Carrier separation (MHz)	Tx power (dBm)	Practical antenna gain (dBi)	ACIR (dB)	Accepted level of I_{ext} at Rx (dBm)	Required pathloss (dB)	Required separation distance (m)	Required additional isolation
TDD macro to FDD macro (LoS)	3.5	34	15 + 15 – 6 = 24	45	–106	140	2 700	40.9 (YES)
TDD macro to FDD micro (NLoS)	3.5	21	15 + 6 – 3 = 8	45	–97	131	44.7	–1.6 (NO)
TDD macro to FDD pico	3.5	12	15 + 0 – 10 = 5	45	–91	125	9.8	–9.3 (NO)
TDD micro to FDD macro	3.5	34	6 + 15 – 13 = 8	45	–106	125	31.6	–7.6 (NO)
TDD micro to FDD micro	3.5	21	6 + 6 = 12	45	–97	116	23.7	–11.4 (NO)
TDD micro to FDD pico	3.5	12	6 + 0 = 6	45	–91	110	3.3	–23.3 (NO)
TDD pico to FDD macro	3.5	34	3 + 15 – 10 = 8	45	–106	116	6.2	–15.3 (NO)
TDD pico to FDD micro	3.5	21	3 + 6 = 9	45	–97	107	3.3	–23.3 (NO)
TDD pico to FDD pico	3.5	12	3 + 0 = 3	45	–91	101	1.3	–35.3 (NO)

4.2.1.4 Co-location scenarios for WCDMA/3.84 Mchip/s TDD

This section describes and quantifies different sources of interference between adjacent-band FDD and TDD systems when the two systems BSs are collocated. Specifically, this contribution accounts for interference into an FDD BS receiver from a collocated TDD BS transmitter, and interference into a TDD BS receiver from a collocated FDD BS transmitter.

Collocation of multiple operators on the same tower or building is a common practice that will become more prevalent in future systems as the number of operators increases and more cell density is required for greater coverage and capacity. Because of deployment constraints, site acquisition difficulties, and other logistical and engineering issues, it is highly likely that WCDMA TDD and FDD sites would be co-sited (i.e. collocated).

The maximum allowed interference (MAI) for receiver desensitization is defined by:

$$\text{MAI\_Desen. (dBm)} = \text{Noise floor (dBm)} + \text{Receiver noise figure} - 6 \text{ dB}$$

TABLE 30

Calculated thresholds for MAI level for receiver desensitization

System	Noise floor (dBm)	Rx noise figure (dB)	MAI (desen.) (dBm)
WCDMA TDD	–108	5	–109
WCDMA FDD	–108	5	–109

The affected interference power received at the receiver input-port of the interfered station is calculated as:

$$\text{Int@\_Rcvr} = \text{C\_Tx\_} - ACIR - MCL$$

where:

Int@_Rcvr: affected interference at the receiver input port of the interfered system (dBm)

C_Tx_: nominal maximum carrier power level at the Tx amplifier output (dBm)

ACIR: 1/(1/*ACS* + 1/*ACLR*)

MCL: minimum coupling loss (dBm) = 30 dB.

Table 31 shows interference calculations on both WCDMA and 3.84 Mchip/s TDD with carrier separations of 5, 10 and 15 MHz. In all cases the MAI of –109 dBm is exceeded.

TABLE 31

Calculated values of interference between TDD and FDD systems

Interfered system	C_Tx_ (dBm)	ACS of Rx	ACLR of Tx	ACIR	Int@_Rcvr (dBm)	Threshold exceeded (–109 dBm)
WCDMA TDD	43	46 @ 5 MHz	45 @ 5 MHz	42.46	–29.46	Yes
WCDMA TDD	43	58 @ 10 MHz	50 @ 10 MHz	49.36	–36.36	Yes
WCDMA TDD	43	66 @ 15 MHz	67 @ 15 MHz	63.46	–50.46	Yes
WCDMA TDD	40.2	46 @ 5 MHz	70 @ 5 MHz	45.98	–35.78	Yes
WCDMA TDD	40.2	58 @ 10 MHz	70 @ 10 MHz	57.73	–47.53	Yes
WCDMA TDD	40.2	66 @ 15 MHz	70 @ 15 MHz	54.34	–54.34	Yes

NOTE – TDD BS Tx output power = 43 dBm
TDD BS activity factor = –2.8 dB
C_Tx_ = 43 +(–2.8) = 40.2 for FDD Tx power.

Receiver overload

A receiver is typically defined as overloaded when the total received input power exceeds the receivers 1 dB compression point minus a safety margin (typically 10 dB).

$$\text{MAI\_Over} = 1 \text{ dB Compression Point} - \text{Safety Margin}$$

A blocking value of –40 dBm is used as specified in 3GPP. The total received carrier power is defined by:

$$\text{C\_Rx\_} = \text{C\_Tx\_} - ACIR - MCL$$

where:

C_Rx_: total carrier power received at input port of the interfered station (dBm)

C_Tx_: total carrier power transmitted at the output port of the interfering station (dBm)

$ACIR$: $1/(1/ACS + 1/ACLR)$

MCL: minimum coupling loss (dBm) = 30 dB.

Using these parameters, the following is obtained:

TABLE 32

Computed values showing interference at the Rx of the interfered system

Interfered system	C_Tx_ (dBm)	ACS of Rx	ACLR of Tx	ACIR	C_Rx (dBm)	MAI_Over threshold exceeded? (–40 dBm)
WCDMA TDD	43	46 @ 5 MHz	45 @ 5 MHz	42.46	–29.46	Yes
WCDMA TDD	43	58 @ 10 MHz	50 @ 10 MHz	49.36	–36.36	Yes
WCDMA TDD	43	66 @ 15 MHz	67 @ 15 MHz	63.46	–50.46	No
WCDMA TDD	40.2	46 @ 5 MHz	70 @ 5 MHz	45.98	–35.78	Yes
WCDMA TDD	40.2	58 @ 10 MHz	70 @ 10 MHz	57.73	–47.53	No
WCDMA TDD	40.2	66 @ 15 MHz	70 @ 15 MHz	54.34	–54.34	No

4.2.1.5 Supportable path loss under alternative BS-BS interference evaluation

Table 33 lists the supportable MS-BS path loss at the edge of a cell under the BS-BS interference evaluation described in § 3.2.2 limited by MS output power and the C/I requirement of the particular service. Table 33 shows the supported cell range for worst case tilting of the BS antennas. Table 34 shows the same under practical antenna tilting (for macro to micro or micro to macro BS interference cases). Depending on the envisioned path loss models and the operator requirements this may or may not correspond to acceptable cell sizes.

TABLE 33

Supported cell range under worst case antenna tilting

BS-BS scenario	**Carrier spacing (MHz)**	**Supported cell range (dB path loss)** **TDD BS ACLR assumptions: set 1**	**Supported cell range (dB path loss)** **TDD BS ACLR assumptions: set 2**
TDD micro → FDD macro	5	124.2	127.7
	10	134.8	139.3
	15	145.5	145.5
FDD macro → TDD micro	5	90.2	Not available
	10	100.9	
	15	111.2	
TDD micro → FDD micro (LoS)	5	117.3	120.7
	10	127.9	132.3
	15	138.3	138.3
TDD micro → FDD micro (NLoS)	5	133.9	137.0
	10	142.0	143.7
	15	144.7	144.7
FDD micro → TDD micro (LoS)	5	105.3	Not available
	10	115.9	
	15	125.5	
FDD micro → TDD micro (NLoS)	5	121.9	
	10	130.0	
	15	132.6	

TABLE 34

Supported cell range under practical antenna tilting

BS-BS scenario	**Carrier Spacing (MHz)**	**Supported cell range (dB path loss)** **TDD BS ACLR assumptions: set 1**	**Supported cell range (dB path loss)** **TDD BS ACLR assumptions: set 2**
TDD micro → FDD macro	5	137.1	140.5
	10	146.9	150.1
	15	152.9	152.9
FDD macro → TDD micro	5	103.2	Not available
	10	113.8	
	15	123.7	

4.2.2 Results from Monte Carlo simulations

4.2.2.1 Capacity consequences in FDD macro/3.84 Mchip/s TDD micro and FDD micro/3.84 Mchip/s TDD micro scenarios

FDD macro – TDD micro

TABLE 35

MS-BS interference (uplink)

Aggressor	Victim	Capacity loss (%)
TDD MS	FDD BS	< 1
FDD MS	TDD BS	< 1

TABLE 36

BS-MS interference (downlink)

Aggressor	Victim	Capacity loss (%)
TDD BS	FDD MS	1
FDD BS	TDD MS	4

TABLE 37

MS-MS interference (downlink)

Aggressor	Victim	Capacity loss (%)
TDD MS	FDD MS	< 1
FDD MS	TDD MS	2

FDD micro – TDD micro

TABLE 38

MS-BS interference (uplink)

Aggressor	Victim	Capacity loss (%)
TDD MS	FDD BS	1
FDD MS	TDD BS	< 1

TABLE 39

BS-MS interference (downlink)

Aggressor	Victim	Capacity loss (%)
TDD BS	FDD MS	< 1
FDD BS	TDD MS	1

TABLE 40

MS-MS interference (downlink)

Aggressor	Victim	Capacity loss (%)
TDD MS	FDD MS	< 1
FDD MS	TDD MS	1

Further studies

Until now, all evaluations have been performed in a Manhattan environment and for symmetric (circuit-switched) services. All users have been located outside. These are particularly beneficial scenarios.

Further studies of interest are e.g. to investigate other environments, like the indoor environment. Indoor coverage should also be studied to see how this affects the performance. Other types of services, e.g. asymmetric, packet-oriented services might also be of interest.

4.2.2.2 Capacity consequences in FDD macro/3.84 Mchip/s TDD macro and FDD macro/ 1.28 Mchip/s TDD scenarios

In the following the results are summarized.

TABLE 41

3.84 Mchip/s TDD/FDD

Interferer/ victim	Macro vs. macro (%)	Micro vs. micro (%)	Pico vs. pico (%)	Macro vs. micro (%)
FDD MS/TDD BS	< 4	< 1	< 2	< 1
FDD MS/TDD MS	< 5	< 1	< 4	< 1
TDD MS/FDD BS	< 4	< 1	< 1	< 1

TABLE 42

1.28 Mchip/s TDD/FDD

Victim (receiver)	Interferer (transmitter)	Relative capacity loss (%)
FDD BS	1.28 Mchip/s TDD MS (cluster = 1)	< 2
1.28 Mchip/s TDD BS (cluster = 1)	FDD MS	< 2
1.28 Mchip/s TDD MS (cluster = 1)	FDD MS	< 2
1.28 Mchip/s TDD MS (cluster = 3)	EM DDF	< 3

4.2.2.3 Outage consequences due to MS-MS interference in FDD/3.84 Mchip/s TDD scenarios

The following paragraphs present the calculated level of outage in two distinct ways. Firstly the results are given for uniformly spatially distributed FDD terminals, which shows the effect of increasing the density of FDD terminals over a cell.

Secondly the results are shown for the level of outage occurring when there are fixed separation distances between an FDD and TDD terminal, whilst the distance for each terminal to its respective BS is varied. The results presented illustrate the distance for which the level of interference becomes significant.

4.2.2.3.1 FDD macro – TDD macro

Table 43 and Table 44 show the results for the FDD macro to TDD macro interference scenario.

The maximum number of speech users per sector for FDD is assumed to be 50. For a cell radius of 0.5 km this corresponds with a density of 191 users/km^2. Other densities are also included to simulate cells that are not fully loaded.

TABLE 43

Interference probability for different interferer densities

Carrier separation (MHz)	5	10
Interferer density (1/km^2):		
50 (%)	< 1	< 1
100 (%)	1	< 1
191 (%)	1	< 1

For the case that the separation distance between the mobile terminals is fixed, the distance between the mobile terminals and their respective BSs will vary. This is incorporated into the Monte Carlo simulation.

TABLE 44

Interference probability for different separation distances

Carrier separation (MHz)	5	10
Separation distance (m):		
1 (%)	24	10
3 (%)	9	3
10 (%)	2	1
30 (%)	1	< 1
100 (%)	< 1	< 1

4.2.2.3.2 FDD macro – TDD pico

For the FDD macro to TDD pico interference scenario the results are shown in Table 45 and Table 46.

The interference probability for this case is higher than for the TDD macro case. It is likely that this is caused by low signal strengths for the desired TDD signal, as the e.i.r.p. of the BS is low and the indoor path loss is high. Additionally, the power controlled transmit power of the FDD mobile terminal will be high, as the path loss to the outdoor BS will be high.

TABLE 45

Interference probability for different interferer densities

Carrier separation (MHz)	5	10
Interferer density (1/km^2):		
50 (%)	3	3
100 (%)	4	3
191 (%)	7	4

TABLE 46

Interference probability for different separation distances

Carrier separation (MHz)	5	10
Separation distance (m):		
1 (%)	73	54
3 (%)	54	34
10 (%)	18	8
30 (%)	3	2
100 (%)	2	2

4.2.3 Results from deterministic MS-to-MS interference calculations

Normally, the average capacity loss due to MS-to-MS interference will be small. However, for the individual MS, the effect of MS-to-MS interference may be severe, and coverage may be even lost. The impact depends on many parameters of which some are listed below:

- Distance between the two MSs.
- Transmission power of the interfering MS.
- Position in the cell (of the affected MS).

Effects of MS-to-MS interference is normally only noticed when the distance between the MSs is very small. However, if the distance is small, it is a high probability of LoS between the terminals which results in a small pathloss.

The transmission power of the interfering MS depends on the deployment scenario (e.g. in average, the transmission power is higher in a macro scenario where the cells are large compared to a micro scenario with small cells) and the load in the system.

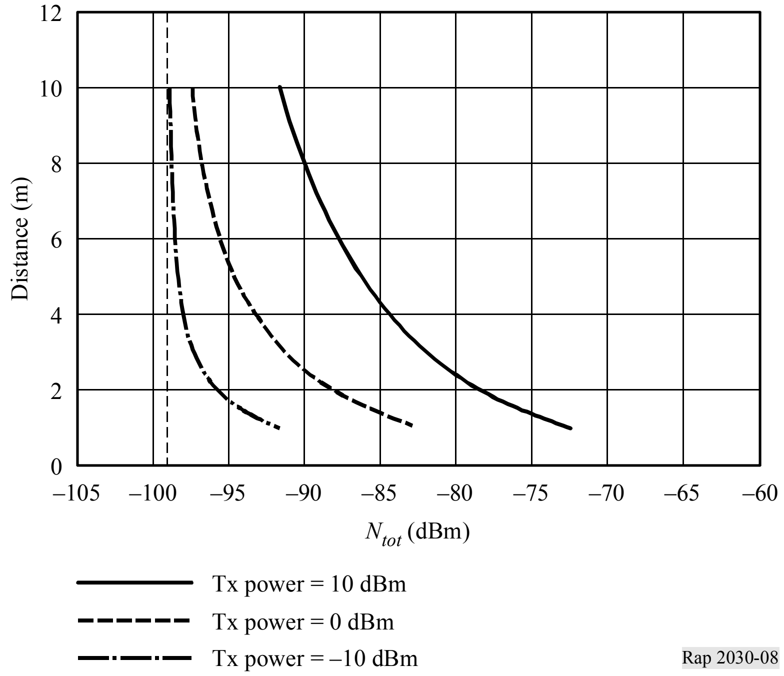
Finally, the effect is smaller if the affected MS is close to its BS. Then, the BS may have a margin to increase the DL power to overcome the interference.

Using the same methodology as for the BS-to-BS cases, but using the MS parameters, the relationship between total noise in the MS and the distance between the mobiles have been calculated for different values of aggressor transmission powers.

Figure 8 shows the distance versus the total noise floor N_{tot} in the case of interference from a TDD MS to a FDD MS. LoS propagation is assumed. A small separation distance together with a high TDD MS transmission power make N_{tot} high (compare with the noise floor at the MS, –99 dBm). However, it is difficult to predict the consequence of the increased noise floor since it depends on many different parameters.

FIGURE 8

Interference to FDD MS Rx, caused by TDD MS Tx



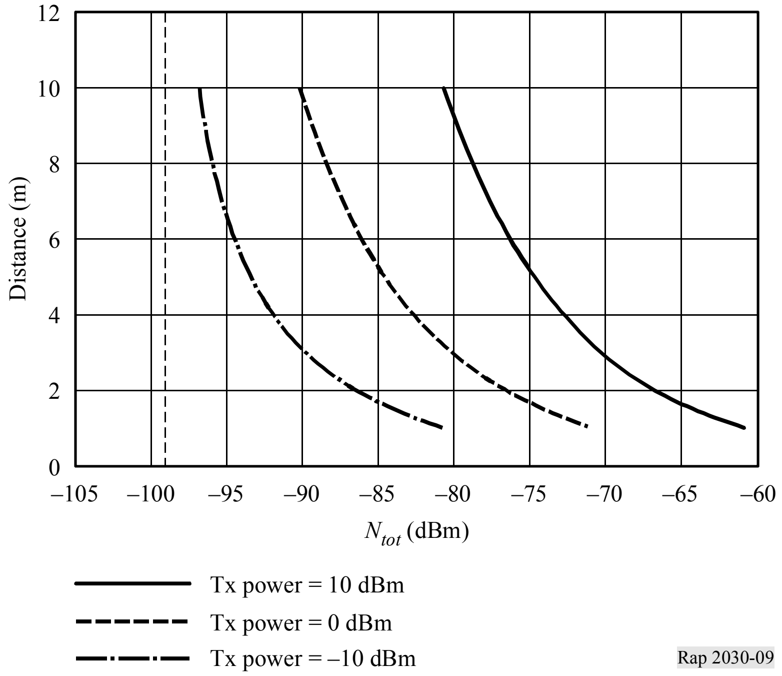
However, a large increase of the noise floor (high value of N_{tot}) for which the BS cannot compensate by means of an increased output power, the consequence for the interfered MS is lost coverage.

Note that the curves are calculated assuming certain instantaneous transmit powers. For TDD which is active 1/15 (–11.8 dB) of the time with the speech service in our example, an instantaneous value of –10, 0 or 10 dBm, correspond to a time averaged value of –21.8, –11.8, and –1.8 dBm, respectively. For the FDD systems, the average and instantaneous powers are the same.

Figure 9 shows the opposite situation, i.e. a TDD MS interfered by a FDD MS. Because of the higher activity factor of the FDD MS, the effect is larger compared to the previous case.

FIGURE 9

Interference to TDD MS Rx, caused by FDD MS Tx



It is not difficult to imagine common scenarios where small distances between mobiles combined with medium to high powers and medium to large distances to serving BS will cause dramatic increases in total noise floor (up to 20-25 dB increase) which the BS cannot compensate. Two mobiles in a bus or a train connected to outdoor micro or macro BSs will likely qualify. The extra interference will often be more than enough to make the victim MS loose the connection.

It seems that the MS-to-MS interference will have severe consequences for those users that experience it, while other users will not experience any degradation at all.

5 Conclusions

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 which correspond to different trade off choices. The above views are by no means excluding other points of views. The conclusions below reflect only the studies made in this Report.

BS-BS: 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 DL to TDD 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 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 (see § 4.2.1.1 and 4.2.1.2). Some scenarios have low separation distances and do not require additional isolation.
- In some deployment scenarios separation distances can be traded off against coverage and higher MS transmit powers in the victim system (see § 4.2.1.4).

BS-BS in proximity: WCDMA/3.84 Mchip/s TDD (see § 4.2.1.1)

TABLE 47

BS-BS: WCDMA/3.84 Mchip/s TDD

Scenario	Carrier separation (MHz)	Required separation distance TDD-FDD (m)	Required separation distance FDD-TDD (m)	Reference separation distance (m)	Required additional isolation (dB)
Macro-to-macro (LoS)	5-15	2 136-9 541	2 689-14 275	100	+49.3
Macro-to-micro (vehicular)	5-15	48-222	61-341	50	+20.4
Micro-to-micro (LoS)	5	130-290	290-650	50	+8.3
	10	33-73	130-290	50	–
	15	16-37	26-60	50	–
Micro-to-micro (pedestrian)	5	33-52	52-80	50	+8.3
	10-15	9-24	12-52	50	–
Micro-to-macro (vehicular)	5-15	58-284	69-341	100	–
Pico-to-macro (outdoor to indoor)	5-15	15-65	11-58	50	–
Pico-to-micro (outdoor to indoor)	5-15	3-15	6-31	20	–12.4
Micro-to-pico (outdoor to indoor)	5-15	4-10	5-25	20	–11.4
Pico-to-pico (LoS)	5-15	1-9	2-7	10	–0.7
Pico-to-pico (indoor)	5-15	1	1	10	–25.3

The separation distances have been calculated with antenna gains given in Table 49 in Appendix 3. Table 47 is a sample of results compiled from Tables 25 and 26 in § 4.2.1.1. Please refer to those Tables for the complete set of results.

BS-BS in proximity: WCDMA/1.28 Mchip/s TDD (see § 4.2.1.3)

TABLE 48

BS-BS: WCDMA/TD-SCDMA

Scenario	Carrier separation (MHz)	Required additional isolation or not (dB)	Reference separation distance (m)	Required separation distance (m)
Macro-to-macro	3.5	40.9 (YES)	100	2 700
Macro-to-micro	3.5	–1.6 (NO)	50	44.7
Macro-to-pico	3.5	–9.3 (NO)	20	9.8
Micro-to-macro	3.5	–7.6 (NO)	50	31.6
Micro-to-micro	3.5	–11.4 (NO)	50	23.4
Micro-to-pico	3.5	–23.3 (NO)	50	3.3
Pico-to-macro (outdoor to indoor)	3.5	–15.3 (NO)	10	6.2
Pico-to-micro (outdoor to indoor)	3.5	–23.3 (NO)	50	3.3
Pico-to-pico (indoor to indoor)	3.5	–35.3 (NO)	10	1.3

BS-BS co-location: WCDMA/3.84 Mchip/s (see § 4.2.1.4)

– 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 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.

Solution proposals for BS-BS interference

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.

– Higher performance filters at both transmitter and receiver side.

– Multi system co-planning in order to locate BSs far from all victim system BSs. This would require, in the case of multiple operators, cooperation between competitors.

- Appropriate guardbands will need to be considered for several scenarios to allow for flexibility of deployment
- Low power operation of interfering systems reduces the problem but also reduces coverage and flexibility of deployment.
- The exact values of guardbands, filter requirements, etc., will depend on a number of factors and a definitive answer is not given in this Report.
- Planning for a higher interference level at the BS receiver taking into account the necessary trade-offs. These include some limits on cell size and the higher mobile transmit power in the victim system and the consequences of these.

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.

References

[1] 3GPP TS 25.104 v3.4.0. Base Station (BS) radio transmission and reception (FDD).

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[3] 3GPP TS 25.101 v3.4.0. User Equipment (UE) radio transmission and reception (FDD).

[4] 3GPP TS 25.102 v3.4.0. User Equipment (UE) radio transmission and reception (TDD).

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Appendix 1

ACLR, ACS and ACIR

ACLR:	Adjacent channel leakage power ratio
ACS:	Adjacent channel selectivity
ACIR:	Adjacent channel interference power ratio

The ACLR is the relation between the power transmitted in the own carrier and the power leaking out in the neighboring frequency bands. ACLR is thus a measure of the transmitter performance.

Likewise, ACS is a measure of the receiver performance. The ACS is the suppression of the adjacent channel power (in relation to the power in the own channel).

Together, the ACLR and the ACS form the protection for adjacent channel interference. The protection is called ACIR and is defined as:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}}$$

where the ACLR and the ACS are expressed as a ratio and not in dB.

To meet specific ACIR requirements, both the ACLR and the ACS have to be larger than the ACIR. If the ACLR and the ACS are equal, they have to be twice as big as the ACIR (3 dB if expressed in dB).

Appendix 2

Derivation of the dual-slope LoS propagation model

The model is constructed as follows:

– We assume free space propagation for small distances, d. Using equations 3.3 and 3.6 in [7] with $f = 2.6$ GHz gives a path loss of $40.7 + 20 \log_{10}(d)$ with unit antenna gains.

– At large distances for the reflective model the distance dependency is $40 \log_{10}(d)$ (see [7, p. 89]).

– The ground appears in the first Fresnel zone at Fresnel distance (see [7, p. 89]): $d_{break} = 4 \frac{h_{tx} \cdot h_{rx}}{\lambda}$

- It is well known that up to the Fresnel distance free space propagation is valid.
- A conservative estimate of the break point is to set it equal to the Fresnel distance.
- Combining the above gives the dual slope LoS model used.

In reality the attenuation parameter is starting to continuously vary from 20 at the Fresnel distance to be ultimately 40 for sufficiently large distances. By introducing one single break point at the Fresnel distance as above we overestimate the propagation loss for distances above the break point.

Hence, above the break point the interference power is underestimated at the victim receiver side. Since the model in this report is used for interference studies it can be seen as a very conservative model.

For example in MS-MS scenarios, the distances are well below the break point and the model corresponds to free space propagation.

Appendix 3

Practical antenna gain of antennas of the interfering station and the victim

There are two main opinions on the practical gain of antennas of the interfering station and the victim.

- The simple sum of the maximum gain of antennas of the interfering station and the victim is thought to be the practical contributing gain (see § 1).
- The practical gain of the antennas is thought to be gain at the direction between the two antennas (see § 2 and 3, where vertical antenna patterns are different).

1 Sum of the maximum gains of antennas of the interfering station and the victim

In general, the resulting antenna gain is dependent on the antenna gain of the transmitter and the receiver as well as the direction of the transmitting and receiving antenna.

If the antennas are located on the same level (height), the resulting antenna gain is assumed to be the sum of the Tx and Rx antenna gains. However, if the heights of the antennas differ significantly, the resulting antenna gain is the gain of the highest located antenna. The resulting antenna gains between different combinations of BSs are presented in Table 49 (the Tx and the Rx antenna gain at a BS is equal). The height of a macro BS is 30 m and the height of a micro and a pico BS is 6 m above the ground. Thus, micro and pico BSs are located at the same height. Macro BSs are located above both the micro and the pico BS.

Table 49 is valid for both the 1.28 Mchip/s and 3.84 Mchip/s TDD systems.

TABLE 49

Resulting antenna gain

	FDD macro BS (15 dBi)	**FDD micro BS (6 dBi)**	**FDD pico BS (0 dBi)**
TDD macro BS (15 dBi)	30	15	15
TDD micro BS (6 dBi)	15	12	6
TDD pico BS (0 dBi)	15	6	0

2 Sum of the gains of antennas at the directions of the interfering station and the victim (vertical antenna pattern defined by the 3 dB and 10 dB angle)

In the following, macro-micro scenarios are employed to analyse the contributing gain of antennas in the practical network.

The practical antenna-to-antenna isolation is a function of the inclination angle, the vertical beam width, and the antenna gain. In practice, to reduce the inter cell interference, the main-lobe of antenna is inclined to a given angle, the inclination angle of antenna is affected by the height of antenna, the radius of cell and the vertical beam width, and so on [8].

On the coexistence between TD-SCDMA and FDD systems in adjacent bands and in the same area, the antenna gain is dependent on the directivity diagram of antenna of the interfering station and the victim as well as the inclination angle of both antennas.

Antenna beam width

The 3 dB power beam width, θ, of antenna can be estimated as follows:

$$\theta = 180/G$$

Where G is the maximum gain of antenna.

For engineering calculation, the 10 dB power beam width of antenna can be roughly estimated as 2 θ.

Practical antennas gain between macro and the micro BS

For the scenarios of micro to macro, the heights of the antennas differ significantly; the practical antenna gain of both systems should be calculated with the sum of the Tx and Rx antenna gains along the direction from the macro BS to the micro BS, as shown in Fig. 3.

Assumptions:

Reference separation distance:	$D = 50$ m
Micro BS Tx antenna gain:	$G_{A,Tx} = 6$ dBi
Macro BS Rx antenna gain:	$G_{A,Rx} = 15$ dBi
Average antenna height of macro cell:	30 m
Average antenna height of micro cell:	6 m
Down inclination angle of macro BS antenna:	4.43°
Down inclination angle of micro Tx antenna:	2.5°

The vertical beam width of macro BS antenna:

$$\theta_{macro} = 180/G_{macro} = 5.7°$$

The vertical beam width of micro BS antenna

$$\theta_{micro} = 180/G_{micro} = 45.2°$$

Angle *c*:

$$c = \tan^{-1}((h_1 - h_2)/D) = \tan^{-1}(Dh/D) = 25.64°$$

Angle *a*:

$$a = c - 4.43 = 21.21°$$

Angle *b*:

$$b = c + 2.5 = 28.14°$$

From the above analysis, angle *a* is larger than vertical beam width θ_{macro}, so the attenuation of the direction is 10 dB less than its maximum gain. Then the contributing gain of macro BS is less than 5 dB (15 – 10 = 5).

The inclination angle *b* is larger than the vertical beam width $\theta_{micro}/2$, so the attenuation of the direction should be 3 dB less than its maximum gain.

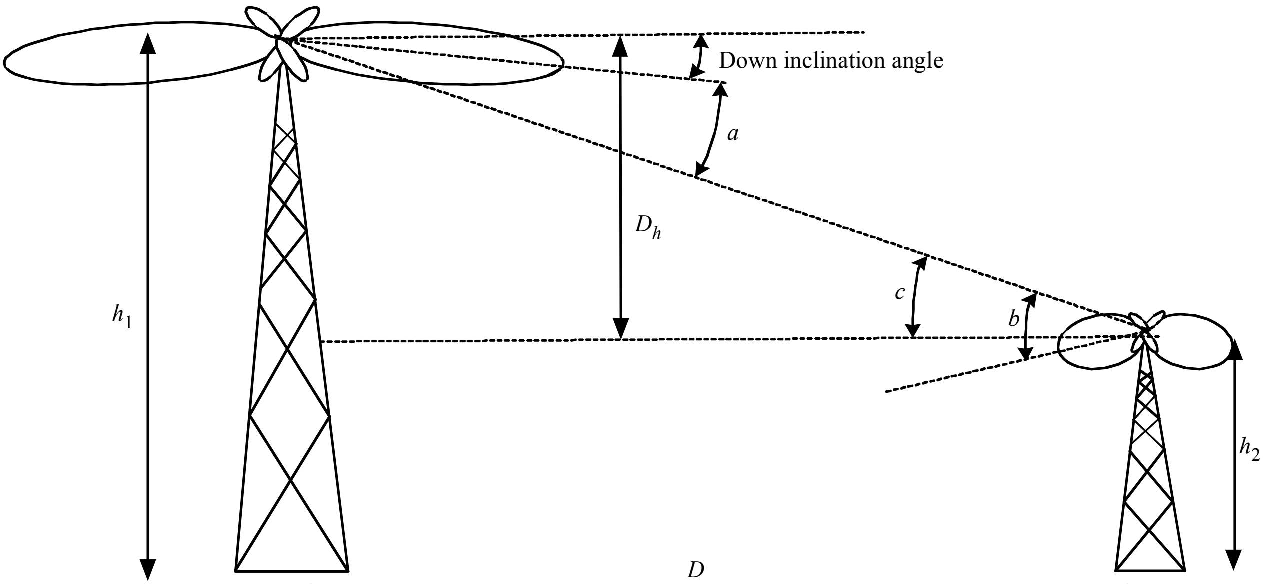
Then the practical gain of the micro BS is less than 3 dB (6 – 3 = 3).

The practical gain of the transmitting and receiving antennas can be estimated as:

$$G_{practical} = G_{macro}(a) + G_{micro}(b) < 5 + 3 = 8 \text{ dB}$$

FIGURE 10

Diagram of the antennas of the BS for macro cell and micro cell



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In case the distance of transmitting and receiving antenna increased, the down inclination angle should be decreased, so the practical gain of transmitting and receiving antenna will be increased too. Nevertheless, the path loss of interfering and the victim station will be increased more rapidly than the increasing of contributing gain, thus the total isolation from interfering and the victim station will be increased in case the distance of transmitting and receiving antenna increased.

Using the method above mentioned, for the scenarios of macro to macro, the antennas are located on the same level, the practical gain of transmitting and receiving antennas should be at least 6 dB less than the sum of the maximum gains of the two antennas.

3 Sum of the gains of antennas at the directions of the interfering station and the victim (vertical antenna pattern modelled with Recommendation ITU-R F.1336)

The calculations made here take advantage of the approach proposed in § 2 and extend it for every possible scenario (as proposed in Table 49). The vertical antenna pattern of macro and micro cells are here obtained by Recommendation ITU-R F.1336, using a *K* shaping factor of 0.2 for any tilt angle (2.5° in any cell deployment scenario here), the antennas are supposed 120° sectoral. In the case of pico cells, the antenna is supposed omnidirectional.

This paragraph is in conformity with Report ITU-R M.2039 – Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses.

The assumptions made for the *K* shaping factor and for the tilt angles may be changed in the near future.

Antenna patterns (macro and micro cells)

Recommendation ITU-R F.1336 defines reference antenna patterns of omnidirectional, sectoral and other antennas in point to multipoint systems for use in sharing studies in the frequency range from 1 to about 70 GHz.

For sectoral antennas, the Recommendation gives the following equations:

$$G(\theta) = \max\left\{ G_1(\theta), G_2(\theta) \right\}$$

$$G_1(\theta) = G_0 - 12\left(\frac{\theta}{\theta_3}\right)^2$$

$$G_2(\theta) = G_0 - 12 + 10\log\left[\left(\max\left\{\frac{|\theta|}{\theta_3}, 1\right\}\right)^{-1.5} + K\right]$$

where:

$G(\theta)$: gain relative to an isotropic antenna (dBi)

G_0: maximum gain in or near the horizontal plane (dBi)

θ: absolute value of the elevation angle relative to the angle of maximum gain (degrees)

θ_3: 3 dB beamwidth in the vertical plane (degrees)

K: parameter which accounts for increased side-lobe levels above what would be expected for an antenna with improved side-lobe performance (typical: $K = 0.7$ between 1 and 3 GHz).

The relationship between the gain (dBi) and the 3 dB beamwidth in the elevation plane (degrees) is, for a sectoral antenna:

$$\theta_3 = \frac{31000 \times 10^{-0.1 G_0}}{\varphi_s}$$

where φ_s is the 3 dB beamwidth of the sector in the azimuthal plane (degrees).

Resulting antenna gains

The geometry of the scenarios is the same as per § 2, Fig. 10. Using the notations in Fig. 10 and the following:

- h_1 and h_2 the antenna heights (macro: 30 m, micro: 6 m).
- Tilt angles for the macro and micro antennas: 2.5° down for tilt 1 and tilt 2.

We obtain:

Angle *a*:

$$a = \sin^{-1}\left(\frac{h_1 - h_2}{\sqrt{(h_1 - h_2)^2 + D^2}}\right) - \text{tilt } 1$$

Angle *b*:

$$b = \sin^{-1}\left(\frac{h_1 - h_2}{\sqrt{(h_1 - h_2)^2 + D^2}}\right) - \text{tilt } 2$$

We have then the resulting antenna gains for two BSs using the gain formulas of Recommendation ITU-R F.1336 (the feeder losses FL_{BS} are 2 dB for all BSs considered):

$$G_{resulting} = G_{EB1}(a) + G_{EB2}(b) - 2FL_{BS}$$

BS characteristics

- Antenna gain: 17 dBi (macro), 8 dBi (micro), 2 dBi (pico)
- Recommendation ITU-R F.1336 *K*-shaping factor: 0.2 (macro and micro), and 1 (pico)
- Sector of the antennas (macro and micro): 120°
- Antenna heights: 30 m (macro), 6 m (micro), 2 m (pico)
- Feeder losses: 2 dB.

The resulting Table 50 would be the following:

TABLE 50

Resulting antenna gain

	FDD macro BS (15 dBi)	**FDD micro BS (6 dBi)**	**FDD pico BS (0 dBi)**
TDD macro BS (15 dBi)	23	0-15	0-15
TDD micro BS (6 dBi)	0-15	12	5
TDD pico BS (0 dBi)	0-15	5	0