ECC REPORT 131

Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

DERIVATION OF A BLOCK EDGE MASK (BEM) FOR TERMINAL STATIONS IN THE 2.6 GHz FREQUENCY BAND (2500-2690 MHz)

Dublin, January, 2009

0 EXECUTIVE SUMMARY

CEPT Report 19 was developed in response to the European Commission mandate to develop least restrictive technical conditions for frequency bands addressed in the context of WAPECS. The aim of the present ECC report is to provide guidance to ETSI on the issue of terminal-to-terminal interference including the derivation of terminal station block edge masks (BEMs) for the 2.6 GHz band. It includes studies that are complementary to those in CEPT Report 19. These technical conditions clarify coexistence between terminals connected by network operators in adjacent spectrum blocks, notably between unrestricted TDD (time division duplex) and FDD operation (frequency division duplex) or in the case of two unsynchronised networks operating in TDD mode. The technical conditions presented in this document address the important balance between enabling operators to make good use of their spectrum and not causing unacceptable interference to the users of the neighbouring spectrum.

The studies in this report have been carried out as a result of comments raised during the public consultation process for CEPT Report 19; these comments related to the absence of studies on the impact of terminal-to-terminal interference[1].

Note that a BEM consists of an in-block part as well as an out-of-block part. The terminal station in-block power level has already been defined in CEPT Report 19 [1], and a total radiated power (TRP) level of 31 dBm/(5 MHz) is specified in the EC decision 2008/477/EC [2].

The report only deals with the out-of-block part of the terminal station BEM. This should be respected by any terminal station controlled by an operator in order to manage the risk of undue interference into adjacent spectrum assigned to another operator, unless operators reach a bilateral agreement to use a less stringent BEM.

This report first describes a deterministic approach (i.e., a minimum coupling-loss analysis) for the calculation of the terminal station out-of-block BEM. Based on specific assumptions[2] with regards to the link budget, a BEM baseline level of -51 dBm/(5 MHz) is calculated (see Section 3).

Subsequently, a more refined stochastic approach (i.e., a spatio-temporal Monte Carlo analysis) is developed which accounts for the statistical likelihood of terminal-to-terminal interference in the calculation of the terminal station out-of-block BEM. The results of this approach indicate that the risk of terminal-to-terminal interference can be appropriately managed while adopting more relaxed BEM baseline levels.

Following this stochastic approach, two distinct studies are presented (see Sections 4 and 5). In the first study, the terminal station BEM baseline level is calculated subject to the requirement that a terminal station serviced in an urban macro-cell is desensitized by up to 3 dB with a probability of up to 5%, given that it is located in a hot-spot of interfering terminal stations. Three different hot spot scenarios have been considered (see Table 8 for details).

Accordingly, based on this stochastic approach:

a) where probability of collision between victim and interferer packets can not be taken into account, a BEM baseline level of -27 dBm/(5 MHz) can be justified;

b) and furthermore, where probability of collision between victim and interferer packets can be taken into account, as it would be the case for two packet-based mobile broadband systems, a BEM baseline level of -15.5 dBm/(5 MHz) can be justified.[3]

In the second study, the impact of terminal-to-terminal interference on the victim terminal's downlink throughput is evaluated for the same geometry and similar parameters as in (b) above, assuming a spectrum

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[1] It should be noted that ECC Report 119 covers various studies that deal with the coexistence between particular types of mobile networks at FDD/TDD boundaries in the 2.6 GHz band. However, the conclusions of ECC Report 119 state that the scenarios considered in that report may not be applicable to cases where administrations authorise use of this spectrum on the basis of the least restrictive technical conditions contained in CEPT Report 19.

[2] 1dB desensitisation for a 4 m TS-TS separation, or 3dB desensitisation for a 2 m TS-TS separation.

[3] This BEM baseline level is calculated based on the probability of collision between wanted packets and interferer packets at the victim receiver assuming a TDD uplink to downlink ratio of 1. Data destined for a receiver is assumed to be transmitted within a single packet of 2.5 ms duration over an interval of 20 ms (i.e., an activity factor of 12.5%).

emission mask of the interfering terminal stations which is upper-bounded by the BEM baseline level of -15.5 dBm/(5 MHz). This second study concludes that, subject to this BEM baseline level, the degradation in the downlink throughput is not significant.

The BEM for a terminal station consists of in-block power limits (specified in EC Decision (2008/477/EC)), out-of-block baseline requirements, and in some cases transitional requirements between them (Section 7). Throughout this document, BEM requirements for terminals are expressed in terms of EIRP. However, an alternative approach could be to express these values as total radiated power (TRP) for nomadic and mobile terminals

The BEM requirements apply without prejudice to spurious emission requirements (which continue to apply). This document does not attempt to address spurious emission levels; this is the responsibility of the standards development organisations (SDOs)[4].

Note that this report deals with the link between the terminal station BEM and the spectrum emission mask (SEM) of a terminal station. It is noted that the BEM concept does not in itself define the means by which the terminal stations in an operator's network meet the BEM[5]. The easiest way to comply with the BEM (at least in regulatory terms) is for the equipment to inherently meet the BEM when the channel edge is aligned with the block edge.

However, operators are entitled to use equipment (or in the case of terminal stations, allow the equipment to connect to their network) that does not inherently meet the BEM, provided that they ensure that the BEM is complied with. In this case, compliance could be achieved by an offset of the nominal channel edge away from the block edge so that the SEM of the equipment falls within the BEM. The operator can apply this approach to both base station and terminal station transmissions, because their operating frequency is under the control of the network. Compliance could also be achieved by reducing the transmit power of the terminal station as might be expected for cells using base stations with antennas placed indoor or with low antenna height..

One important possibility is also for operators in adjacent blocks to reach a bilateral agreement to use a different mask at the block edge. This could exploit some additional characteristic related to a particular radio technology or for specific conditions of deployment networks.

[4] The CEPT recommended spurious emission limits are given in ERC Recommendation 74-01.

[5] The BEM values presented in this report do not take into account the feasibility of the terminal station equipment complying with a BEM.

Table of Contents

LIST OF ABBREVIATIONS

Abbreviation	**Explanation**
ACLR	Adjacent-channel leakage ratio
ACS	Adjacent-channel selectivity
ACIR	Adjacent-channel interference ratio
ATPC	Automatic transmit power control
AWGN	Additive White Gaussian Noise
BEM	Block edge mask
BS	Base station
BWA	Broadband wireless access
CDF	Cumulative distribution function
CDMA	Code division multiple access
CEPT	European Conference of Postal and Telecommunications
DL	Downlink
EIRP	Equivalent isotropic radiated power
EC	European Commission
ECC	Electronic Communications Committee
ERO	European Radiocommunication Office
ETSI	European Telecommunications Standards Institute
FDD	Frequency division duplex
HEN	Harmonised Standard (European Norm)
HSDPA	High speed downlink packet access
IM	Inter-modulation
LOS	Line of sight
LTE	Long term evolution
MCL	Minimum coupling loss
MS	Mobile station
NRA	National regulatory authority
OFDM	Orthogonal frequency division multiplexing
PSD	Power spectral density
R&TTE	Radio and Telecommunications Terminal Equipment
SDO	Standards development organisations
SEM	Spectrum emission mask
SINR	Signal to interference plus noise ratio
TDD	Time division duplex
TDMA	Time division multiple access
TRP	Total radiated power
TS	Terminal Station
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRA	Universal Terrestrial Radio Access
VoIP	Voice over Internet Protocol
WAPECS	Wireless Access Policy for Electronic Communications Services
WIMAX	Worldwide Interoperability for Microwave Access

1 INTRODUCTION

1.1 Overview of block-edge masks

Block-edge masks (BEMs) are related to spectrum licensing and the avoidance of interference between users of spectrum. A BEM is a spectrum mask that is defined, as a function of frequency, relative to the edge of a block of spectrum that is licensed to an operator. On one side of this frequency boundary is the in-block power limit and on the other side is the out-of-block spectrum mask. The out-of-block component of the BEM itself consists of a baseline level and, where applicable[6], intermediate levels which describe the transition from the in-block level to the baseline level as a function of frequency. This is illustrated in Figure 1.

Note that it is usually necessary to separate different types of spectrum use to some extent. In CEPT Report 19 this has been achieved by 5 MHz guard bands located between TDD blocks, and between TDD and FDD uplink in the 2.6 GHz band. These guard bands may be used as a *restricted* block with no guarantee of freedom from interference (and may additionally be associated with a reduced base station EIRP limit, depending on the boundary). The in-block power limit is constant across the unrestricted, also known as *standard*, blocks.

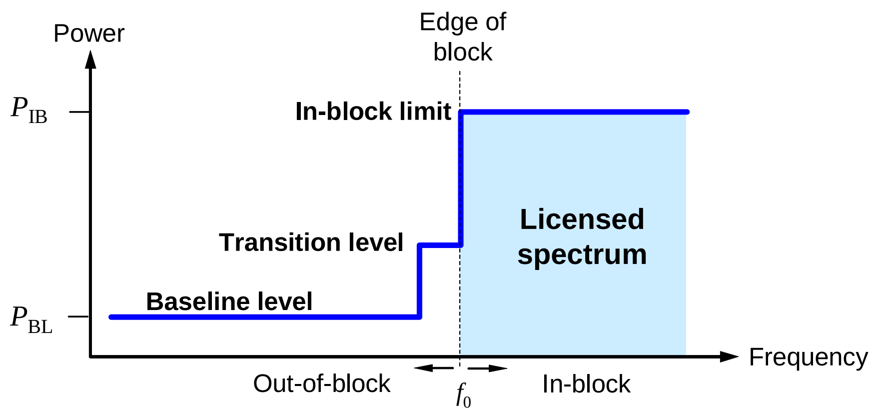


Figure 1: Illustration of a block-edge mask.

On the other hand, a spectrum emission mask (SEM) is defined for equipment by standardization organizations. It is normally defined relative to the channel centre frequency, but the mask relative to edge of the channel can be easily derived by subtracting half of the nominal channel bandwidth from the frequency offsets.

It is noted that the BEM concept does not in itself define the means by which the terminal stations in an operator's network meet the BEM. The BEM values presented in this report do not take into account the feasibility of the terminal station equipment to comply with a BEM.

[6] This depends mainly on the channel arrangement (duplex gap, guard band, and the particular status of blocks).

1.2 Relationship between BEMs and SEMs

In considering the relationship between BEMs and SEMs, there are four distinct cases to consider:

1. The SEM for the equipment (relative to its channel edge) is at least as stringent as the BEM (see Figure 2). The equipment therefore can be operated at any centre frequency for which the nominal channel is completely within the block.

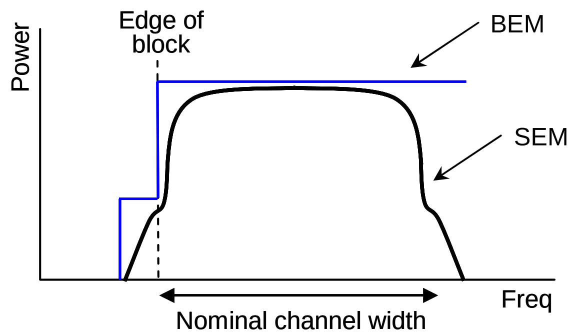


Figure 2: Case 1 – Equipment SEM inherently complies with the BEM.

2. The SEM for the equipment does not comply with the BEM (see Figure 3). However, the operator can use extra measures to meet the BEM, such as adding extra filtering (applicable to base stations), or reducing the transmitted power (applicable to both base stations and terminal stations).

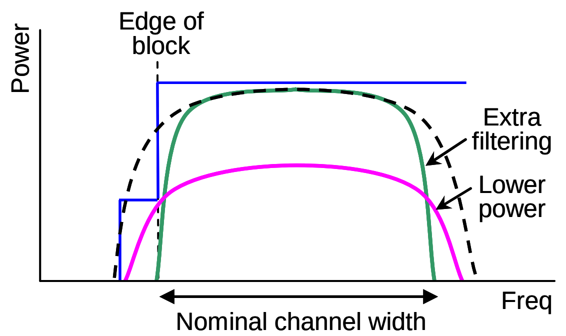


Figure 3: Case 2 – Equipment needs extra measures to comply with the BEM.

3. The SEM for the equipment again does not comply with the BEM. However, in this case, the operator offsets the nominal channel edge away from the block edge so that the SEM of the equipment falls within the BEM (see Figure 4). The operator can do this for both base station and terminal station, because the operating frequency of the terminal station is under the control of the network.

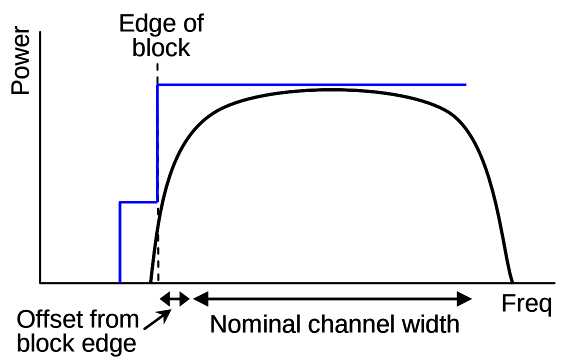


Figure 4: Case 3 – Channel offset from edge of block.

4. The operators in two adjacent blocks reach a bilateral agreement to use a less stringent mask at the block edge or exploit some additional characteristic related to a particular radio technology to justify the relaxation of the BEM values (see Figure 5).

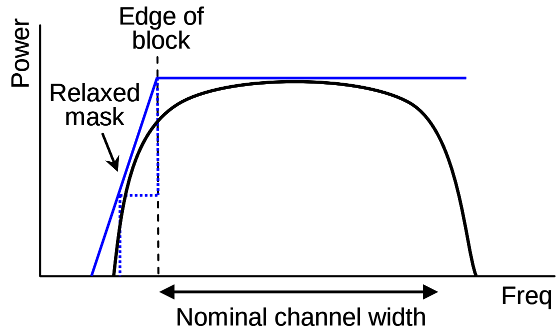


Figure 5: Case 4: Operators agree relaxed mask.

1.3 Considerations for base stations

Base stations (BSs) and other radio infrastructure are operated under the control of a network operator, and under the terms of a license issued to it by the national spectrum regulatory authority. The operator is therefore fully responsible for complying with the terms of the license for the infrastructure, including any BEM.

An operator can use any of the four approaches described above to meet the BS BEM.

1.4 Considerations for terminal stations

The situation is different for terminal stations (TSs), because they are not owned by a network operator.

Within the EU, mobile terminals are generally exempted from individual licensing. Under the R&TTE Directive [5], Member States notify the Commission of the conditions of the interfaces that they have regulated in this way (as well as interfaces that are regulated through individual licences). Network operators are required to connect TSs having an appropriate interface and meeting the essential requirements of Article 3 of the R&TTE Directive (in the context of spectrum masks, the relevant provision is Article 3.2, relating to harmful interference).

Under the R&TTE Directive, manufacturers[7] indicate conformity with these essential requirements[8] by affixing a CE mark on the product. They must also supply information for the user on the countries and/or geographic areas where the equipment can be used, and the interface(s) to which it is intended to be connected.

The Commission Decision on the 2.6 GHz band allows operators to negotiate and agree less stringent technical parameters for the BEM[9]. This provision applies both to BSs and TSs. Operators might offset a channel away from the block edge, so that TSs with less stringent SEMs can be used. However, users may try to use these TSs on other networks.

In the most desirable case (that is, without operational restrictions or bilateral negotiations), the SEM for the TS relative to the nominal channel edge will be the same as the BEM relative to the block edge, or more stringent.

1.5 Regulatory implications

The R&TTE Directive relates to both placing equipment on the market and putting it into service. In the past, there has generally been a one-to-one correspondence between harmonised standard, application/technology and frequency band (i.e., one applicable harmonised standard for an application or technology in a particular

[7] Or the person responsible for placing the product on the market in the EU.

[8] Together with the essential requirements of all other applicable Directives.

[9] First paragraph of the Annex to the Decision: “Member States should ensure that network operators are free to enter into bilateral or multilateral agreements to develop less stringent technical parameters and, if agree among all affected parties, these less stringent technical parameters may be used”.

frequency band), and the national measures for license exemption have almost always been based on this standard. However, there is no fundamental reason why this must be the case. There might be different criteria for putting equipment into service, associated with different operational restrictions.

It is inherent to the BEM concept that it does not define the means by which operators meet the BEM. The easiest way to achieve this (at least, in regulatory terms) is for the equipment to inherently comply with the BEM when the channel edge is aligned with the block edge. However, operators are entitled to use equipment (or for TSs, allow the equipment to connect to their network) that does not inherently meet the BEM provided that they ensure that the BEM is complied with. This situation is less likely to occur with specifications that have been designed for the European market for that frequency band.

1.6 The scope of this report

This report sets out guidance on the terminal station (TS) block-edge masks (BEMs) required for the appropriate management of the risk of terminal-to-terminal interference in the 2.6 GHz band.

Note that this report focuses only on 'intra' 2.6 GHz solutions. An alternative would be to switch to another frequency band when interference becomes unacceptable (i.e., harmful). However, this solution is only available when operators have access to alternative bands, and where the application(s) and technolog(ies) they use support this. It was felt that such a solution is outside the scope of the WAPECS Mandate. Information on the use of frequency planning and channel allocation mechanisms to mitigate the impact of terminal-to-terminal interference is given in ANNEX 1:.

The in-block components of the TS BEMs have already been defined in CEPT Report 19 [1] and the EC Decision [2] on the 2.6 GHz band. Consequently, this report only focuses on the derivation of out-of-block baseline levels – and where applicable, transitional levels – of the TS BEM.

Section (2) presents information with regards to the band-plan in the 2.6 GHz band, the nature of terminal-to-terminal interference, and assumptions on the radio network geometries examined in subsequent sections of the report.

In defining the methodology for computing the TS BEM levels, the conclusions of ECC Report 119 have been taken into account.

ECC Report 119 states that, "The impact of MS-MS interference can be difficult to ascertain, due to the strong influence of the terminal distribution. It is clear that two terminals in close proximity may interfere with each other strongly, especially when the terminal transmits at full power, i.e., when located at the border of the coverage area of their base station. However, it is difficult to determine how often this happens".

ECC Report 119 further recognises that: "It is essential that when considering MS-MS interference, Monte Carlo analyses must be conducted to capture a more realistic system behaviour, and correspondingly to determine levels of interference that will be experienced within a real system. Such analysis would need to include realistic assumptions such as appropriate user distribution (i.e., non uniform), user activity factor, type of services, etc."

Based on the above recommendations, it was decided to proceed with a two step approach.

In the first step, presented in Section (3), a worst-case deterministic approach (i.e., a minimum coupling-loss analysis) assuming 1 and 3 dB desensitization is used to explore the range of BEM baseline levels which ensure protection of a victim TS for different separation distances from the interferer TS.

While the above approach effectively captures the inter-relationship between victim receiver desensitisation and the interferer-victim separation, it does not account for the likelihood of such desensitization (or its impact on the performance of the receiver) in a cellular environment. Consequently, it can be expected that the required baseline levels suggested by the MCL analysis might be over-stringent.

For this reason a second step is adopted which focuses on a stochastic approach (i.e., a spatio-temporal Monte Carlo analysis) to estimate the required BEM baseline level for the most likely uses and deployment scenarios in the band.

Based on this stochastic approach, two distinct studies are presented in Section (4) and Section (5) respectively. In the first study, the TS BEM out-of-block baseline level is calculated subject to the requirement that a TS serviced in an urban macro-cell is desensitized by no more than 3 dB with a probability of no more than 5%, given that it is located in a hot-spot of interfering TSs. In the second study, the impact of terminal-to-terminal interference on the victim terminal's downlink throughput is evaluated for the same geometry and similar parameters as in the first study.

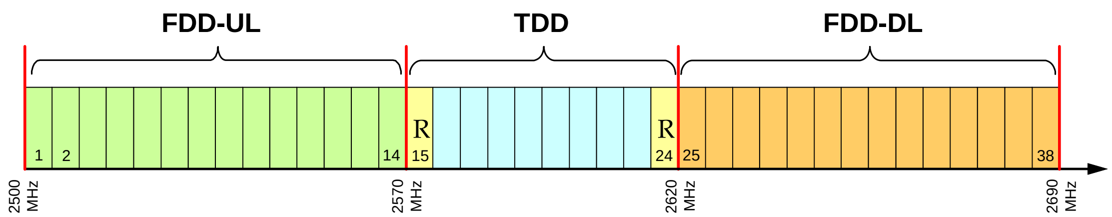
Finally in the concluding Section (6) the computed out-of-block baseline levels are combined with the previously defined in-block limits to construct TS BEMs at the different frequency boundaries in the 2.6 GHz band.

A list of references is provided in ANNEX 4:. ANNEX 1: contains some informative information on the possibility of using judicious frequency planning and channel allocation mechanisms to mitigate the impact of terminal-to-terminal interference. ANNEX 2: describes the radio propagation models used in this report. ANNEX 3: presents details of the modelling methodology used in the second study.

2 GENERAL ASSUMPTIONS

2.1 Interference and the 2.6 GHz band-plan

The Commission Decision 2008/477/EC on the harmonisation of the 2500-2690 MHz frequency band for terrestrial systems [2] sets out a flexible spectrum arrangement for the use of this band. Within the band 2500 – 2690 MHz, the duplex spacing for FDD operation shall be 120 MHz with terminal station transmission (up link) located in the lower part of the band starting at 2500 MHz (extending to a maximum limit of 2570 MHz) and base station transmission (down link) located in the upper part of the band starting at 2620 MHz. Figure 6 illustrates the above band-plan[10] and the different forms of adjacent-channel interference[11] caused by TSs in the 2.6 GHz band.



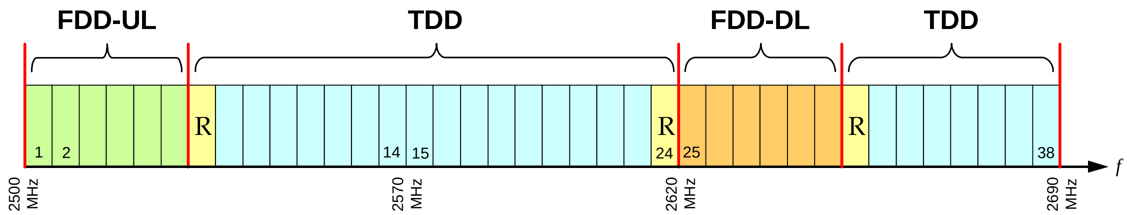
Victim: FDD BS	Victim: TDD BS/TS	Victim: FDD TS
TS → FDD BS	TS → TDD BS TS → TDD TS	TS → FDD TS

Figure 6: Interference from TS and the ECC/DEC/(05)05 band-plan.
Restricted blocks are marked with "R"

The sub-band 2570 – 2620 MHz can be used by TDD or other usage modes complying with the same BEMs. Outside of the sub-band 2570 – 2620 MHz such usage can be decided at national level and shall be in equal parts in both the upper part of the band starting at 2690 MHz (extending downwards) and the lower part of the band starting at 2570 MHz (extending downwards). An example of such a band-plan (with three FDD/TDD boundaries) is illustrated in Figure 7, along with the different forms of adjacent-channel interference.

[10] Note that a 5 MHz restricted block exists also between different TDD operators

[11] TS-TS co-channel interference may occur in adjacent geographical areas (e.g., in cross-border situations). In that case, this should be solved via bi-lateral agreements and additional constraints (see Section 5.4.5. of CEPT Report 19). This is not studied in this report.



Victim: FDD BS	Victim: TDD BS/TS	Victim: FDD TS	Victim: TDD BS/TS
TS → FDD BS	TS → TDD BS TS → TDD TS	TS → FDD TS	TS → TDD BS TS → TDD TS

Figure 7: Interference from TS and a possible 2.6 GHz band-plan. Restricted blocks are marked with "R"

Note that a deviation from the ECC/DEC/(05)05 band-plan, as shown in Figure 7, increases the number of FDD/TDD boundaries. This does not change the number of interference scenarios that need to be considered. This is because the interference scenario at the additional FDD/TDD boundary is similar to that at 2620 MHz. However, the constraints will be more important since the frequency response of the front-end filter of the FDD TS will not reduce the interference from any TDD TSs operating above 2620 MHz.

In general, one may identify four types of inter-system adjacent-channel interference. These include:

a) base station to terminal station (BS-TS)interference;
b) terminal station to base station (TS-BS) interference;
c) base station to base station (BS-BS) interference; and
d) terminal station to terminal station (TS-TS) interference.

Categories (a) and (b) above are not different from the types of interference which occur at the frequency boundaries which separate adjacent FDD cellular systems, or those which separate adjacent TDD cellular systems. Moreover, similar types of intra-system interference occur at the channel boundaries within any type of cellular system. Consequently, regulatory provisions for the mitigation of base-to-terminal or terminal-to-base adjacent-channel interference in the 2.6 GHz band are embedded in the relevant technology standards.

Categories (c) and (d) above, however, are specific to scenarios where transmissions in adjacent frequencies are subject to uplink and downlink phases which are not synchronised in time. This is characteristic at frequency boundaries which separate paired (FDD) and unpaired (TDD) spectrum, or at those which separate (uncoordinated) licensees of unpaired (TDD) spectrum.

This report focuses on TS-TS interference; i.e., where a TDD TS interferes with a FDD TS, where a FDD TS interferes with a TDD TS, and where a TDD TS interferes with a TDD TS.

Although BEMs are defined over the whole of the 2500-2690 MHz band, the transition from BEM in-block limits to baseline levels are most severe at the FDD/TDD (2570 MHz, and 2620 MHz) and TDD/TDD (within the FDD duplex gap) boundaries.

2.2 The nature of adjacent-channel interference

The scope for TS-TS adjacent-channel interference is driven by a mix of factors relating to:

i) The experienced interference as a result of radiation spectral leakage and non-ideal receiver filter characteristics.

According to information theory, the maximum data throughput per unit bandwidth achievable over a communication link is a logarithmic function of the signal-to-interference-plus-noise ratio (SINR) experienced at the receiver. Consequently, the SINR is the key parameter in defining the spectral efficiency of a radio link. The level of SINR at a receiver is, in turn, a function of the radiated powers and spatial geometries of the transmitters of wanted and unwanted signals, in addition to the radio propagation environment.

Where an interferer transmits at a frequency that lies outside the nominal pass-band of the wanted signal, the level of interference experienced is a function of a) the interferer's spectral leakage, as defined by its emission power spectral density, and b) the frequency response of the filtering at the receiver. These two effects can be characterised by the interferer's adjacent-channel leakage ratio (ACLR) and the receiver's adjacent-channel selectivity (ACS) respectively[12], as illustrated in Figure 8. The combination of these two parameters, in the form of $(\text{ACLR}^{-1} + \text{ACS}^{-1})^{-1}$, represents the fraction of the received interferer power which is experienced as interference by the receiver, and is referred to as the adjacent-channel interference ratio (ACIR)[13]. In other words, for a received interferer power $P_{\text{AC}}(\Delta f)$ at frequency offset Δf from the wanted signal, and for an ACIR of $A(\Delta f)$, the experienced interference power is given by $P_I = P_{\text{AC}}(\Delta f)/A(\Delta f)$.

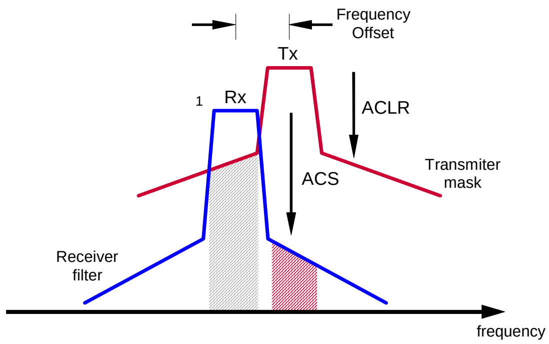


Figure 8: Interference as a result of limited ACLR and ACS

ii) Third-order inter-modulation products, which represent the interference caused by non-linear behaviour at the receiver.

In addition to the effects discussed in (i) above, it is also possible for signals received at adjacent channels to result in interference through inter-modulation products caused by the non-linear behaviour of the receiver. Consider a wanted signal received in frequency block n_0. Then, third-order nonlinearities in the behaviour of the receiver would imply that two interferers received at frequency blocks $n_0+\Delta n$ and $n_0+2\Delta n$ can result in co-channel interference within frequency block n_0. These so-called inter-modulation (IM) products can be a significant source of degradation in SINR when the receiver is exposed to multiple un-attenuated adjacent-channel interferers. For example in Figure 7, a FDD terminal station receiving in block #30 would be subject to third-order IM products caused by TDD terminal station interferers received in block pairs (#31, #32), (#32, #34), and (#33, #36). Similarly, a FDD terminal station receiving in block #25 would be subject to third-order IM products originating from block pairs (#23, #24), (#21, #23), and others[14].

iii) Saturation, or "blocking", where a terminal station becomes overloaded by the high power levels of received adjacent-channel interferers which prevent the receiver from processing the wanted signal.

Naturally, the components in a receiver chain are unable to deal with arbitrarily large signal levels. If the absolute values of the received adjacent-channel signals are beyond a certain threshold, the receiver will be overloaded or saturated. The performance of the receiver is difficult to model in such circumstances, and parameters (such as the ACIR) which model the normal operation of the receiver are no longer helpful in predicting the levels of interference experienced or the achievable throughputs. In this report it is assumed that the saturation of the receiver would result in a zero radio link throughput. This is a conservative assumption, as in practice it is unlikely that throughput would fall to zero in all cases.

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[12] The ACLR of a signal is defined as the ratio of the signal's power (nominally equal to the power over the signal's pass-band) divided by the power of the signal when measured at the output of a (nominally rectangular) receiver filter centred on an adjacent frequency channel. The ACS of a receiver is defined as the ratio of the receiver's filter attenuation over its pass-band divided by the receiver's filter attenuation over an adjacent frequency channel. It can be readily shown that $\text{ACIR}^{-1} = \text{ACLR}^{-1} + \text{ACS}^{-1}$.

[13] The ACIR is defined as the ratio of the power of an adjacent-channel interferer as received at the victim, divided by the interference power "experienced" by the victim receiver as a result of both transmitter and receiver imperfections.

[14] Interferers at lower frequency blocks would be increasingly attenuated by the FDD terminal station's front-end (duplex) filter.

Note that the derivation of the TS BEM out-of-block levels presented in Sections (3) and (4) is related to the spectral leakage of emissions by the interferer into adjacent channels. The impact of receiver filtering, inter-modulation and saturation are investigated in Section (5).

2.3 Investigated geometries

In addition to a minimum coupling loss analysis, Monte Carlo simulations are used in this report to analyse the impact of TS-TS interference. For this purpose, a scenario is considered where a TDD cellular network is deployed in the same geographical area as a FDD cellular network. It is further assumed that the TDD network operates within 5 MHz frequency blocks that are neighbouring those used by the FDD network in the downlink direction, thereby giving rise to the possibility of TS-TS interference. This is depicted in Figure 9.

Note that while the interference scenario of Figure 9 is formulated for the case of interference from TDD TSs to FDD TSs, the arguments and results in this report also broadly apply in the opposite direction, and also in the case of interference between TDD TSs.

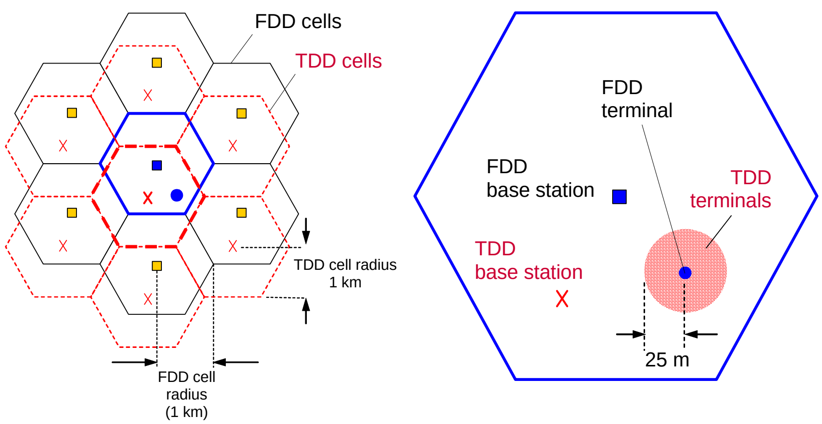

Figure 9: Urban macro-cellular scenario

A macro-cellular deployment is considered in order to capture geometries where both the interferer and victim terminals are far from their serving base stations. In such geometries, the interferer can cause most interference (by radiating at high power) and the victim is most susceptible to interference (by receiving wanted signals at low power).

In each Monte Carlo trial, the target victim FDD TS is randomly placed within the central FDD cell. A number of TDD TSs are then randomly distributed within a given radius of the FDD TS. Finally, the FDD TS (along with the surrounding TDD TSs) is appropriately placed within a serving TDD cell. Note that this formulation corresponds to the case where the FDD TS is always in the proximity of a high density of TDD TSs (i.e., a TDD hot-spot). All terminal station locations are subject to a uniform probability density function.

A nominal hot-spot radius of 25 or 50 metres is justified by noting that for greater distances the path from an interferer TS to a victim TS is likely to be heavily obstructed, and the impact of TS-TS interference would be correspondingly mitigated. A macro-cell radius of 1 km is considered, consistent with a typical urban deployment.

Density of interferer terminals in the hot-spot

In the representative hot-spot scenario examined, the number of TDD TSs simulated is derived by reference to an average spatial density of 1 person per 3 square-metres. This figure is consistent with measurements of population densities observed in very high-density hot-spot locations such as cafes and conference centres. It is then assumed that 1 in 10 individuals, randomly selected within the hot-spot, will be using their wireless device at any Monte-Carlo snapshot.

This still corresponds to a substantial number of 65 TSs simultaneously operating (although not necessarily simultaneously transmitting) within a radius of 25 m from a potential victim of TS-TS interference. For this scenario, it is considered to be a reasonable assumption that 50% of the population use wireless equipment operating in bands other than the 2.6 GHz band, and that, of those who do use the 2.6 GHz band, only 50% use TDD technology.

The above assumptions imply that the spatial density of TDD terminal stations operating in the 2.6 GHz band at any Monte-Carlo snapshot would be of the order of 1/120 per square-metre. Given a total of 10 unpaired (TDD) blocks in the band-plan example considered, and assuming a uniform distribution of TDD terminals across the blocks, the above corresponds to a density of 1/1200 per square-metre per 5 MHz TDD block. This corresponds to an average of $M = 2$ interferer TSs in a 5 MHz block within a 25 m hotspot.

3 MINIMUM COUPLING LOSS ANALYSIS

A deterministic approach − based on a minimum coupling-loss (MCL) analysis − for the derivation of the TS BEM out-of-block baseline level is presented in this section. In Section (3.1) acceptable levels of interference are formulated as a function of receiver desensitization. The corresponding TS out-of-block baseline levels are then calculated in Section (3.2) for different TS-TS separations, subject to the requirement that the level of interference experienced at the victim TS does not exceed the values derived in Section (3.1). Conclusions are presented in Section (3.3).

3.1 Interference protection level

Consider a victim TS with a receiver thermal noise floor, P_{N}, in dBm/MHz. Then the tolerable, or *target*, interference power at the receiver may be written (in the logarithmic domain) as

$$P_{\mathrm{I,Target}} = P_{\mathrm{N}} + 10\log_{10}\left(10^{D/10} - 1\right), \tag{3.1}$$

where D is the acceptable degradation in receiver sensitivity, or *desensitization*, in units of dB, and the receiver thermal noise power is given by

$$P_{\mathrm{N}} = 10\log_{10}(kT) + 10\log_{10}(10^{6}) + \mathrm{NF}_{\mathrm{TS}}, \tag{3.2}$$

where k is Boltzmann’s constant (W/K/Hz), T is the ambient temperature (K), and $\mathrm{NF}_{\mathrm{TS}}$ is the receiver noise figure (dB). For $k = 1.3804\times10^{-23}$, $T = 290$, and $\mathrm{NF}_{\mathrm{TS}} = 9$, we have

$$P_{\mathrm{N}} = -105 \text{ dBm/MHz}.$$

Substitution back into Equation (3.1) indicates that

- $P_{\mathrm{I,Target}} = -105$ dBm/MHz for a 3 dB desensitization (i.e., $D = 3$ dB),
- $P_{\mathrm{I,Target}} = -111$ dBm/MHz for a 1 dB desensitization (i.e., $D = 1$ dB).

3.2 TS out-of-block baseline requirement

The objective here is to compute the interferer TS out-of-block EIRP such that, for a specific TS-TS separation (and hence, propagation path-gain), the level of interference experienced at the victim TS does not exceed the target values derived in the previous section (3.1).

Hence, for an adjacent-channel TS interferer radiating with an out-of-block EIRP level of P_{OOB} dBm/MHz in the vicinity of the victim TS, one may write

$$P_{\mathrm{OOB}} + G_{\mathrm{PL,\,TS-TS}} \le P_{\mathrm{I,\,Target}}, \tag{3.3}$$

where $G_{\mathrm{PL,\,TS-TS}}$ is the TS-TS propagation path gain in dB.

For the purposes of this minimum coupling loss (MCL) analysis, TS-TS propagation gain is assumed to follow a free-space path loss model. Therefore,

$$G_{\mathrm{PL,\,TS-TS}} = 27.56 - 20\log(f) - 20\log(d), \tag{3.4}$$

where f is the operating frequency in MHz, and d is the TS-TS separation in metres. An operating frequency of 2600 MHz is used in this study.

Table 1 shows the required TS out-of-block EIRP values derived from Equation (3.3) as a function of TS-TS separation and for receiver desensitization levels of 1 dB and 3 dB respectively.

TS-TS separation d (m)	Path gain $G_{PL,TS-TS}$ (dB)	TS BEM baseline P_{OOB} (dBm/MHz)	
		1 dB desensitization	3 dB desensitization
1	–40.7	–70	–64
2	–47	–64	–58
3.5	–51.6	–59.4	–53.4
4	–53	–58	–52
5	–54.7	–56.3	–50.3
10	–60.7	–50.3	–44.3

Table 1: TS BEM baseline levels required for 1 and 3 dB receiver desensitization, and different TS-TS separation distances

For comparison, consider the out-of-block emission levels implied by the TS BEM proposed in CEPT Report 19. These are shown in Table 2 below.

Frequency offset from block-edge (MHz)	P_{OOB} (dBm/MHz)
0 to 1	+2.8[15]
1 to 5	–10
5 to 6	–13
> 6	–19

Table 2: TS BEM proposed in CEPT Report 19

As can be seen, the minimum TS out-of-block emission level of –19 dBm/MHz specified in CEPT Report 19 is considerably greater than the baseline requirements suggested by the MCL analysis in Table 1, even for TS-TS separations of up to 10 m.

The minimum TS-TS separations implied by CEPT Report 19 out-of-block emission levels are presented in Table 3. These are derived by substituting the CEPT Report 19 emission levels into Equation (3.1), and then computing the maximum allowed TS-TS path-gain, and hence, the minimum required TS-TS separation.

CEPT Report 19 P_{OOB} (dBm/MHz)	Max. Path gain $G_{PL, TS-TS}$ (dB)		Min. separation d (m)	
	D = 1 dB	D = 3 dB	D = 1 dB	D = 3 dB
+2.8	-113.8	-107.8	180	113
-10	-101	-95	93	78
-13	-98	-92	84	71
-19	-92	-86	71	59

Table 3: Minimum TS-TS separation, based on a MCL analysis, for the CEPT Report 19 out-of-block emission levels

3.3 Conclusions of MCL analysis

A deterministic approach, based on MCL analysis, was presented in this section for the calculation of the TS BEM out-of-block baseline level.

The analysis indicates that for a TS BEM baseline level of –58 dBm/MHz, a victim TS would be desensitized by 1 dB at a TS-TS separation of 4 m, and would be desensitized by 3 dB at a TS-TS separation of 2 m.

[15] Specified as –15 dBm/(30 kHz) in CEPT Report 19.

The study also indicates that the required baseline levels suggested by the MCL analysis are considerably smaller than the out-of-block emission levels implied by the TS BEM specified in CEPT Report 19.

It should be noted that while the presented MCL analysis effectively captures the inter-relationship between victim receiver desensitisation and the interferer-victim separation, it does not account for the likelihood of such desensitization (or its impact on the performance of the receiver) in a cellular environment. Consequently, it can be expected that the required baseline levels suggested by the MCL analysis are likely to be over-stringent. For this reason, a stochastic approach for the computation of the required baseline levels is presented in the next section.

4 STUDY-1: COMPUTATION OF BEM OUT-OF-BLOCK BASELINE LEVELS

In Section (3), a deterministic approach (i.e., a minimum coupling-loss analysis) for the calculation of the TS BEM out-of-block baseline level was presented. In that approach, the baseline level was calculated as a function of the separation distance between an interferer and a victim TS subject to the requirement that the victim receiver is desensitized by no more than 1 (or 3) dB. This is equivalent to the requirement that the interference power at the victim receiver is at a fixed level of -6 (or 0) dB with respect to the thermal noise level.

In the approach presented in this section, the methodology for the calculation of the TS BEM baseline level is refined, through a Monte Carlo approach, to incorporate:

a) the statistics of the victim and interferer TS locations within their respective cells,

b) the statistics of the victim's received signal level and the interferer's transmission power control, and

c) the statistics of collisions between interfering uplink packets and wanted downlink packets at the victim receiver when applicable.

The TS BEM baseline level is then derived subject to the requirement that the victim receiver is desensitised by no more than 1 or 3 dB with a certain probability across the ensemble of all Monte Carlo trials.

In Section (4.1) we first describe a mathematical model for the computation of the TS out-of-block EIRP statistics. Section (4.2) describes the various steps involved in the Monte Carlo simulations. Simulation results are presented in Section (4.3), with a list of assumed parameter values in Section (4.3.1), followed by various results in Sections (4.3.2) to (4.3.5). In this analysis, the interferer is initially assumed to be a TDD TS and the victim is assumed to be a FDD TS. Results for scenarios involving interference from FDD TSs to TDD TSs, and from TDD TSs to TDD TSs (in unsynchronised networks) are presented in section (4.3.6). Conclusions with regards to the appropriate TS BEM baseline levels are finally derived in Section (4.4).

4.1 Modeling of TS-TS interference

Consider an interferer TS and a victim TS as shown in Figure 10 below. For illustrative purposes, and without loss of generality, the interferer is assumed to be a TDD TS and the victim is assumed to be a FDD TS. This is with the understanding that the results equally apply in the opposite direction, and also in the context of interference between TDD terminal stations.

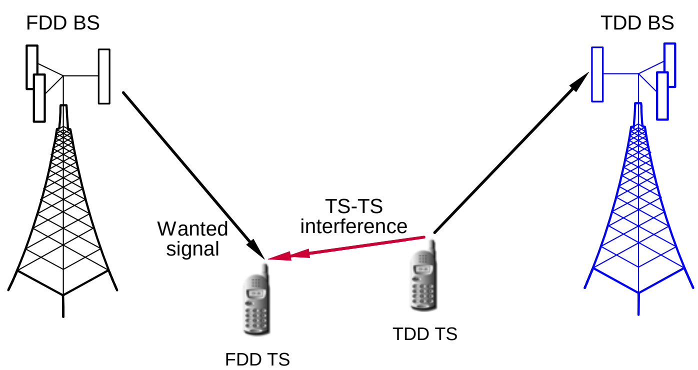

Figure 10: Illustration of interference between two terminal stations

The tolerable, or *target*, interference power level, $P_{\mathrm{I,\,FDD,\,Target}}$ in dBm/MHz, at the victim FDD TS receiver caused by a non-co-channel TS interferer may then be written (in the logarithmic domain) as

$$P_{\mathrm{I,\,FDD,\,Target}} = P_{\mathrm{N}} + G_{\mathrm{I,FDD}} + G_{\mathrm{D,FDD}} + G_{\mathrm{A,FDD}}\,, \tag{4.1}$$

where P_{N} is the thermal noise floor at the receiver[16] in dBm/MHz, $G_{\mathrm{I,FDD}}$ is the *noise rise* in dB due to the presence of intra-system interference power in the DL of the FDD network, $G_{\mathrm{D,FDD}}$ represents the tolerable increase in dB of the interference-plus-noise power level (receiver desensitisation) at the cell-edge, and $G_{\mathrm{A,\,FDD}}$ represents the increase in dB of the tolerable interference due to proximity of the victim to its serving base station.

Note that the intra-system interference that is experienced in a FDD network includes multiple-access interference (co-channel), inter-cell interference (co-channel), as well as all forms of intra-system adjacent-channel interference.

The term, $G_{\mathrm{D,FDD}}$, is related to the receiver desensitization in dB at the cell-edge. For a 3 dB desensitization, for example, the target interference, $P_{\mathrm{I,\,FDD,\,Target}}$, would be equal to the intra-system interference-plus-noise power, $P_{\mathrm{N}} + G_{\mathrm{I,FDD}}$, at the receiver, in which case $G_{\mathrm{D,FDD}}$ = 0 dB. Equally, for a 1 dB desensitization, $G_{\mathrm{D,FDD}} = -6$ dB.

The interference allowance, $G_{\mathrm{A,\,FDD}}$, accounts for the fact that, as a victim TS moves in from the cell-edge and approaches its serving base station, the wanted DL signal increases, and so for a fixed signal-to-interference-plus-noise ratio (and hence DL quality), the victim receiver can tolerate a proportionally greater amount of interference. Specifically,

$$G_{\mathrm{A,FDD}} = G_{\mathrm{1,FDD}} - G_{\mathrm{0,FDD}} \geq 0\,, \tag{4.2}$$

where $G_{\mathrm{1,\,FDD}}$ and $G_{\mathrm{0,FDD}}$ are the base-to-terminal mean path-gains in dB at the victim terminal's location and the cell edge respectively.

The objective here is to compute the interferer TS out-of-block EIRP for which, given all realisations of TS locations and TS-TS propagation path-gains in the envisaged scenario, the level of interference experienced at the victim TS does not exceed the target value of Equation (4.1).

Hence, for a non-co-channel TDD TS interferer radiating with an out-of-block EIRP level of $P_{\mathrm{OOB,\,TDD}}$ dBm/MHz in the vicinity of the victim FDD TS, one may write

$$P_{\mathrm{OOB,\,TDD}} + G_{\mathrm{PL,\,TS-TS}} + G_{\mathrm{PC,\,TDD}} + G_{\mathrm{Coll}} \leq P_{\mathrm{I,\,FDD,\,Target}}\,, \tag{4.3}$$

where $G_{\mathrm{PL,\,TS-TS}}$ is the TS-TS propagation path gain in dB, $G_{\mathrm{PC,\,TDD}}$ is a power control factor in dB, and G_{Coll} accounts for the extent of collision (in time) between a packet transmitted by the interferer and a packet received by the victim.

The term $G_{\mathrm{PC,TDD}}$, accounts for the fact that, as the interferer TS moves in from the cell-edge and approaches its serving base station, the wanted signal level on the UL increases, and so for a fixed signal-to-interference-plus-noise ratio (and hence UL quality), the interferer can transmit at a proportionally reduced in-block EIRP, implying a correspondingly reduced out-of-block EIRP, $P_{\mathrm{OOB,\,TDD}}$. Specifically,

$$G_{\mathrm{PC,TDD}} = G_{\mathrm{0,TDD}} - G_{\mathrm{1,TDD}} \leq 0\,, \tag{4.4}$$

where $G_{\mathrm{1,\,TDD}}$ and $G_{\mathrm{0,TDD}}$ are the base-to-terminal mean path-gains in dB at the victim terminal's location and the cell edge respectively.

[16] This is equal to 10 $\log_{10}(k\,T\,B)$ + $\mathrm{NF_{TS}}$, where k is Boltzmann's constant (W/K/Hz), T is the ambient temperature (K), B is the noise-equivalent bandwidth (Hz), and $\mathrm{NF_{TS}}$ is the TS receiver noise figure (dB).

The impact of packet collisions

One important aspect to be considered in the analysis is the likelihood of partial overlaps between the interfering and victim signals. This is relevant in cases where the radio technologies used by the victim and the interferer incorporate some element of time-division multiple-access (TDMA), as is the case, for example, in packet-based transmission.

Modern radio access technologies increasingly employ packet-based transmissions over the air-interface in order to better deal with the bursty nature of traffic, and to more efficiently utilise the radio resource by appropriately scheduling transmissions to and from those terminal stations associated with favourable radio link conditions at any given instant in time.

Consequently, the terminal stations in such systems transmit and receive data in bursts of finite duration. As a result, the probability of collision at a victim TS receiver between a wanted DL packet and an interfering UL packet (originating from a non-co-channel TS) is inevitably less than unity. Furthermore, the extent of interference experienced by the victim is also a function of the *degree* of overlap (in time) between the wanted and interfering packets, as illustrated in Figure 11.

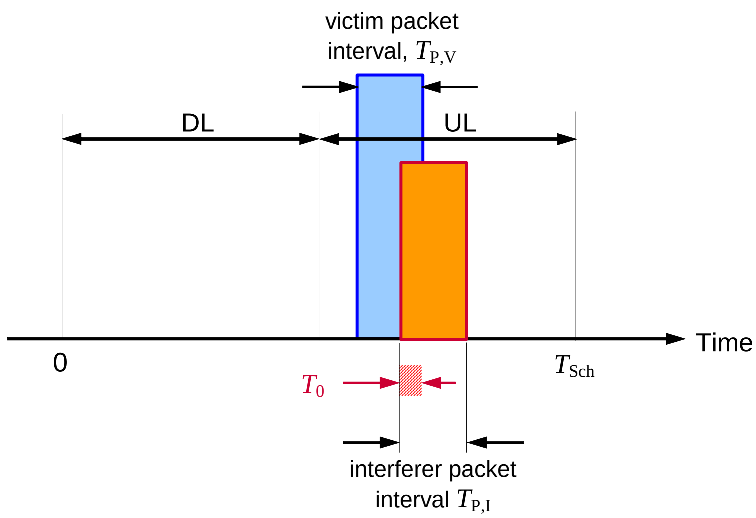

Figure 11: Illustration of a partial overlap between the interferer and victim packets.

In this study, the above effects are captured by the factor, G_{Coll}, where

$$G_{Coll} = 10\log_{10}\left(\frac{T_0}{T_{P,V}}\right), \tag{4.5}$$

where T_0 is the overlap interval between a wanted DL packet (of duration $T_{P,V}$) and an interfering UL packet (of duration $T_{P,I}$) at the victim receiver.

Naturally, in the case of a complete overlap we have, $T_0 = T_{P,V}$. This means that the victim will observe an interfering signal at every instant in time during its reception interval, $T_{P,V}$. This is as if the interferer were always present. For this reason, no scaling of the interference power is required in Equation 4.3 (i.e., $G_{Coll} = 0\text{ dB}$), and the victim experiences the full effect of interference.

Conversely, in the case of no overlap we have, $T_0 = 0$. This means that the victim does not observe the interfering signal at any time during its reception interval, $T_{P,V}$. It is as if the interferer were not present at all. For this reason, the interference power in Equation 4.3 must be scaled down to zero (i.e., $G_{Coll} = -\infty$ dB), and the victim experiences no interference.

Finally, consider the case of a partial overlap where, for example, $T_0 = 0.25\,T_{P,V}$. This means that the victim will observe the interfering signal at only one quarter of the time during its reception interval, $T_{P,V}$. This can be coarsely interpreted as the victim experiencing one quarter of the interferer power when averaged over the whole of its reception interval $T_{P,V}$. Consequently, the interference power in Equation 4.3 must be scaled by a factor of one quarter (i.e., $G_{Coll} = -6\text{ dB}$).

The extent of packet overlap, and hence the value of G_{Coll}, is re-calculated at each Monte Carlo trial when a collision between interferers and the victim in the time domain exists. The FDD DL packet destined for the victim TS is assumed to be received (at a uniformly distributed time of arrival) within a scheduling interval T_{Sch}. The TDD UL packet transmitted by an adjacent-channel interfering TS is then assumed to be received by the victim TS (at a uniformly distributed time of arrival) within the UL phase of the TDD network.

In order for the modelling of interference to equally apply to a TDD victim as well as a FDD victim, we assume equal packet durations, $T_{\mathrm{P,V}} = T_{\mathrm{P,I}}$, and a TDD UL/DL ratio of 1. The latter assumption implies that the TDD TS is a potential interferer during half the scheduling interval, and is a potential victim during the other half of the scheduling interval.

4.2 Description of the simulation process

Figure 12 depicts a realisation of the TS locations within their respective macro-cells in a typical Monte Carlo trial. This is for the example of an interferer TS spatial density per 5 MHz block[17] of (1/3)/(10×2×2×10) m^{-2}, which equates to $M = 2$ interferer TSs within a 25 m radius hot-spot..

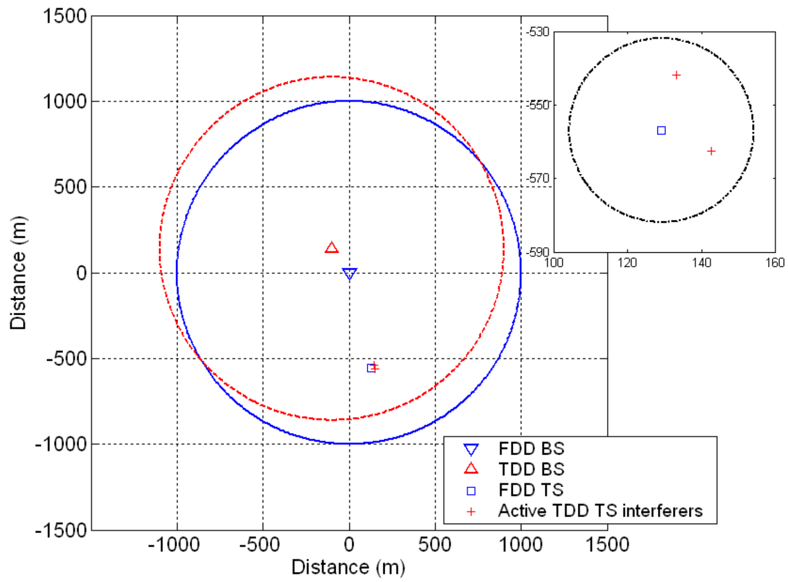

Figure 12: Illustration of TDD and FDD TS spatial distributions in a Monte Carlo trial

The following steps are performed at each Monte Carlo trial:

1) Drop the victim FDD TS at a random (uniformly distributed) location within the FDD macro-cell.

2) Drop M TDD TS interferers at random (uniformly distributed) locations within a hot-spot surrounding the FDD TS.

3) Drop the TDD hot-spot at an appropriate location within the TDD macro-cell[18].

4) Calculate the TDD power control factor, $-40\,\mathrm{dB} \le G_{\mathrm{PC,\,TDD}} \le 0\,\mathrm{dB}$, based on the location of the TDD TS within the TDD macro-cell, according to Equation (4.4).

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[17] A spatial density of 1 person per 3m² is assumed, 10% of whom are considered to be using their wireless device. It is then assumed that 50% of the terminals operate in the 2.6 GHz band (the rest operating in other frequency bands). Of those terminals operating in the 2.6GHz band, it is assumed that half operate in FDD mode and half in TDD mode. The TDD terminals are then assumed to be uniformly distributed across a total of 10 available unpaired (TDD) 5 MHz blocks.

[18] When considering a fixed base station separation across the Monte Carlo trials, a correction is made to ensure that the largest separation between a TDD TS and the TDD BS is not greater than the TDD cell radius. When considering stochastic realisations of base station locations across the Monte Carlo trials, the TDD hot-spot is dropped at a random (uniformly distributed) location fully within the TDD macro-cell, again to ensure that the largest separation between a TDD TS and the TDD BS is not greater than the TDD cell radius.

5) Calculate the interference allowance factor, $G_{A,FDD}$, based on the location of the FDD TS within the FDD macro-cell, according to Equation (4.2).

6) Calculate the tolerable interference, $P_{I, FDD, Target}$, at the victim FDD TS, based on Equation (4.1).

7) Calculate the path gain between the victim TS and each of the M TS interferers.

8) Calculate a collision factor, G_{Coll}, for each victim-interferer pair based on Equation (4.5).

9) Select the dominant TS interferer (i.e., which would cause greatest interference).

10) Compute the out-of-block EIRP, $P_{OOB, TDD}$, for the dominant interferer, as indicated in Equation (4.3).

Following a sufficiently large number of Monte Carlo trials, the statistical distribution of the TS out-of-block EIRP, $P_{OOB, TDD}$, can be derived. This process fully identifies the characteristics of a TS interferer's out-of-block EIRP subject to the requirement that, across the ensemble of all realisations considered, the victim TS does not experience interference that is greater than a certain tolerable level.

4.3 Simulation results

4.3.1 Parameter values

A list of all parameter values used in the derivation of the results in this section is presented in Table 4 to Table 6 below.

FDD

Cell radius	1000 metres
BS antenna height	30 metres
Minimum BS-TS separation	50 metres
BS-TS path loss model	Extended (urban) Hata (see ANNEX 2:)
TS antenna gain	0 dBi
Noise-equivalent bandwidth, B	5 MHz
TS noise figure, NF_{TS}	9 dB
Desensitization	1 dB ($G_{D,FDD}$ = –6 dB), or 3 dB ($G_{D,FDD}$ = 0 dB)
Intra-system noise rise, $G_{I,FDD}$	0 or 6 dB
Downlink packet duration, $T_{P,V}$	2.5 ms

Table 4: List of FDD receiver parameter values

TDD

Cell radius	1000 metres
Hot-spot radius	25 or 50 metres
BS antenna height	30 metres
Minimum BS-TS separation	50 metres
BS-TS path loss model	Extended (urban) Hata (see ANNEX 2:)
TS spatial density	1/(10×2×2×10)/3 metre^{-2} (per 5 MHz) 1/(10×2×2×10)/5 metre^{-2} (per 5 MHz) 1/(10×2×2×10)/10 metre^{-2} (per 5 MHz)
Number of interferers in hot-spot, M	2 or 1 (per 5 MHz)
Uplink packet duration, $T_{P,I}$	2.5 ms
Uplink/downlink ratio, $u_{UL/DL}$	1:1

Table 5: List of TDD transmitter parameter values

General

Operating frequency	2.6 GHz
Number of Monte Carlo trials	5000
TS-TS separation	25 or 50 metres (max), 1 metre (min)
TS-TS path loss model	IEEE 802.11 Model C (see ANNEX 2:)
Separation between FDD and TDD base stations	Fixed or stochastic
Scheduling interval, T_{Sch}	20 ms
TS antenna height	1.5 m
Boltzmann's constant, k	1.3804×10^{-23} (W/K/Hz)
Ambient temperature, T	290 Kelvin

Table 6: List of generic parameter values

Note that, in practice, the duration of radio packets transmitted and received by a TS is a function of the multiple-access technique, the modulation and coding scheme used at any given instant, and the details of the multi-user scheduling algorithm implemented by the base station across the cell. In line with the principle of technology neutrality, a packet interval of 2.5 ms is adopted for the purposes of this study. This value can be justified by noting that many of the packet-based radio access technologies today use transmission time intervals of the order of 1 to 2 ms[19]. Furthermore, the considered scheduling interval of 20 ms is consistent with the encoding interval of many multi-media compression algorithms.

The packet duration of 2.5ms, in conjunction with a scheduling interval of 20 ms, implies a TS *activity factor* of 12.5%.

4.3.2 Statistics of TS out-of-block EIRP without consideration of packet collisions

Figure 13 shows the distribution of the TS out-of-block EIRP, $P_{\mathrm{OOB,TDD}}$, over 5000 Monte Carlo trials, derived based on the assumption that, across the ensemble of all geometries examined, the victim TS is desensitised by 1 dB (i.e., $G_{\mathrm{D,FDD}} = -6$ dB).

Note that the impact of packet collisions is not considered in this example (i.e., $G_{\mathrm{Coll}} = 0\,\mathrm{dB}$). Furthermore, for ease of comparison with the MCL analysis of Section (3), intra-system interference in the FDD system is assumed to be zero (i.e., $G_{\mathrm{I,FDD}} = 0\,\mathrm{dB}$). Finally, note that the separation between the FDD and TDD base station is fixed at 100 metres in this example. Other parameter values are as described in Table 4 to Table 6.

[19] For example, WiMAX air-interface specifications (Part 16) indicate that time-frequency slots over a 2.5 ms uplink sub-frame are allocated first in time, and then in frequency, to various users. This implies that terminal TTIs are likely to be large fractions of the uplink sub-frame interval of 2.5 ms (up to a maximum of 2.5 ms). Other technologies support TTIs of 2 ms or less. Examples include HSPA (2 ms), LTE (0.5/1 ms), and WiFi (several hundred μs).

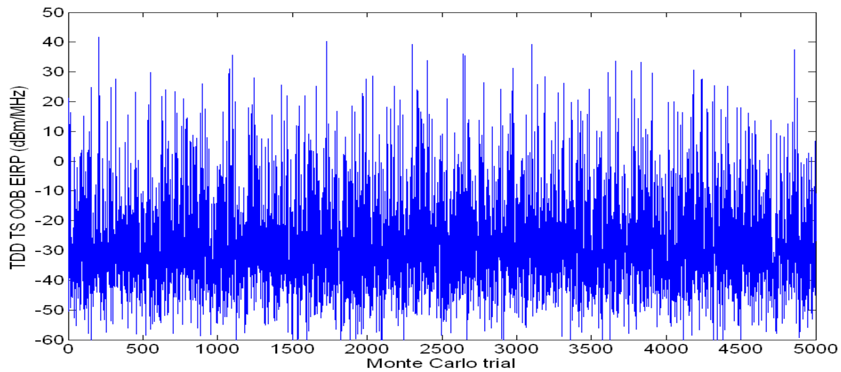

Figure 13: Distribution of interferer TS out-of-block EIRP, for a 1 dB desensitization of the victim TS ($G_{D,FDD}$ = -6 dB), no noise rise ($G_{I,FDD}$ = 0 dB), and not accounting for the likelihood of packet collisions (G_{Coll} = 0 dB)

The distribution of the TS out-of-block EIRP, $P_{\mathrm{OOB,TDD}}$, can also be depicted in the form of a cumulative distribution function (CDF), as shown in Figure 14. The CDF is useful since it shows the probability that $P_{\mathrm{OOB,TDD}}$ does not exceed a given value. The probability of undue interference is then defined by a threshold (e.g., 2% or 5%) for which an excess of interference would be manageable. The baseline requirement is defined as the TDD TS out-of-block EIRP value for this threshold.

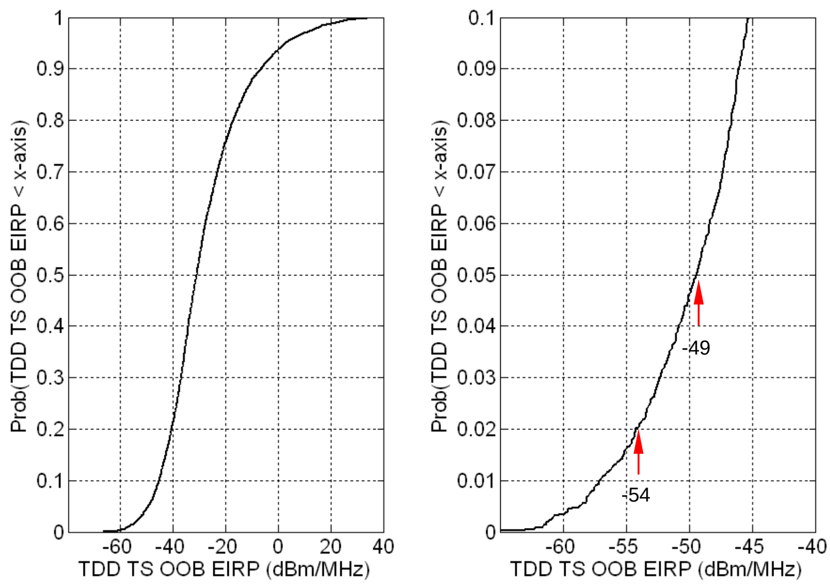

Figure 14: CDF of interferer TS out-of-block EIRP, for a 1 dB desensitization of the victim TS ($G_{D,FDD}$ = -6 dB), no intra-system noise rise ($G_{I,FDD}$ = 0 dB), and not accounting for the likelihood of packet collisions (G_{Coll} = 0 dB).

Based on the above results, one can conclude that, if the permitted TS out-of-block EIRP is limited to a maximum of –54 dBm/MHz, this would exclude 98% of the realisations in which the victim TS is desensitized by at most 1 dB (referenced at cell-edge).

Stated differently, a maximum permitted TS BEM baseline level of –54 dBm/MHz would imply a 2% probability of the victim TS being desensitized by more than 1 dB (referenced at cell-edge).

In practice, a receiver in a cellular network is subject to intra-system interference, and this raises the experienced intra-system interference-plus-noise power floor, $P_{\mathrm{N}} + G_{\mathrm{I,FDD}}$, above the thermal noise power floor, P_{N}. We refer to this as an intra-system *noise rise* of $G_{\mathrm{I,FDD}}$.

Figure 15 shows the CDFs of the TS out-of-block EIRP, $P_{\mathrm{OOB,TDD}}$, for combinations of a 0 dB intra-system noise rise, a 6 dB intra-system noise rise, a 1 dB desensitization ($G_{\mathrm{D,FDD}}$ = –6 dB), and a 3 dB desensitization ($G_{\mathrm{D,FDD}}$ = 0 dB). Again, the separation between the FDD and TDD base station is fixed at 100 metres in this example. Other parameter values are as described in Table 4 to Table 6.

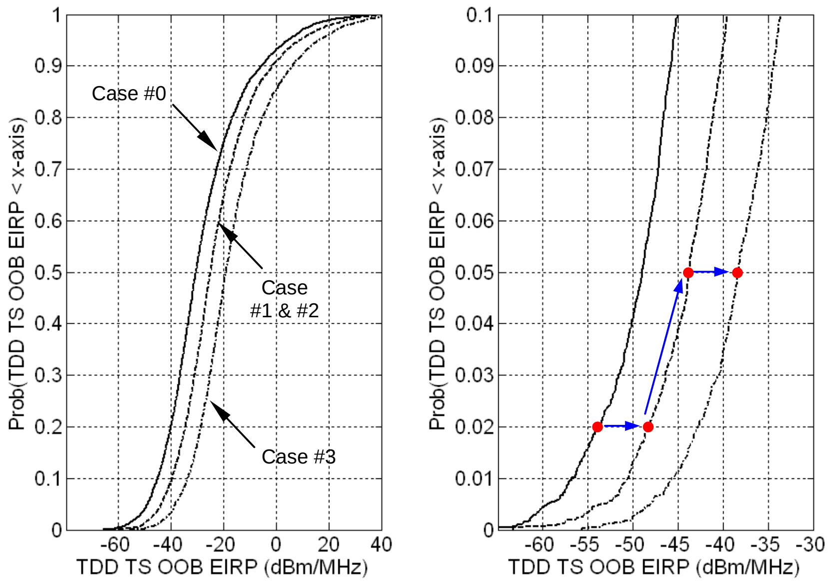

Figure 15: Impact of desensitization and intra-system noise-rise assumptions on the CDF of interferer TS out-of-block EIRP

The results of Figure 14 and Figure 15 can be interpreted in terms of the four cases described in Table 7 below.

Case	Protection criterion and assumptions	Relaxation of out-of-block limit (dB)	BEM Baseline level (dBm/MHz)
#0	2% probability of desensitization > 1 dB (referenced at cell edge)	-	-54
#1	2% probability of desensitization > 3 dB (referenced at cell edge)	+6	-48
#2	5% probability of desensitization > 3 dB (referenced at cell edge)	+4	-44
#3	5% probability of desensitization > 3 dB (referenced at cell edge), and intra-system noise rise of 6 dB	+6	-38

Table 7: TS BEM baseline levels for different protection criteria

The above results indicate that, where the probability of collision between victim and interferer packets is not taken into account, and depending on the accepted protection criterion, TS BEM baseline levels of between -54 and -38 dBm/MHz are required to ensure that the impact of TS-TS interference is appropriately mitigated in the 2.6 GHz band.

It should be noted that a 2% probability of 1 dB desensitization is a reasonable protection criterion for *typical* interference events, but is too stringent in the context of the more atypical TS-TS interference events investigated in this study. Specifically:

- The probability of being in a very densely populated hot-spot is itself significantly less than unity. As a result, a 2% outage probability in a hot-spot actually implies a significantly lower outage probability when averaged across non-hot-spot geometries. A 5% probability threshold is considered more appropriate in the context of this study.

- A 1 dB desensitisation level ($G_{D,FDD}$ = –6 dB) may be a reasonable performance degradation criterion in the case of events such as BS-BS interference, where the interference is potentially present (deterministically) at all times, and where the interference immediately impacts all users in the cell. This is not the case for TS-TS interference. A 3 dB desensitisation ($G_{D,FDD}$ = 0 dB) is considered to be a more appropriate degradation metric for the purposes of this study.

Based on the above arguments, it can be concluded that where the probability of collision between victim and interferer packets is not taken into account, a TS BEM baseline level of -38 dBm/MHz is required to ensure that the impact of TS-TS interference is appropriately mitigated for the geometries considered.

4.3.3 Impact of packet collisions on the statistics of TS out-of-block EIRP

Figure 16 shows the CDFs of the TS out-of-block EIRP, $P_{OOB,TDD}$, where the probability of packet collisions in not taken into account (i.e., G_{Coll} = 0 dB), and where the probability of packet collisions is incorporated through recalculation of G_{Coll} at every Monte Carlo trial, as described in Section (4.1).

As for Case #3 in Table 7, the CDFs here are derived for an intra-system noise rise of 6 dB, a 3 dB desensitization ($G_{D,FDD}$ = 0 dB) of the victim TS, and a fixed 100 m separation between the FDD and TDD base stations. All other parameter values are as described in Table 4 to Table 6.

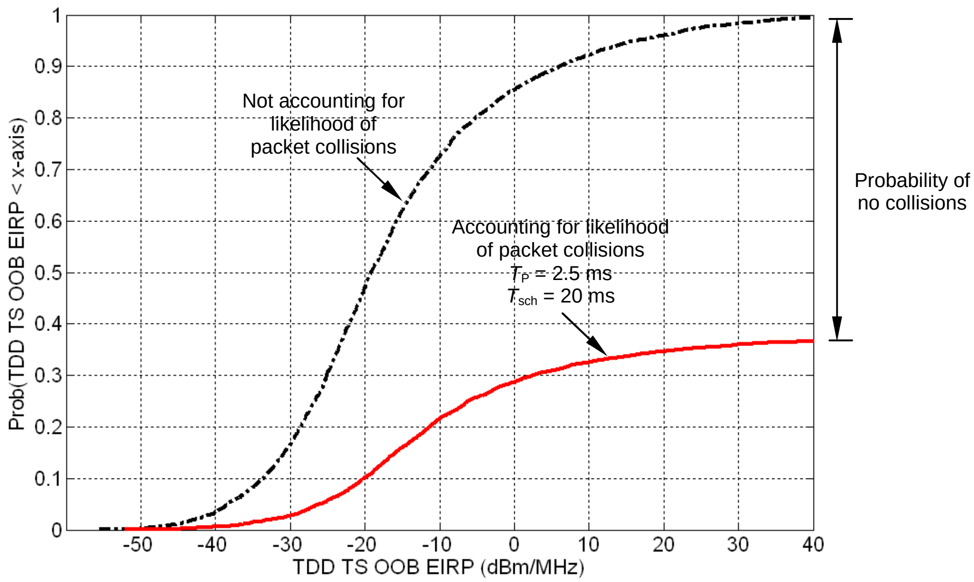

Figure 16: CDF of interferer TS out-of-block EIRP, for a 3 dB desensitization of the victim TS ($G_{D,FDD}$ = 0 dB), intra-system noise rise of $G_{I,FDD}$ = 6 dB, and accounting for the likelihood of packet collisions ($G_{Coll} \leq 0$ dB)

Note that the right-most CDF in Figure 16 does not approach a value of unity, since there are Monte Carlo trials where no packet collisions occur (i.e., G_{Coll} = –∞ dB). More specifically, the M = 2 TDD packets each of 2.5 ms duration will together partially occupy the available time in the 10 ms UL phase of the TDD network. For this reason, the probability that no collisions occur is mainly determined by the number of trials where the FDD packet falls within the 10 ms DL phase of the TDD network. Therefore, the probability that no collisions occur is lower bounded by a value of 10/20 = 0.5.

The results of Figure 16 indicate that, where the probability of collision between victim and interferer packets is taken into account, a TS BEM baseline level of -27 dBm/MHz can be justified to ensure that the impact of TS-TS interference is appropriate.

4.3.4 Sensitivity of results to separation between FDD and TDD base stations

The results presented so far have been based on the assumption of a 100 m separation between the FDD and TDD base stations. This is consistent with the base-to-base coordination distance of 100 m considered in CEPT Report 19.

In practice, the separation between the base stations is likely to be greater than 100 m (to mitigate the need for inter-network co-ordination), and is also a function of network deployment (i.e., cell planning) in the individual FDD and TDD networks.

Figure 17 illustrates the resulting CDFs of the TS out-of-block EIRP, $P_{\mathrm{OOB,TDD}}$, for fixed base-to-base separations of 100 m up to 1000 m in steps of 100 m (thin curves). Also shown, are the resulting CDFs where the location of the TDD base station within the FDD macro-cell is changed randomly at each Monte Carlo trial (thick curves), as described in Section (4.2). Such Monte Carlo modelling of the base-to-base separation captures (with equal probability) all possible base-to-base geometries.

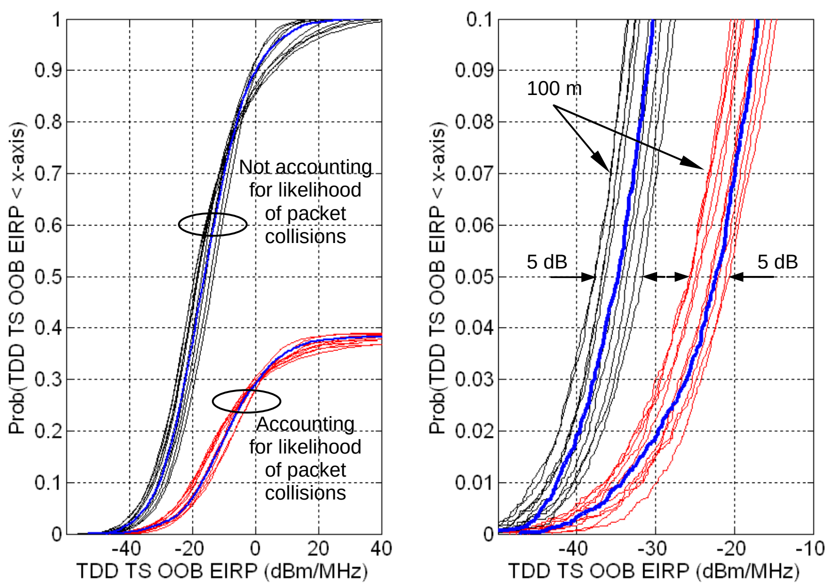

Figure 17: Impact of separation between FDD and TDD base stations on the CDF of interferer TS out-of-block EIRP. Results are for a 3 dB desensitization of the victim TS ($G_{D,FDD}$ = 0 dB), and intra-system noise rise of $G_{I,FDD}$ = 6 dB

The results indicate that the TS BEM baseline levels (derived for 5% outage probability) can increase by up to 5 dB for large base-to-base separations. The results also indicate that with Monte Carlo modelling of the base-to-base separation, the derived TS BEM base line levels are 2.5 dB greater than those derived with a fixed base-to-base separation of 100 m.

Although the separation between the FDD and TDD base stations might be unknown in any given situation, it remains fixed for a given network deployment. Consequently, the interference perceived by a victim will also be caused by a fixed (but unknown) deployment of base stations. For this reason, it was considered appropriate to derive the TS BEM baseline levels based on the worst case scenario involving a BS-BS separation of 100 m.

4.3.5 Sensitivity of results to user spatial density in the hot-spot

The results presented so far have been based on a hot-spot TS interferer spatial density that is derived with reference to an average density of 1 person per 3 square-metres, and with 1 person in 10 using their wireless communication device[20] (see Section (2.3)).This implies a substantial number of 65 TSs simultaneously operating within a radius of 25 m from a victim TS.

It is evident that, while such TS densities might be plausible in *very high-density* hot-spots, these occur rarely, and where they might occur regularly, it is likely that the terminals would be serviced by pico-cells rather than macro-cells.

For the above reasons, it is interesting to evaluate the TS BEM baseline levels required in what might be considered to be more typical geometries experienced across a macro-cell, as described in Table 8 and Figure 18.

	People density (m^{-2})	Hot-spot radius (m)	No. of people in hot-spot	Interferer TS Density† (m^{-2})	No. of TS interferers, *M*, in hot-spot+
Very high-density hot-spot	1/3	25	655	1/(10×2×2×10)/3	2
High-density hot-spot	1/5	25	392	1/(10×2×2×10)/5	1
Hot-spot	1/10	50	785	1/(10×2×2×10)/10	2

† See Section (2.3) for a description. Density is per 5 MHz block.
\+ Number of TS interferers per 5 MHz block.

Table 8: Hot-spot categories within a macro-cell

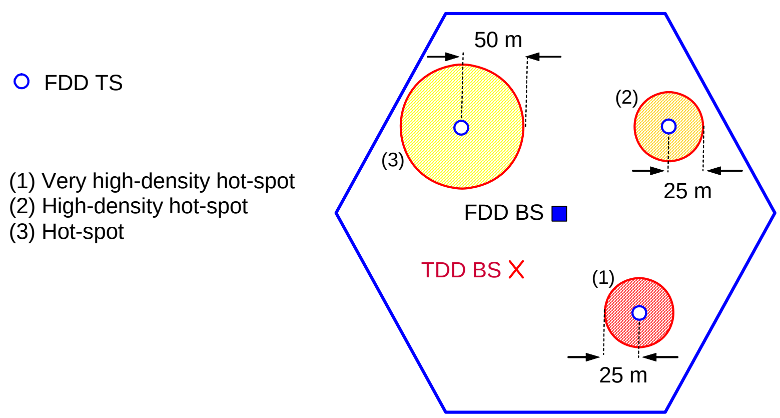

Figure 18: Three hot-spot categories within a 1 km macro-cell

Figure 19 shows the variation in the CDFs of the TS out-of-block EIRP, $P_{OOB,TDD}$, for each of the three hot-spot geometries described above. Also shown is the CDF of the TS out-of-block EIRP when aggregated (with equal weighting) over the three hot-spot geometries. This means that the CDF is calculated by pooling all the Monte Carlo trials observed in the macro cell for the different hot-spot geometries.

Results are presented for cases where probability of collisions between victim and interferer packets:

a) can not be taken into account, as investigated in Section (4.3.2);
b) can be taken into account, as investigated in Section (4.3.3).

Table 9 shows the corresponding maximum permitted TS BEM baseline levels for a 5% probability of the victim TS being desensitized by more than 3 dB.

[20] With half of the terminals using other bands, and another half using FDD, this would imply *M* = 2 TDD TSs in a 25 m hotspot per 5 MHz channel.

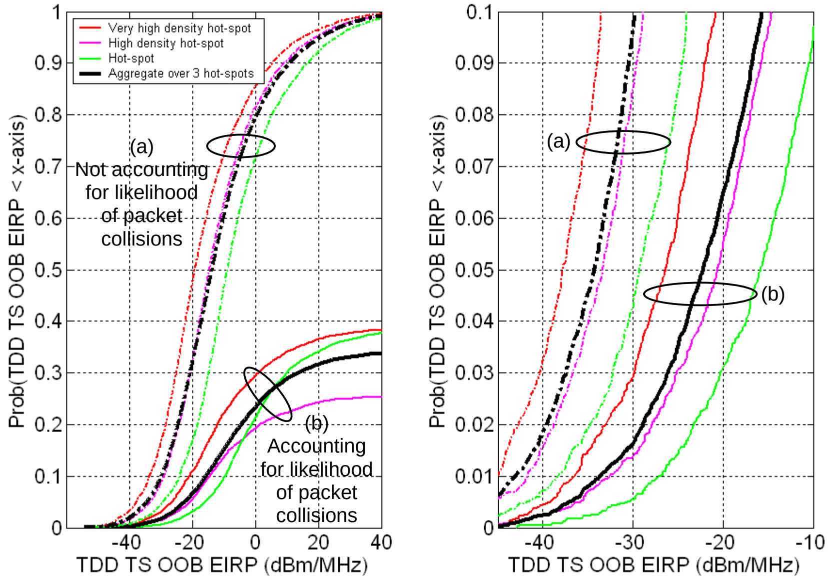

Figure 19: CDFs of interferer TS out-of-block EIRP for three different hot-spot geometries in a macro-cell. Results are for a 3 dB desensitization of the victim TS ($G_{D,FDD}$ = 0 dB), and intra-system noise rise of $G_{I,FDD}$ = 6 dB

Hot-spot geometry	BEM Baseline level (dBm/MHz)	
	Case (a)	**Case (b)**
Radius = 25m, 1 person / 3 m² (M = 2)	-38	-27
Radius = 25m, 1 person / 5 m² (M = 1)	-33.5	-20.7
Radius = 50m, 1 person/10 m² (M = 2)	-29.4	-15.9
Average over three hotspot geometries	**-34**	**-22.5**

Table 9: TS BEM baseline levels for different hotspot densities

It can therefore be concluded that, where the probability of collision between victim and interferer packets is taken into account, a TS BEM baseline level of -22.5 dBm/MHz can be justified. Otherwise, a TS BEM baseline level of -34 dBm/MHz can be justified.

4.3.6 Results for FDD TSs to TDD TS and for two unsynchronised TDD TSs

The TS BEM baseline levels derived above were calculated in the context of adjacent-channel interference from TDD TSs to FDD TSs. Figure 20 shows additionally the corresponding CDFs of the TS out-of-block EIRP for cases where interference is i) from FDD TSs to TDD TSs, and ii) from TDD TSs to TDD TSs (in unsynchronised TDD networks). Simulation parameters are unchanged.

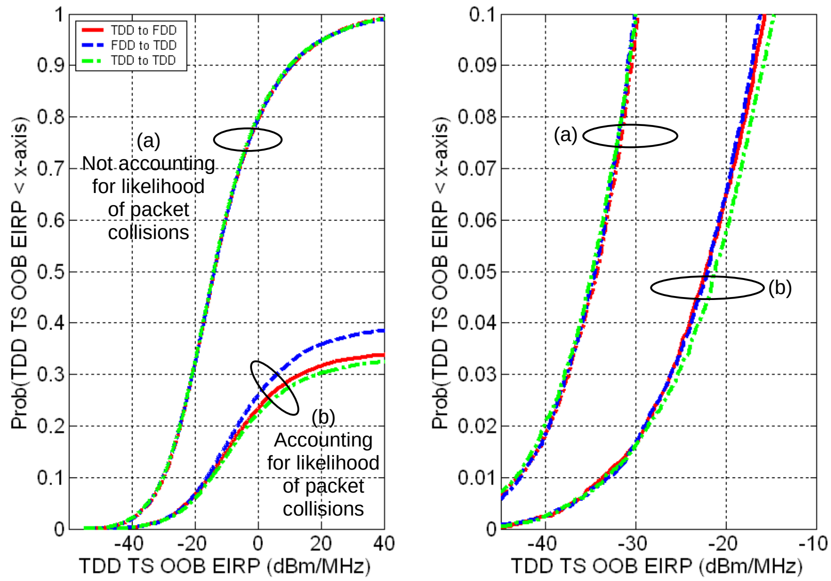

Figure 20: CDFs of interferer TS out-of-block EIRP averaged over three different hot-spot geometries. Results are for a 3 dB desensitization of the victim TS ($G_{D,FDD}$ = 0 dB), and intra-system noise rise of $G_{I,FDD}$ = 6 dB

Simulation results for case (a) are unchanged since the probability of collision is not taken into account. Simulation results for case (b) indicate that, while the precise shape of the TS out-of-block EIRP is different for the latter two interference scenarios (e.g., due to different probabilities of no collision), this has little impact on the lower tail of the CDFs. Hence, the BEM baseline levels derived in Section (4.3.5) for interference from TDD TSs to FDD TSs broadly apply to the case of interference from FDD TSs to TDD TSs and TDD TSs to TSS TSs.

4.4 Conclusions of Study-1

In this section a Monte Carlo approach for the computation of the TS BEM baseline level was presented. This approach accounts for the statistics of victim TS and interferer TS locations within their respective cells, as well as the statistics of collisions between interfering and wanted packets at the victim receiver.

The scenario examined consists of macro-cellular urban FDD and TDD network deployment, with the victim TS always located at the centre of a very densely populated hot-spot of TS interferers (people density of 1 per 3 square-metres).

The simulations indicate that, where the probability of collision between victim and interferer packets can not be taken into account, and depending on the protection criterion considered, TS BEM baseline levels of between -54 and -38 dBm/MHz are required for the mitigation of TS-TS interference. Specifically, for a 5% probability of 3 dB desensitization (referenced at the cell edge), a TS BEM baseline of -38 dBm/MHz can be justified.

Under similar conditions the simulations indicate that, where the probability of collision can be taken into account (e.g., for a typical TS transmission time interval of 2.5 ms over a 20 ms scheduling interval), a more relaxed TS BEM baseline of -27dBm/MHz can be justified.

It should be pointed out that the above baseline values are sensitive to the spatial density of interferer TSs within the examined hot-spot. The presented analysis indicates that, if one accounts for the range of different TS spatial densities which might be observed over a macro-cell (corresponding to people densities of 1/3, 1/5, and 1/10 m^{-2}), then baseline levels in the range of -38 to -29 dBm/MHz and -27 to -16 dBm/MHz (accounting for probability of collision) can be justified. An equal-weighted average over the three different hot spot TS densities suggests that aggregate baseline levels of -34 dBm/MHz and -22.5dBm/MHz (accounting for packet collisions) can be justified.

In all of the analysis presented in this section the interferer TS out-of-block EIRP is given in units of dBm/MHz. However, it has to be noted that the victim receiver is sensitive to the aggregate interference power over the whole of the receiver noise-equivalent bandwidth[21]. For this reason, the TS BEM baseline level will be specified in units of dBm/(5 MHz). This has the advantage of allowing a certain degree of flexibility in the detailed shape of the emission mask over a 5 MHz block) while still complying the baseline level (See also Section 6).

Based on the results summarised above, it can be concluded that:

a) where probability of collisions between victim and interfere packets can not be taken into account, a BEM baseline level of -27 dBm/(5MHz) can be justified,

b) and furthermore, where probability of collisions between victim and interfere packets can be taken into account (as among packet-based mobile broadband systems), a BEM baseline level of -15.5dBm/(5MHz) can be justified[22]..

Although the above levels were derived in the context of interference from TDD TSs to FDD TSs, these results equally apply to cases of interference from FDD TSs to TDD TSs, and from TDD TSs to TDD TSs (in unsynchronised networks).

5 STUDY-2: IMPACT OF TS-TS INTERFERENCE ON THROUGHPUT

Study-1 presented in Section (4) involved a Monte Carlo approach for the computation of the TS BEM baseline level. This section reports on a second Monte Carlo study to investigate the impact of adjacent-channel interference from TDD TSs to FDD TSs in the 2.6 GHz band, conditioned on the BEM baseline levels derived in Study-1.

The analysis examines scenarios where a TDD cellular network and a FDD cellular network both serve the same geographical area, and where the TDD network operates within frequency blocks that are adjacent to those used by the FDD network in the downlink direction, thereby giving rise to the possibility of TS-TS interference. The TS densities considered are commensurate with those observed in *high-density* hot-spots (see Sections 2.3 and 4.3.5).

The impact of TS-TS interference on the downlink data throughput of a FDD TS is evaluated by taking account of interferer radiation masks, non-ideal receiver filter characteristics, non-linear effects at the receiver, and receiver saturation (or blocking). These features have been quantified based on the measured performance [6] of a number of commercially available UTRA-FDD handsets in the 2.1 GHz band. Moreover, we have used realistic models to characterise the behaviour of the TSs, including the operation of functions such as adaptive modulation and coding, power control, and scheduling (i.e., bursty transmissions).

In Sections (5.1) and (5.2) we provide an overview of the investigated band-plan and the modelling of TS transceiver characteristics that are used in the analysis of TS-TS interference. Sections (5.3) and (5.4) contain a summary of the interference modelling methodology and the simulation process. Section (5.5) reports on the results of the evaluation of TS-TS interference, followed by conclusions in Section (5.6).

ANNEX 3: includes a detailed account of the methodology and calculations used in the modelling of TS-TS interference in this study.

5.1 Assumed band-plan

Figure 20 shows an illustrative 2.6 GHz band-plan examined in this study. As can be seen, blocks #35 to #38 in this band-plan are used as unpaired lots, corresponding to a total of 18 unpaired (TDD) blocks in the 2.6 GHz band. The figure also illustrates the frequency boundaries where TS-TS interference would occur. In this study we focus on block #34 since this is the FDD block that will be most susceptible to TS-TS interference in this example.

[21] An obvious example is UMTS, where the reference sensitivity level is given over 3.84 MHz.

[22] This BEM baseline level is calculated based on the probability of collision between wanted packets and interferer packets at the victim receiver assuming a TDD uplink to downlink ratio of 1. Data destined for a receiver is assumed to be transmitted within a single packet of 2.5 ms duration over an interval of 20 ms (i.e., an activity factor of 12.5%).

The terms “adjacent channel” and “adjacent block” are used interchangeably in this study to generally refer to frequency blocks in the vicinity of a block of interest. Where we refer to the block immediately adjacent to a block of interest (i.e., where there is no frequency gap between the two blocks), we use the terms “1st adjacent channel” or “1st adjacent block”.

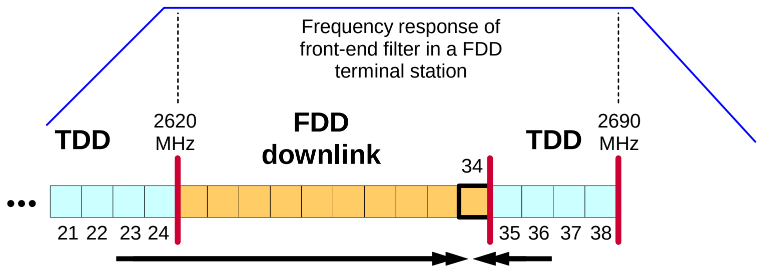

Figure 21: Sources of TS-TS interference into block #34 for the considered band-plan. Arrows indicate direction of potential TS-S interference

Note that the nature of TS-TS interference is potentially different across the different boundaries illustrated in Figure 20. For example, there is a greater probability of TDD TSs which operate in the top end of the band (blocks #35 to #38 in the figure) to cause saturation (or blocking) of FDD TSs in the FDD downlink range. This is because standard FDD terminals made for the European marketplace are likely to have a front-end pass-band filter which allows through signals transmitted at all frequencies in the blocks #25 to #38. Hence, interference into FDD terminals from TDD terminals across this top boundary is likely to be greater than interference from TDD terminals operating from below block #24 where the pass-band filter should provide some attenuation. Meanwhile, the interference into TDD terminals will depend on their filter characteristics and on whether adjacent TDD systems are synchronised or not; but, in principle, TDD terminals could receive interference from terminals of other FDD or non-synchronised TDD systems operating anywhere between block #1 and block #24.

5.2 Modelling of TS radio characteristics relating to adjacent channel interference

In this study we consider the impact of TS-TS interference due to transceiver linear frequency discrimination (ACIR) and non-linear (inter-modulation) receiver behaviour, as well as due to saturation, caused by interferers from a number of adjacent channels.

We consider below the way in which each of the above interference modes can be most appropriately characterised. In the process, we report on the measured performance of commercially available UTRA-FDD user equipment [6]. Parameters derived from these measurements (as opposed to the minimum requirements specified by 3GPP) are used in our analysis of TS-TS interference.

i) Adjacent-channel interference ratio

Table 10 indicates the ACIRs for a TS-TS link with the interferer transmitting in the 1st to 4th adjacent 5 MHz blocks with respect to the wanted signal. These are computed based on the ACLR required for

a) compliance in the 1st and 2nd adjacent blocks with the TS emission BEM baseline level of -15.5 dBm/(5 MHz) derived in Section (4);

b) compliance[23] in the 3rd and 4th adjacent blocks with the spurious emission limit of –30 dBm/MHz (i.e., for frequency offsets greater than 12.5 MHz, or 2.5 times the channel bandwidth, from the carrier frequency),

and the measured [6] filtering characteristics (i.e., ACS) of commercially available UTRA-FDD user equipment in the 2.1 GHz band.

	nth adjacent block			
	n = 1	n = 2	n = 3	n = 4
ACLR (dB)	46.5	46.5	57	57
ACS (dB)	53	65	65	65
ACIR (dB)	45.5	45.5	56	56

Table 10: TS-TS ACIR = $(ACLR^{-1} + ACS^{-1})^{-1}$, where the out-of-band emissions of the interfering TS comply with the TS BEM baseline level when radiating at maximum in-block EIRP

The above ACIR values are applicable in circumstances where the interfering TS just complies with the TS BEM baseline level when radiating at full power (i.e., an EIRP of 31 dBm/(5 MHz). These ACIR values are dominated by the emission spectral leakage (ACLR) of the interferer, and are used in the analysis of TS-TS interference in Section (5.5).

ii) Third-order inter-modulation products

3GPP TS 25.101 specifies that the inter-modulation characteristics of a FDD TS receiver should be such that the reception of two interferers, each at a level of –46 dBm and at frequency offsets of 10 and 20 MHz from the wanted carrier, should at most result in a 3 dB desensitisation. Measurements [6] suggest that commercially available UTRA-FDD user equipment in the 2.1 GHz band suffer from 3 dB desensitisation with interferers at power levels of around –30 dBm. This latter result, which implies that actual terminals perform 16 dB better than the 3GPP minimum requirements, is used for the modelling of IM products in our analysis.

iii) Receiver saturation (blocking)

3GPP TS 25.101 specifies that a UTRA-FDD TS receiver should be able to apply a linear ACS of 33 dB to a 1st adjacent-channel interferer received at a power level of up to –25 dBm. Measurements [6] suggest that commercially available UTRA-FDD user equipment in the 2.1 GHz band perform much better than this and can apply an ACS of 33 dB when subjected to a 1st adjacent-channel interferer power of up to –10 dBm or greater[24], i.e., 15 dB better than the 3GPP minimum requirements. Measurements indicate that even greater interferer power levels can be supported at the 2nd and 3rd adjacent channels. A threshold of –10 dBm is used in our modelling of saturation effects; i.e., if the aggregate received power of the adjacent-channel interferers exceeds this threshold then the TS is assumed to suffer from saturation and the downlink throughput is assumed to drop to zero.

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[23] As this study is intended to apply to a population of terminal stations, it is not reasonable to expect that the "typical terminal" would have a radiation PSD which would “just” comply with specified upper limits. If this were the case, then around 50% of the terminal station radiation PSDs would not comply with those limits. There are two factors that lead to the typical terminal station PSD being lower than specified upper limits: a) the manufacturing spread, whereby the median performance has to be better than specifications in order that the worst performance is still compliant with the specifications, and b) systematic variations such as power supply and temperature, which are unlikely to be at their worst values in all the scenarios under evaluation. It is therefore reasonable to assume that an "average" terminal station radiation PSD, drawn from a population that is designed to comply with specified upper limits, would be at least 3dB better than those limits.

[24] Furthermore, measurements indicate that an ACS of around 53 dB applies when the power of the adjacent-channel interferer is –20 dBm.

5.3 Modelling of TS-TS interference

A detailed description of the modelling of the TDD uplink and FDD downlink is presented in ANNEX 3:. A brief overview of the modelling is presented here.

The interferer TDD system is modelled based on physical layer parameters that are broadly similar to those of WiMAX[25]. Each TDD TS is scheduled for uplink transmission by its serving base station and is allocated the appropriate frequency and time resource in accordance with the throughput required by the service and the throughput achievable on the radio link. The latter is a function of uplink EIRP, propagation path loss and shadowing, and interference. The model includes uplink intra-system interference from a ring of adjacent TDD cells.

The victim FDD system is modelled based on physical layer parameters that are broadly similar to those of UTRA-FDD HSDPA[26]. Here the metric of interest is the statistics of downlink throughput over the cell area as a result of a FDD TS receiving one packet per scheduling interval from its serving base station. The FDD downlink throughput is a function of downlink EIRP, propagation path loss and shadowing, and interference. The model includes downlink intra-system interference from a ring of adjacent FDD cells.

The impact of TS-TS interference on the FDD downlink is strongly dictated by the bursty natures of both TDD TS transmissions and FDD TS receptions. These effects are captured in this study by a) modelling the uplink scheduling of TDD packets, with those requiring least resources scheduled first, and b) assuming a FDD downlink packet arrival time that is uniformly distributed over the scheduling interval.

As noted in Study-1, collisions between uplink TDD packets and a FDD downlink packet received at a FDD TS need not necessarily have a severe impact on the FDD downlink throughput. The effects of such collisions depend on the number of TDD transmitters, the amount of time-frequency resource utilised by each TDD packet transmission and their degrees of overlap (in time) with the FDD packet, the EIRP of the TDD TSs, and their spatial separations from the FDD TS.

The above effects are captured via Monte Carlo simulations modelling the urban macro-cellular scenario of Figure 9, as described next.

5.4 Description of the simulation process

The following steps are performed at each Monte Carlo trial:

1) Drop the victim FDD TS (in block #34) at a random (uniformly distributed) location within the central FDD macro-cell. Surround the central FDD macro-cell with a ring of six adjacent-cells.
2) Drop *M* TDD TS interferers (in blocks #35 to #38 and #21 to #24), at random (uniformly distributed) locations within a TDD hot-spot surrounding the FDD TS.

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[25] The TDD system is modelled with a nominal channel bandwidth of 4.1 MHz, uplink/downlink ratio of 1:3, frame duration of 5 ms, uplink sub-frame duration of 1.25 ms, scheduling interval of 20 ms, and adaptive modulation and coding (up to 64-QAM, ¾ rate coding) with power control. A throughput of 75% of the Shannon Limit is assumed over the radio link. It is assumed that VOIP and video conferencing services require throughputs of 30 kbits/s and 360 kbits/s respectively.

[26] The FDD system is modelled with a nominal channel bandwidth of 3.84 MHz, downlink packet duration of 2 ms, scheduling interval of 20 ms, and adaptive modulation and coding (up to 16-QAM, ¾ rate coding). A throughput of 75% of the Shannon Limit is assumed over the radio link.

3) Drop the TDD hot-spot at an appropriate location within the central TDD macro-cell[27]. Surround the central TDD macro-cell with a ring of six adjacent-cells.
4) Calculate the intra-system interference in the TDD uplink by accounting for TDD TS transmissions in the ring of six adjacent cells for each frequency block.
5) Calculate the fraction of the uplink resource required by each TDD TS in the hot-spot, and schedule their packet transmissions over a scheduling interval (of 20 ms) for each frequency block.
6) Calculate the intra-system (co-channel) interference in the FDD downlink by accounting for FDD BS transmissions in the ring of six adjacent cells in block #34.
7) Calculate the DL throughput (for a 2.5 ms packet received over a 20 ms scheduling interval) available to the victim FDD TS in the absence of any transmissions by TDD TSs.
8) Calculate the extent of collisions in time between the packets transmitted by the TDD TSs and a 2.5 ms packet received by the victim FDD TS over a 20 ms scheduling interval.
9) Calculate the DL throughput (for a 2.5 ms packet received over a 20 ms scheduling interval) available to the victim FDD TS in the presence of transmissions by TDD TSs, accounting for saturation, and any degradation in SINR due to limited ACIR and inter-modulation products.

Following a sufficiently large number of Monte Carlo trials, the statistical distributions of the various signals and the downlink throughput available to the victim FDD TS receiver can be derived. The calculations for each step are detailed in ANNEX 3:.

5.5 Simulation results

5.5.1 Parameter values

The parameter values used in this study are identical to those listed in Table 4, Table 5, and Table 6 used in the Monte Carlo analysis of Study-1. The values of any additional parameters are listed in Table 11, Table 12, and Table 13 below.

FDD

BS maximum in-block EIRP, P_{max}	57 dBm (Tx power: 40 dBm) 44 dBm (Tx power: 27 dBm)
BS antenna gain	17 dBi
TS antenna gain	0 dBi
Noise-equivalent channel bandwidth, B	3.84 MHz
Maximum DL SINR via power control and AMC, γ_{TH}	15 dB
TS front-end filter gain, $G_{X,k}$	0, -4, -8, -12 dB @ blocks #24, #23, #22, #21 0 dB @ blocks #35, #36, #37, #38
TS third-order inter-modulation reference interferer power, Π_{AC}	-30 dBm
TS saturation threshold, Π_{Sat}	-10 dBm

Table 11: List of FDD parameter values.

[27] When considering a fixed base station separation across the Monte Carlo trials, a correction is made to ensure that the largest separation between a TDD TS and the TDD BS is not greater than the TDD cell radius. When considering stochastic realisations of base station locations across the Monte Carlo trials, the TDD hot-spot is dropped at a random (uniformly distributed) location fully within the TDD macro-cell, again to ensure that the largest separation between a TDD TS and the TDD BS is not greater than the TDD cell radius.

TDD

TS maximum in-block EIRP, P_{max}	31 dBm
BS antenna gain	17 dBi
TS antenna gain	0 dBi
Noise-equivalent channel bandwidth, B	4.1 MHz
BS noise figure, NF_{BS}	5 dB
TS spatial density	1/(10×2×2×18)/3 metre^{-2} (per 5 MHz)
Number of interferers in hot-spot, M	1 (per 5 MHz)
Maximum SINR achieved by power control and AMC, γ_{TH}	22.5 dB
Frame duration, T_F	5 ms (N_F = 4 frames per scheduling interval)

Table 12: List of TDD parameter values

General

Separation between FDD and TDD base stations	stochastic
TS-TS link adjacent-channel interference ratio (ACIR)	(45.5, 45.5, 56, 56) dB (TDD macro-cell) @ the (1st, 2nd, 3rd, 4th) adjacent channels
Service Rate, R_S	30 kbits/s over scheduling interval (VOIP) 360 kbits/s over scheduling interval (video)

Table 13: List of generic parameter values

The investigated TDD hot-spot has a radius of 25 m, with a spatial density of 1/3 persons per square-metre. Given the total of 18 unpaired (TDD) blocks in the considered band-plan (see Figure 7) and the description in Section (2.3), this implies a TDD TS density of (1/3)/(10×2×2×18) per square-metre, or M = 1 actively interfering TDD TSs per 5 MHz TDD block in the 2.6 GHz band. In terms of interference, this is equivalent to the *high-density* hot-spot of Study-1 (see Table 8).

As described earlier, there is a greater risk of IM products and saturation from adjacent-channel interferers received in blocks #25 to #38, than there is from those received in blocks #24 and below. This is because interferers received in blocks #25 to #38 fall within the pass-band of a FDD TS's front-end (duplex) filter, and would therefore not be attenuated prior to amplification and further processing. As shown in Figure 21, the pass-band of the front-end filter would nominally cover the frequency range 2620 MHz to 2690 MHz in order to allow the TS to receive signals from base stations transmitting in any of the paired (FDD) downlink blocks[28]. Interferers received in blocks #24 and below, however, would fall outside the filter's pass-band and would therefore be attenuated according to their frequency offsets from the pass-band edge. In the modelling of inter-modulation and blocking, we account for the roll-off of the front-end filter via attenuations of 0, 4, 8, and 12 dB at blocks #24, #23, #22, and #21 respectively.

5.5.2 Statistics of FDD DL throughput with TDD VOIP services

Here we consider the situation where the high-density TDD hot-spot is served by macro-cells operating in blocks #35 to #38, and #21 to #24. The relevant geometry and frequency plan are as depicted in Figure 9 and Figure 21 respectively. We assume that the TDD TSs access a real-time VOIP service which requires a throughput of 30 kbits/s within a 20 ms scheduling interval.

[28] While the use of tuneable front-end filters could in principle mitigate against adjacent-channel interferers in blocks #25 to #38, we do not envisage that such technologies can be cost-effectively incorporated within terminal stations in the near future.

Note that two cases are presented for each set of results:

Case (A) – Here the intra-system (co-channel) interference on the FDD downlink and TDD uplink is computed explicitly by modelling transmissions from BSs in adjacent cells. For this purpose, the BSs and TSs in adjacent cells are assumed to transmit at in-block EIRP levels of 57 dBm[29] and 31 dBm[30] respectively. This computation is detailed in ANNEX 3:. For the centre cell, the *maximum* BS and TS in-block EIRPs are also assumed to be 57 dBm and 31 dBm respectively.

Case (B) – The intra-system (co-channel) interference is modelled as a rise in the receiver's noise floor of 6 dB (as assumed in the derivation of BEM baseline levels in Study-1). For a FDD cell-radius of 1 km, such a noise rise implies a BS in-block EIRP of 44 dBm[31]. For the centre cell, the *maximum* BS and TS in-block EIRPs are therefore assumed to be 44 dBm and 31 dBm respectively.

Figure 22 shows the resulting cumulative probability distributions of the signal powers present at the output of the front-end (duplex) filter of a FDD TS over the time interval in which a FDD downlink packet is received in block #34.

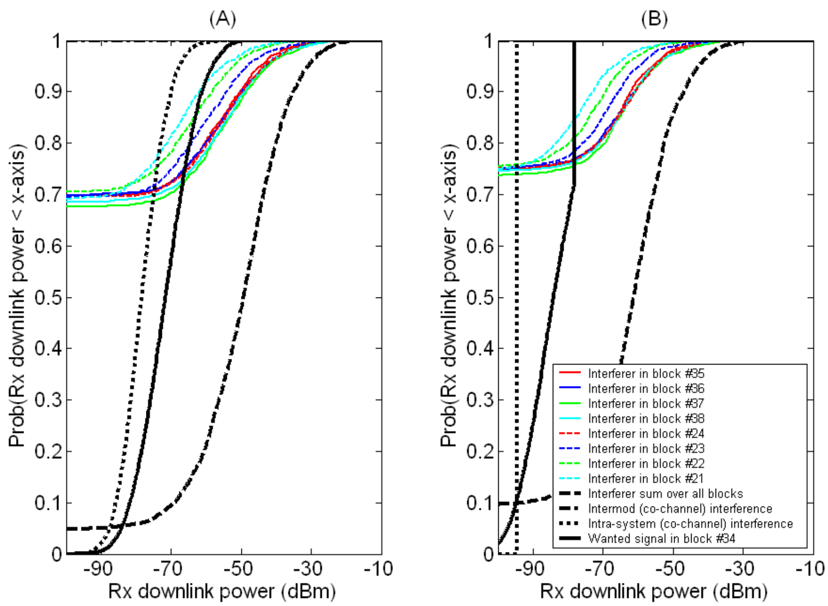

Figure 22: Cumulative probability distributions of signal powers received at a FDD TS operating in block #34, in the presence of adjacent-channel TDD macro-cells supporting TSs accessing VOIP services. (A): BS EIRP of 57 dBm. (B): BS EIRP of 44 dBm

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[29] This corresponds to a 10 W transmitter with a 17 dBi antenna gain, typically deployed in urban areas. Note that CEPT Report 19 and EC Decision (2008/477/EC) specify a maximum permitted mean in-block EIRP of 61dBm/(5 MHz) for BSs in the 2.6 GHz band.

[30] This EIRP level is characteristic of portable (but not handheld) terminal stations, and is consistent with the maximum permitted (omni-directional) mean in-block EIRP of 31dBm/(5 MHz) specified in CEPT Report 19 and EC Decision (2008/477/EC) for the 2.6 GHz band.

[31] This corresponds to the emission power of each of the 6 BSs surrounding the cell under investigation which would result in a noise rise of up to 6 dB within the cell..

As stated earlier, the adjacent-channel transmissions by TDD TSs in blocks #35 to #38 fall within the pass-band of the FDD TS's front-end filter, and so are un-attenuated (thin solid lines). In comparison, the adjacent-channel transmissions by TDD TSs in blocks #21 to #24 fall outside the pass-band of the FDD TS's front-end filter, and so are attenuated in accordance with their respective frequency offsets from the pass-band edge (thin dashed lines). The thick dashed line corresponds to the aggregate (sum) of the received adjacent-channel interferer powers from TDD TS transmissions in blocks #21 to #24, and #34 to #38[32].

As can be seen, the aggregate interferer power does not exceed the –10 dBm saturation threshold of commercially available 3G user equipment. This implies that the probability of blocking is very low, even in high-density hot-spot situations. Also note that the levels of inter-modulation interference are considerably less than those of intra-system co-channel interference.

The impact of the adjacent-channel interferers on the FDD downlink throughput and SINR is shown in Figure 23 and Figure 24, again expressed in the form of cumulative probability distributions.

The throughput distributions are shown both in the absence and presence of interference from TDD TS transmissions in adjacent blocks #35 to #38, and in blocks #21 to #24. Note that the throughputs correspond to a single 2.5 ms packet received over a 20 ms scheduling interval.

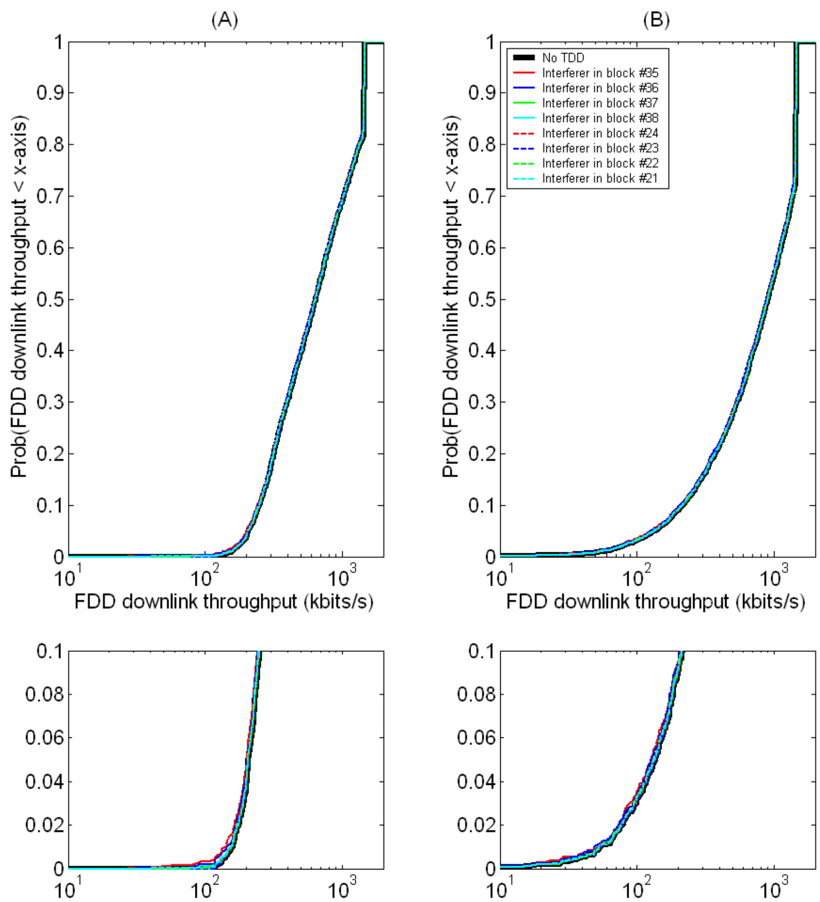

Figure 23: Cumulative probability distributions of FDD downlink throughput in block #34, in the presence of adjacent-channel TDD macro-cells supporting TSs accessing VOIP services. (A): BS EIRP of 57 dBm. (B): BS EIRP of 44 dBm

[32] Note that it is the aggregate (sum) of the received adjacent-channel interferer powers from TDD terminal station transmissions which is relevant when considering the potential for saturation to occur. As can be seen, this total unwanted received power (thick dashed line in Figure 22) is significantly greater than the wanted received power in block #34 (thick solid line in Figure 22). However, the FDD terminal receiver will be tuned to block #34 and, provided it has not been saturated, will discriminate between the wanted and unwanted signals by suppressing the adjacent channel interferers through various stages of (intermediate-frequency and baseband) channel filtering.

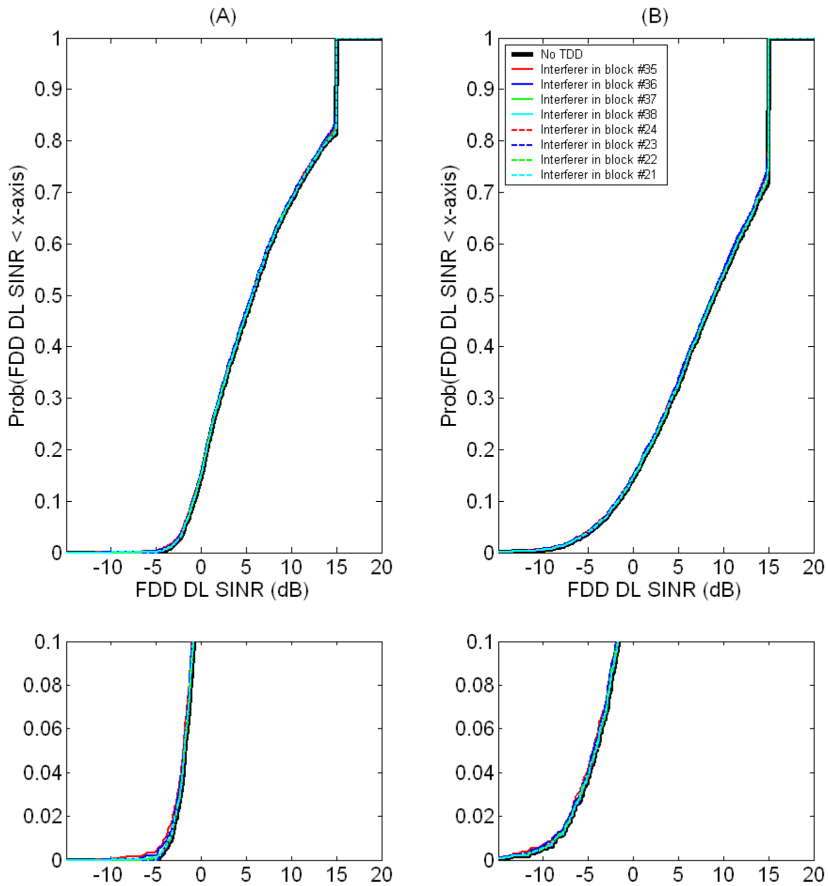

Figure 24: Cumulative probability distributions of FDD downlink SINR in block #34, in the presence of adjacent-channel TDD macro-cells supporting TSs accessing VOIP services. (A): BS EIRP of 57 dBm. (B): BS EIRP of 44 dBm.

The above results indicate that the impact of interference from TDD TSs operating in blocks #35 to #38 and #21 to #24 is negligible since the statistics of FDD downlink throughput and SINR are broadly unchanged in the presence of TDD interferers.

5.5.3 Statistics of FDD DL throughput with TDD video services

Here we repeat the simulations of Section (5.5.2), with the difference that the TDD TSs are assumed to access a real-time video service which requires a throughput of 360 kbits/s within a 20 ms scheduling interval. Figure 25 to Figure 27 show the resulting statistics.

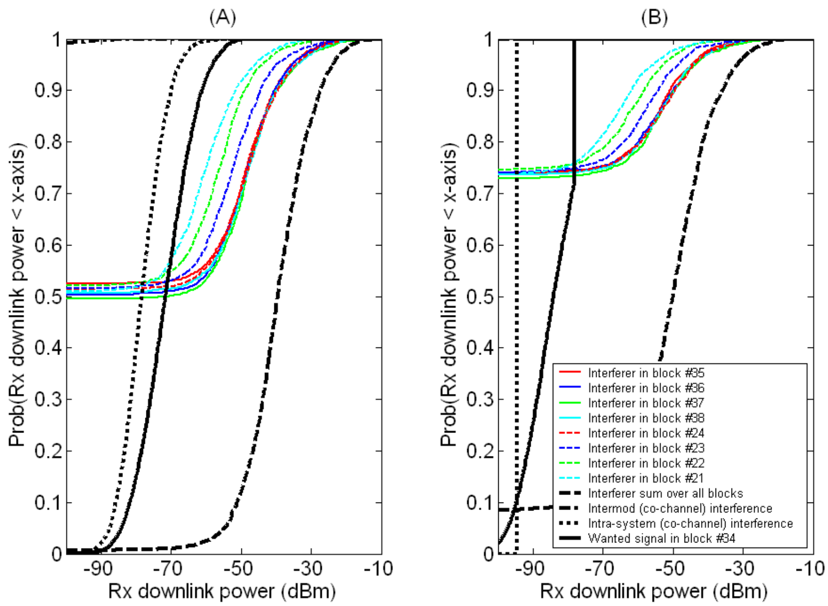

Figure 25: Cumulative probability distributions of FDD downlink throughput in block #34, in the presence of adjacent-channel TDD macro-cells supporting TSs accessing video services. (A): BS EIRP of 57 dBm. (B): BS EIRP of 44 dBm

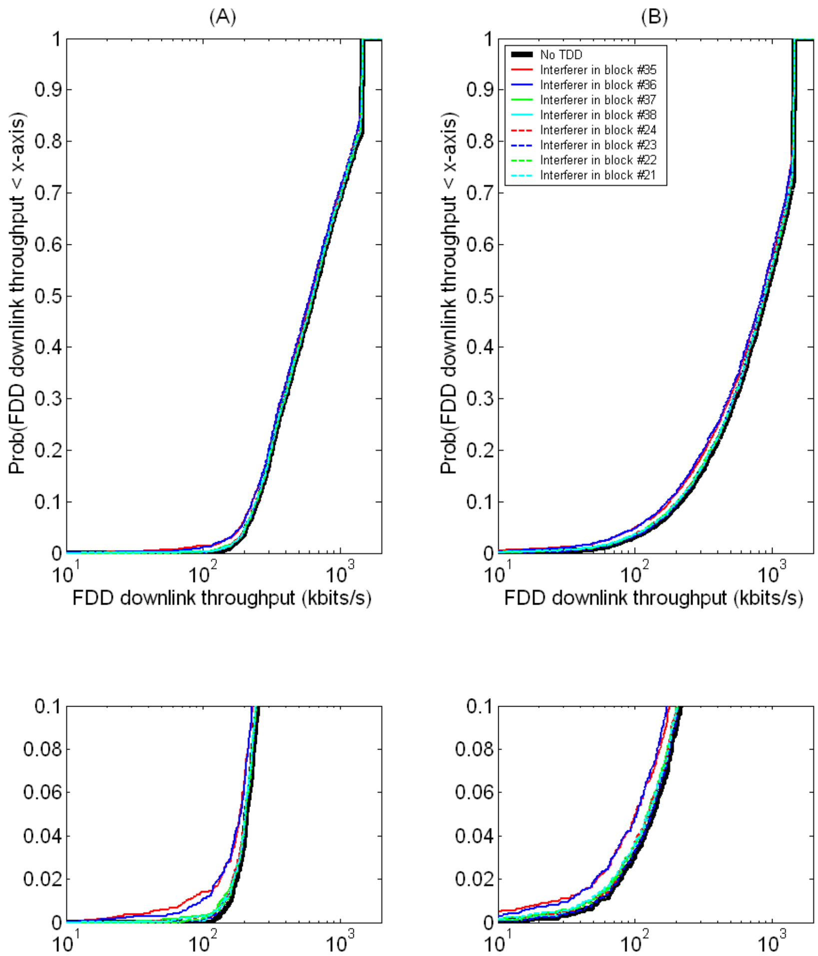

Figure 26: Cumulative probability distributions of FDD downlink throughput in block #34, in the presence of adjacent-channel TDD macro-cells supporting TSs accessing video services. (A): BS EIRP of 57 dBm. (B): BS EIRP of 44 dBm.

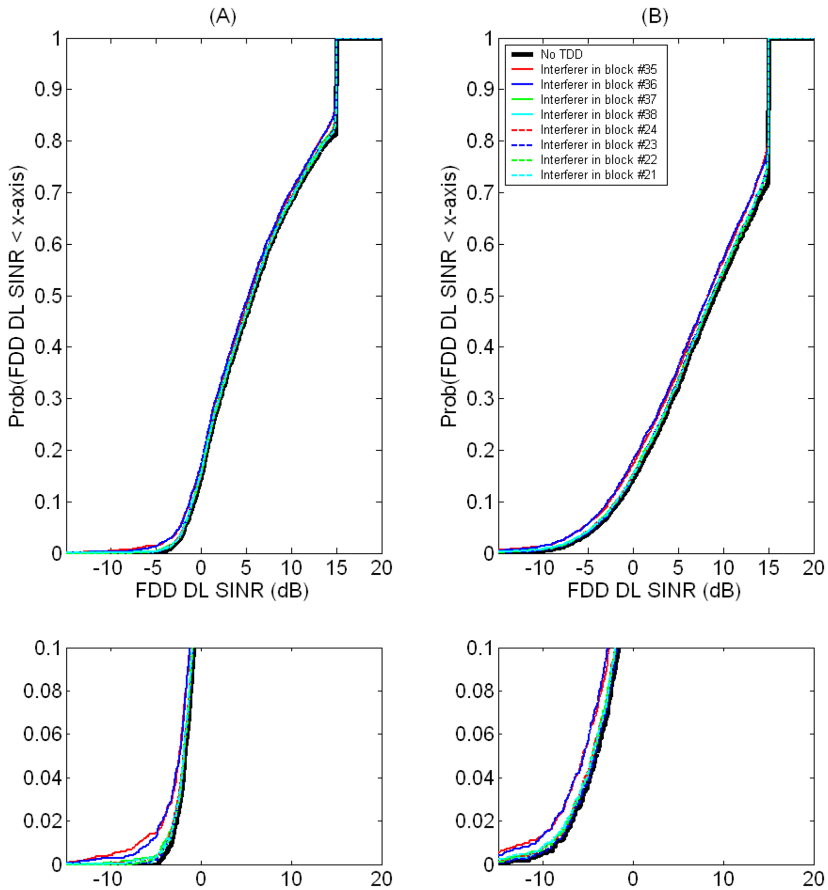

Figure 27: Cumulative probability distributions of FDD downlink SINR in block #34, in the presence of adjacent-channel TDD macro-cells supporting TSs accessing video services. (A): BS EIRP of 57 dBm. (B): BS EIRP of 44 dBm.

5.5.4 Discussion

Based on the above results, we can draw the following conclusions.

i) Out-of-band emissions by TDD TSs operating in the 1st adjacent block (and beyond) with respect to a FDD TS cause little degradation in the FDD downlink throughput when the former comply with the BEM baseline level of −15.5 dBm/(5 MHz). The ACIR of 46.5 dB at the 1st adjacent block is sufficient to mitigate the impact of TS-TS interference.

ii) In principle, saturation of the FDD TS receiver can result in a severe (i.e., non-graceful) degradation in FDD downlink throughput. However, even in the challenging geometries investigated, the total received adjacent-channel interferer power is well below the −10 dBm threshold (see Figure 22) supported by 2.1 GHz UTRA-FDD user equipment commercially available today. This means that FDD TSs in the 2.6 GHz band, with receiver characteristics identical to (or better than) those that are available today in other bands, would be able to operate in the presence of TDD TSs without suffering from saturation. Consequently, one may conclude that saturation (or blocking) is not a material cause of throughput degradation in the context of TS-TS interference[33].

[33] Note that even in the unlikely event that TS-TS saturation effects were to cause material degradations in downlink throughput, such degradations would be observed equally in all FDD downlink blocks. This is because terminal station receiver components that are most likely to be saturated as a result of adjacent-channel interferers are typically protected only by a front-end RF filter whose pass-band covers the whole of the FDD downlink spectrum. An important implication of this is that, so far as saturation is concerned, all FDD downlink blocks in the 2.6 GHz band would have a similar usability.

iii) Third-order inter-modulation products were found to cause little degradation in downlink throughput in the scenarios investigated. This is because the received powers of any two adjacent-channel interferers rarely jointly exceed the threshold of –30 dBm (see Figure 22) supported by 2.1 GHz UTRA-FDD user equipment commercially available today.

Once again, we point out that the results apply to a scenario where a high density of interfering TDD TSs is always present within a 25 metre radius of the FDD TS. This is clearly not always (or often) the case in practice, as discussed in Section (4.3.5). Moreover, in those situations where such high densities of users are anticipated (e.g., conference centres, train stations, etc.) it is likely that operators of TDD networks would in any case want to deploy pico-cells, rather then macro-cells, in order to adequately satisfy the demands for throughput.

5.6 Conclusions of Study-2

The results of this analysis confirm that the effects of TS-TS interference are very modest if the out-of-band emissions of TSs comply with a BEM baseline level of -15.5 dBm/(5 MHz). We have probed in detail into high-density hot-spot scenarios, and we have confirmed that the impact of interference is likely to be very limited even in these situations. In carrying out this analysis we have taken into account of interference experienced as a result of limited ACIR, inter-modulation products, and saturation effects. The results suggest that the chances of saturation (or blocking) are, in fact, smaller than that due to limited ACIR.

Whilst this analysis has focused on hot-spot scenarios, we can infer that the effects of interference in average density scenarios are likely to be even more modest.

6 CONCLUSIONS ON TERMINAL STATION BEM CHARACTERISTICS

As described in Section (1), a terminal station (TS) block-edge mask (BEM) consists of in-block and out-of-block components as a function of frequency. The out-of-block component of the TS BEM itself consists of a baseline level and, where applicable, intermediate levels which describe the transition from the in-block level to the baseline level as a function of frequency.

Furthermore, it was shown in Section (4) that, in order to appropriately manage the risk of TS-TS adjacent-channel interference:

a) where probability of collisions between victim and interfere packets can not be taken into account, a TS BEM baseline level of P_{BL} = -27 dBm/(5 MHz) can be justified,

b) and furthermore, where probability of collisions between victim and interfere packets can be taken into account (as among packet-based mobile broadband systems), a TS BEM baseline level of P_{BL} = -15.5 dBm/(5 MHz) can be justified[34].

In this section, all components of the TS BEMs are presented for the channel plan of the 2.6 GHz band.

In Section (6.1) the proposed TS BEM in-block levels are presented. This is followed by a description in Section (6.1) of the proposed shapes of the TS BEMs at the various frequency boundaries between FDD and TDD (or TDD and TDD) networks. Finally, the proposed TS BEM out-of-block levels are presented in tabular form in Section (6.3), with examples of the TS BEMs illustrated in Section (6.4).

[34] This BEM baseline level was calculated based on the probability of collision between wanted packets and interferer packets at the victim receiver assuming a TDD uplink:downlink ratio of 1.. Data destined for a receiver is assumed to be transmitted within a single packet of 2.5 ms duration over an interval of 20 ms (i.e., an activity factor of 12.5%).

6.1 TS BEM in-block emission level

shows the maximum permitted in-block emission level, P_{IB} , for FDD or TDD TSs. These limits are derived from CEPT Report 19 and EC Decision (2008/477/EC).

In-block power, P_{IB}	Maximum mean level
Total radiated power (TRP)	31 dBm/(5 MHz)
Equivalent isotropic radiated power (EIRP)	35 dBm/(5 MHz)
Note: EIRP should be used for fixed or installed terminal stations and TRP should be used for mobile or nomadic terminal stations. TRP is a measure of how much power the antenna actually radiates. The TRP is defined as the integral of the power transmitted in different directions over the entire radiation sphere.	

Table 14: In-block emission limits for terminal stations (FDD or TDD).

6.2 BEM transition levels at different frequency boundaries

Note that in the following sub-sections, a *restricted* block refers to a 5 MHz block which may be used with no guarantee of freedom from interference (and may additionally be associated with a reduced base station EIRP limit, depending on the boundary location). Restricted blocks may also be used as guard blocks.

6.2.1 Boundary between TDD and FDD downlink

Figure 28 illustrates the proposed shape of the BEM for a TDD TS at the frequency boundary, f_0, between TDD and FDD downlink. As indicated, there is a potential for TS-TS interference from TDD to FDD at this boundary.

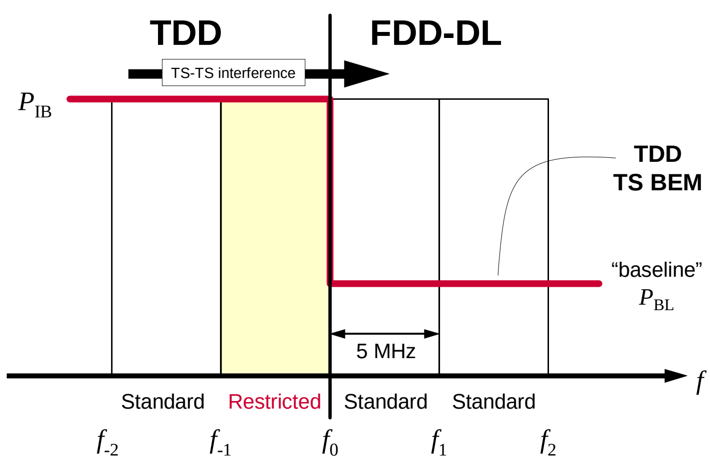

Figure 28: TS BEM at the boundary between TDD and FDD-DL

For TDD blocks below the frequency boundary ($f < f_0$ in Figure 28), the value of the TDD TS BEM is equal to the in-block emission levels, P_{IB} , as defined in Table 14.

It is necessary to appropriately manage the risk of interference from TSs in the TDD network to TSs operating in the standard blocks of the FDD network. For this reason, the value of the TS BEM for the TDD network is set equal to the baseline level, P_{BL} , over all the standard blocks of the FDD network ($f > f_0$ in Figure 28). Note that, in this example, there are no transition levels and the BEM changes from the in-block power level, P_{IB} , directly to the baseline level, P_{BL} .

An implication of the sharp transition in the above BEM is that the operation of TDD TSs in the 5 MHz block immediately below f_0 would be somewhat restricted. In this restricted block, the terminal stations may, for example, need to operate at lower power levels in order to comply with the TS BEM (See Section 1.1). The mirror image of Figure 28 applies in the case where a TDD network operates at frequencies above the FDD DL blocks.

6.2.2 Boundary between TDD and FDD uplink

Figure 29 illustrates the proposed shape of the BEMs for TDD and FDD TSs at the frequency boundary, f_0, between TDD and FDD (uplink) networks. As indicated, there is a potential for TS-TS interference from FDD to TDD at this boundary. Note that the first 5 MHz block immediately above the frequency boundary is designated as a *restricted* block in accordance to the technical conditions specified in CEPT Report 19.

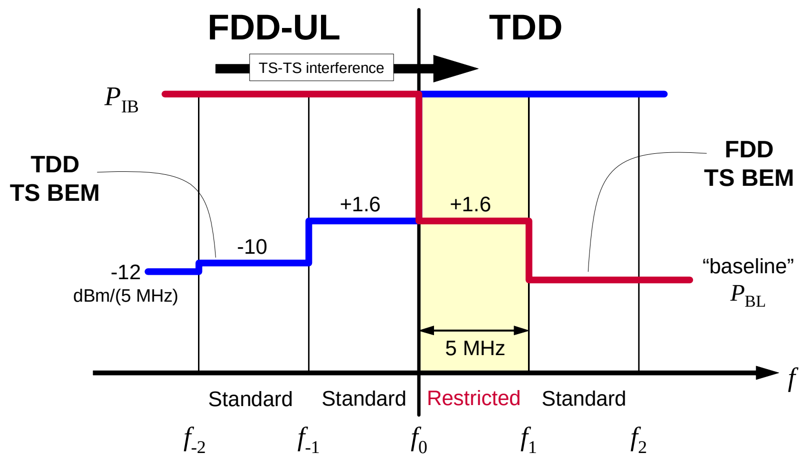

Figure 29: TS BEM at the boundary between FDD-UL and TDD

TDD terminal station BEM

For TDD blocks above the frequency boundary ($f > f_0$ in Figure 29), the value of the TDD TS BEM is equal to the in-block emission levels, P_{IB}, as defined in Table 14.

Note that there is no risk of interference from TDD TSs to FDD TSs across this frequency boundary. As a result, no restrictions – beyond those that are implied by the relevant technology standards – need to be applied with respect to the out-of-block emissions of the TDD TSs. For this reason, it is proposed that the TDD TS BEM out-of-block levels (for $f < f_0$ in Figure 29) follow those specified in CEPT Report 19 (normalized to a measurement bandwidth of 5 MHz).

FDD terminal station BEM

For FDD blocks below the frequency boundary ($f < f_0$ in Figure 29), the value of the FDD TS BEM is equal to the in-block emission levels, P_{IB}, as defined in Table 14.

It is necessary to appropriately manage the risk of interference from FDD TSs to TSs which operate in standard TDD blocks. For this reason, the value of the FDD TS BEM is set equal to the baseline level, P_{BL}, over all standard TDD blocks (i.e., for $f > f_1$ in Figure 29).

However, the restricted TDD block is not afforded the same level of protection as standard TDD blocks. As a result, no restrictions – beyond those that are implied by the relevant technology standards – need to be applied with respect to the out-of-block emissions of FDD TSs over the frequency range of the restricted TDD block. For this reason, it is proposed the FDD TS BEM out-of-block levels over the restricted TDD block (f_0 to f_1 in Figure 29) follow those specified in CEPT Report 19 (normalized to a measurement bandwidth of 5 MHz). This implies a transition level between the in-block power limit, P_{IB} (below f_0) and the baseline level P_{BL} (above f_1).

6.2.3 Boundary between TDD and TDD

Figure 30 illustrates the proposed shape of the BEMs for TDD TSs at the frequency boundary, f_0, between two unsynchronised[35] TDD networks. As indicated, there is a potential for TS-TS interference in both directions at this boundary. Note that the first 5 MHz block immediately above the frequency boundary is designated as a restricted block in accordance to the technical conditions specified in CEPT Report 19.

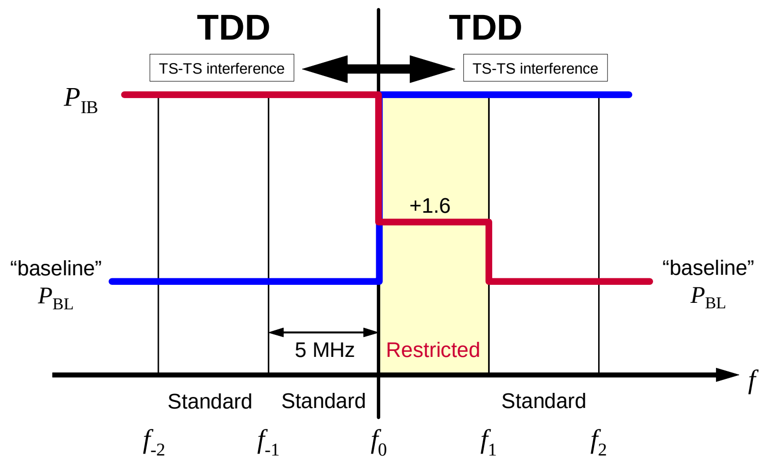

Figure 30: TS BEM at the boundary between TDD networks

TDD terminal station BEM in higher frequency network

For TDD blocks above the frequency boundary ($f > f_0$ in Figure 30), the value of the TDD TS BEM is equal to the in-block emission levels, P_{IB}, as defined in Table 14.

It is necessary to appropriately manage the risk of interference from TSs in the higher frequency TDD network to TSs operating in the standard blocks of the lower frequency network. For this reason, the value of the TS BEM for the higher frequency TDD network is set equal to the baseline level, P_{BL}, over all standard blocks of the lower frequency TDD network (i.e., $f < f_0$ in Figure 30). Again, in this example, there are no transition levels and the BEM changes from the in-block power level, P_{IB}, directly to the baseline level, P_{BL}.

TDD terminal station BEM in lower frequency network

For TDD blocks below the frequency boundary ($f < f_0$ in Figure 30), the value of the TDD TS BEM is equal to the in-block emission levels, P_{IB}, as defined in Table 14.

It is necessary to appropriately manage the risk of interference from TSs in the lower frequency TDD network to TSs operating in the standard blocks of the higher frequency network. For this reason, the value of the TS BEM for the lower frequency TDD network is set equal to the baseline level, P_{BL}, over all standard blocks of the higher frequency TDD network (i.e., $f > f_1$ in Figure 30).

However, the restricted block in the higher frequency TDD network is not afforded the same level of protection as the standard TDD blocks. As a result, no restriction – beyond those that are implied by the relevant technology standards – need to be applied with respect to the out-of-block emissions of TSs over the frequency range of the restricted block. For this reason, it is proposed that the TDD TS BEM out-of-block levels over the restricted TDD block (f_0 to f_1 in Figure 30) follow those specified in CEPT Report 19 (normalized to a measurement bandwidth of 5 MHz). This implies a transition level between the in-block power limit, P_{IB} (below f_0) and the baseline level P_{BL} (above f_1).

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[35] Where the frequency-adjacent TDD networks have synchronised uplink and downlink phases, no restrictions – beyond those that are implied by the relevant technology standards – need to be applied with respect to the out-of-block emissions of TDD TSs. In such circumstances, it is proposed that the TDD TS BEM out-of-block levels follow those specified in CEPT Report 19.

6.3 TS BEM out-of-block emission levels

The shape of the TS BEMs at the various frequency boundaries in the 2.6 GHz band were described in the previous section.

Correspondingly, the TS BEMs over all frequencies in the 2.6 GHz band may be built up by combining the values in Table 15, Table 16Table 16, and Table 17 in such a way that the limit at each frequency is given by the higher (less stringent) value of a) the baseline requirements, and b) the boundary-specific requirements.

Frequency range in which out-of-block emissions are received	Maximum mean EIRP
Frequencies allocated to FDD uplink	-12 dBm/(5 MHz)
Frequencies allocated to FDD down link and TDD	P_{BL}

Table 15: Baseline requirements – TS BEM out-of-block EIRP levels

Offset from relevant block edge	Maximum mean EIRP
–10 to –5 MHz (lower edge)	-10 dBm/(5 MHz)
–5 to 0 MHz (lower edge)	+1.6 dBm/(5 MHz)
0 to +5 MHz (lower edge)	+1.6 dBm/(5 MHz)
+5 to +10 MHz (lower edge)	-10 dBm/(5 MHz)

**Table 16: Boundary-specific requirements –
TS BEM out-of-block EIRP levels over frequencies occupied by FDD UL**

Offset from relevant block edge	Maximum mean EIRP
0.0 to +5.0 MHz (upper edge)	+1.6 dBm/(5 MHz)

**Table 17: Boundary-specific requirements –
TS BEM out-of-block EIRP levels over frequencies occupied by TDD**

In this study, EIRP values for mobile and nomadic terminals do not incorporate the influence of the person carrying the equipment. Although EIRP has been used throughout this report to express the terminal BEMs, there are alternatives such as total radiated power or conducted power. It is not investigated further here which advantages or disadvantages different measures may have.

6.4 Illustrative examples

Figure 31 to Figure 35 illustrate the shapes of the TS BEMs over the 2.6 GHz band for different examples of spectrum allocation.

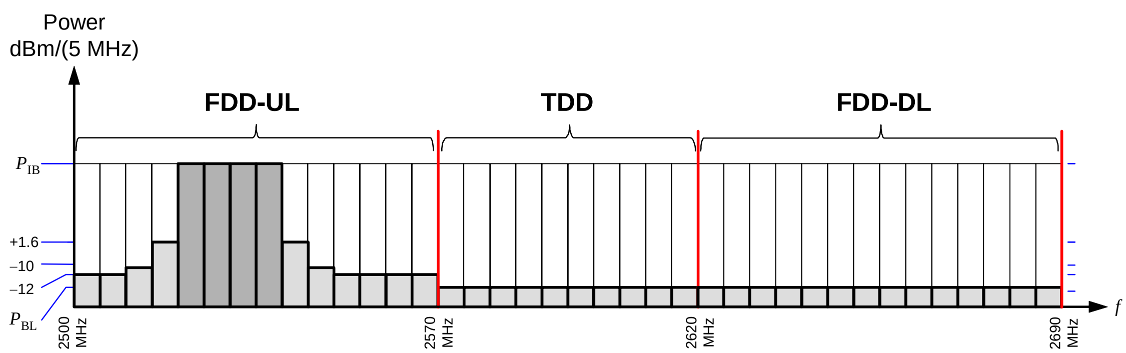

**Figure 31: TS BEM for an FDD operator without a FDD/TDD frequency boundary.
Note the two transition levels on each side of the licensed spectrum)**

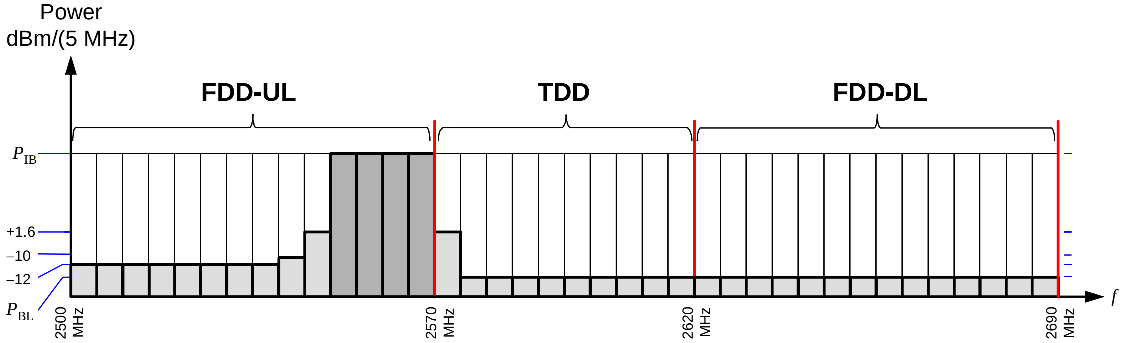

Figure 32: TS BEM for an FDD operator with a FDD/TDD frequency boundary. Note that there are two transition levels on the left side, and only one transition level on the right side of the licensed spectrum

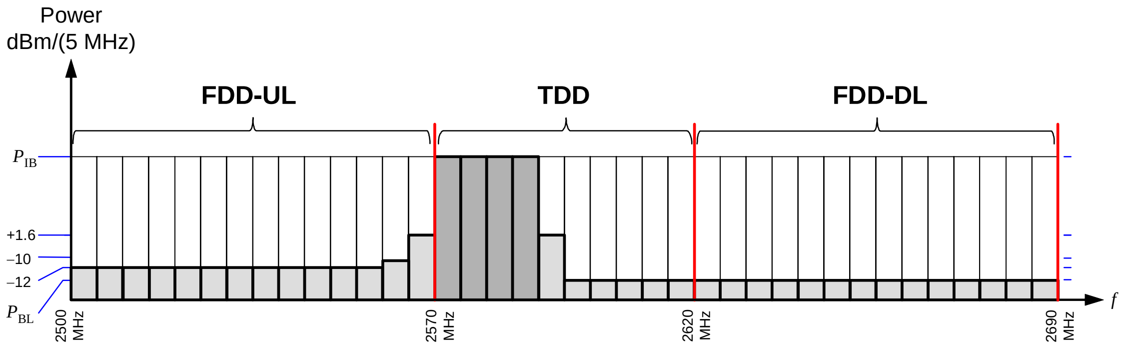

Figure 33: TS BEM for a TDD operator with a FDD-UL/TDD lower frequency boundary. Note that there are two transition levels on the left side, and only one transition level on the right side of the licensed spectrum

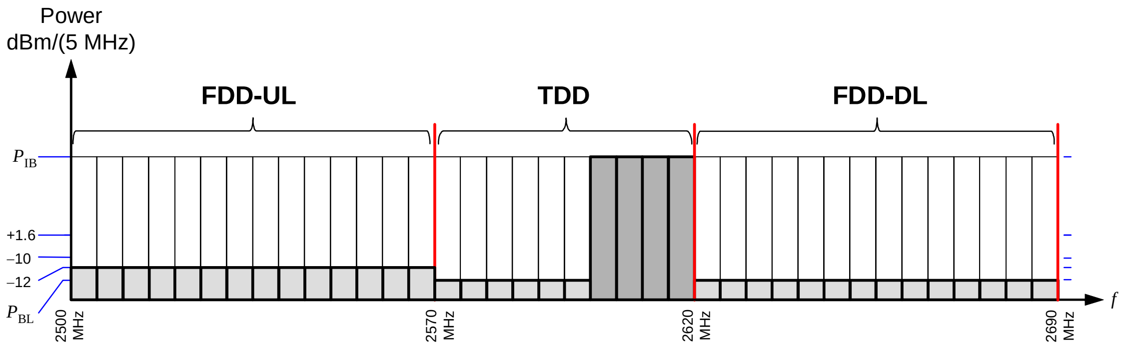

Figure 34: TS BEM for a TDD operator with a FDD-DL/TDD upper frequency boundary. Note that there are no transition levels either side of the licensed spectrum

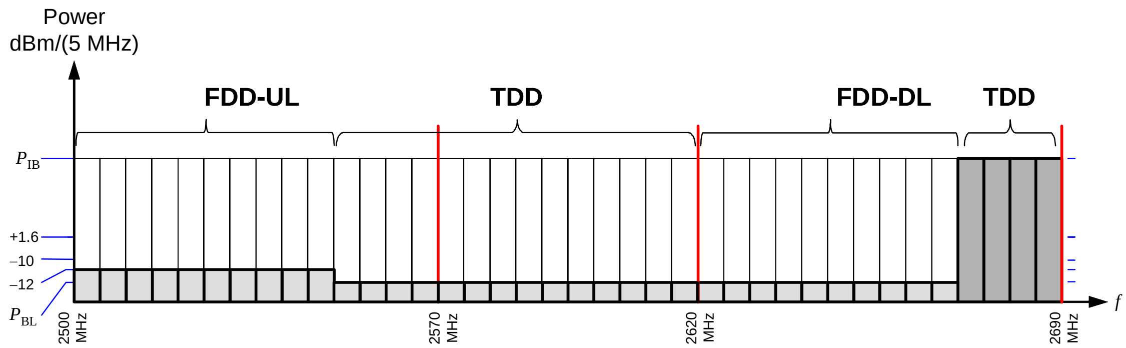

Figure 35: TS BEM for a TDD operator with a FDD-DL/TDD lower frequency boundary. Note that there are no transition levels on the left side of the licensed spectrum

ANNEX 1: USE OF ALTERNATIVE FREQUENCIES AND FREQUENCY PLAN COORDINATION

Where interference is experienced by a TS in the 2.6 GHz band, other frequency channels or frequency bands may be available as an alternative. This would be the case, for example, if the operator owns multi-channel licences in multiple frequency bands.

Such availability of alternative frequencies would normally be used for the purpose of radio resource management in cellular systems. For example, when TSs move out of the coverage areas for the 2.6 GHz band (because there is insufficient signal quality to support a service), the TSs could be switched over to another band used by the network operator (e.g. the 2 GHz band). Or where a certain channel is congested, the TSs could be switched over to a less congested channel within the same band.

Nevertheless, the use of alternative frequencies is only a possible technique when all of the following conditions are met:

- The operator has access to spectrum in other frequency bands (which a new entrant may not)[36] or other channels within the 2.6 GHz band[37].
- The TS supports the other channels or frequency bands and technologies.
- The technology deployed in the other channels or other frequency bands is compatible with the technology deployed in the channel subject to interference, in terms of handover, resource allocation protocol and service capabilities.
- There is capacity available in the other bands[38].
- It is possible for the signalling to perform a handover.

The handover mechanisms in mobile systems are designed for situations where the optimum base station for a mobile changes as the result of movement of the mobile. This change is gradual, and the signalling protocols are designed to be able to complete the process for the highest expected rate of change of signal strength or quality. In contrast, the interference from another TS can cause an instantaneous break in communication, for both traffic and control channels, making handover impossible. In fact, such a complex interference assessment technique will result in huge amount of signalling load in the network. It would most likely fail to provide a remedy, because the signalling link required for inter-frequency handover will be dropped due to harmful interference, prior being able to move the TS into another frequency band.

Therefore, in the event of a victim TS station experiencing unacceptable interference from a closely neighbouring interfering TS, it might be possible for the victim TS to switch to an alternative channel in a different band or in the same band, to avoid the effect of the interference, but this cannot be relied upon.

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[36] Such a proposal is hence a serious threat to potential new entrants who do not have existing telecommunication network in other frequency bands. It stands for a restriction of competition where only incumbents could afford to offer commercial services in the band while potential new entrants would be deterred as no commercial-grade network could be built solely on equipment operating in this band

[37] Given the developments in IMT-2000 technologies and the proposed requirements for IMT-Advanced leading to wider bandwidth channels, it cannot be assumed that an operator will have more than one channel (multiple of 5 MHz blocks) in the 2.6GHz band.

[38] For example the 2.6 GHz band can potentially support LTE system with 20MHz wide channels. No other telecommunication band can offer such channels

ANNEX 2: PROPAGATION MODELS

Free space path loss

Free space path loss is used for modelling TS-TS radio propagation in the MCL analysis of Section (3). The free space path loss, L_{FS}, in dB is given by the well-known formula

$$L_{\mathrm{FS}}(d) = 32.4 + 20\log_{10}(d) + 20\log_{10}(f), \quad \text{(A3.1)}$$

where *d* is the separation between the transmitter and receiver in kilometres, and *f* is the carrier frequency in MHz.

Extended Hata model for urban area [7]

The extended Hata (urban) model is used for characterising BS-TS radio propagation in the Monte Carlo studies of Sections (4) and (5). The mean path loss, *L*, in dB is given by different equations for different separations, *d*, between transmitter and receiver.

For $d < 0.04$ km,

$$L(d) = 32.4 + 20\log_{10}(f) + 10\log_{10}\left(d^2 + (H_b - H_m)^2/10^6\right), \quad \text{(A3.2)}$$

for $d < 0.1$ km and $d > 0.04$ km,

$$L(d) = L(0.04) + \frac{\log_{10}(d) - \log_{10}(0.04)}{\log_{10}(0.1) - \log_{10}(0.04)}\left(L(0.1) - L(0.04)\right) \quad \text{(A3.3)}$$

for $d > 0.1$ km and $d < 20$ km,

$$\begin{aligned} L(d) = {} & 46.3 + 33.9\log_{10}(2000) + 10\log_{10}(f/2000) - 13.82\log_{10}(\max\{30, H_b\}) \\ & + \left[44.9 - 6.55\log_{10}(\max\{30, H_b\})\right]\left(\log_{10}(d)\right) - a(H_m) - b(H_b), \end{aligned} \quad \text{(A3.4)}$$

$$\begin{aligned} a(H_m) = {} & \left(1.1\log_{10}(f) - 0.7\right)\min\{10, H_m\} \\ & - \left(1.56\log_{10}(f) - 0.8\right) + \max\{0, 20\log_{10}(H_m/10)\}, \end{aligned} \quad \text{(A3.5)}$$

$$b(H_b) = \min\{0, 20\log_{10}(H_b/30)\}, \quad \text{(A3.6)}$$

and for low antenna height H_b, $b(H_b)$ is replaced by

$$\begin{aligned} b(H_b) = {} & \left(1.1\log_{10}(f) - 0.7\right)\min\{10, H_b\} \\ & - \left(1.56\log_{10}(f) - 0.8\right) + \max\{0, 20\log_{10}(H_b/10)\}, \end{aligned} \quad \text{(A3.7)}$$

where

- *d* transmitter-receiver separation in kilometres,
- *f* is the carrier frequency in MHz,
- $H_b = \max(h_{\mathrm{tx}}, h_{\mathrm{rx}})$ of transmitter and receiver antenna height in m, and
- $H_m = \min(h_{\mathrm{tx}}, h_{\mathrm{rx}})$ of transmitter and receiver antenna height in m.

Where the path loss, *L*, is less than the free space attenuation for the same distance, the free space attenuation should be used instead.

Path-loss exponents similar to those implied by the extended (urban) Hata model [7] described above are used in this report to characterise the mean path loss over all radio links, assuming antenna heights (above ground level) of 30 and 1.5 metres for base stations and terminal stations respectively. The corresponding variations of mean path loss as a function of separation are illustrated in Figure 36 for different transmit-receive antenna height combinations at a frequency of 2.6 GHz. The mean path loss is modelled as free-space propagation (exponent of 2) for all distances less than 40 metres.

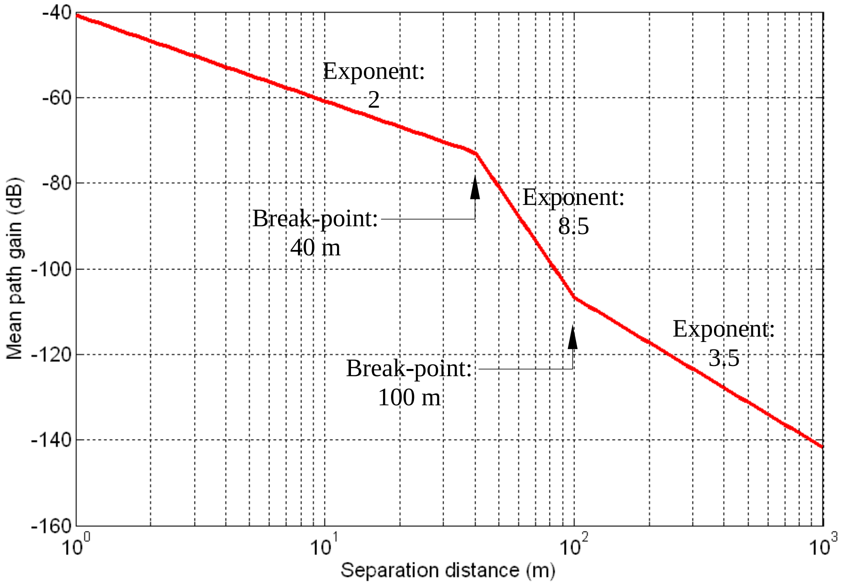

Figure 36: Mean path loss for different transmit-receive antenna height combinations.

For all base-terminal links, log-normal distributed shadowing with standard deviations of 3.5 dB and 12 dB are assumed for separations of less than 40 metres and greater than 40 metres respectively. Minimum base-terminal separation of 50 and 5 metres are also assumed in macro-cells and pico-cells respectively.

IEEE 802.11 Model [8]

Measurements results reported in the literature indicate that the presence of people across the propagation link between a transmitter and a receiver could cause additional loss (of up to 20 to 30dB), as a result of body loss or multi-path interference due to body scattering.

In circumstances where the spatial density of TSs is high (as in the geometries investigated in this report), the probability of TS-TS path blocking is also high, and hence the TS-TS path can no longer be treated as line-of-sight. Consequently, a path loss model with a greater exponent is more suitable than the free space path loss model for the characterisation of TS-TS links in dense hotspots.

Based on the above arguments, it is proposed to use the IEEE 802.11 (Model C) [8] to characterise all TS-TS radio propagation in the Monte Carlo studies of Sections (4) and (5).

Accordingly, the mean path loss is characterised by a dual-slope model with a break point at 5 metres, an exponent of 2 for all distances less than 5 metres, and an exponent of 3.5 otherwise. In short, the mean path loss, L, in dB is

$$L(d) = \begin{cases} L_{\mathrm{FS}}(d) \ \ \mathrm{dB} & d < d_{\mathrm{BP}} \\ L_{\mathrm{FS}}(d_{\mathrm{BP}}) + 35 \log \dfrac{d}{d_{\mathrm{BP}}} \ \ \mathrm{dB} & d \geq d_{\mathrm{BP}} \end{cases} \qquad \text{(A3.8)}$$

where d is the separation between the transmitter and receiver in kilometres, $d_{\mathrm{BP}} = 0.005$ is the break-point in kilometres, and $L_{\mathrm{FS}}(d)$ is free space path loss.

Furthermore, log-normal distributed shadowing with standard deviations of 3 dB and 4 dB is assumed for separations of less than 5 metres and greater than 5 metres respectively. Where the calculated path loss is less than free space attenuation for the same distance, the free space attenuation is used instead.

This propagation model is used to calculate terminal-terminal interference and takes account of shadowing losses due to objects between the two terminals, but does not explicitly account for any loss from near-field objects, such as the person carrying the equipment.

ANNEX 3: MODELLING METHODOLOGY IN STUDY-2

1. Introduction

In this annex we present a detailed quantitative description of the modelling methodology and assumptions used in our analysis of adjacent-channel interference from TDD terminal stations to FDD terminal stations in the 2.6 GHz band. This is intended to complement the qualitative descriptions presented in Section (5) of this document.

We first explain the model used for the operation of the TDD uplink. This includes features such as adaptive modulation and coding, power control, and scheduling of TDD terminal station transmissions. Co-channel uplink interference from a ring of adjacent cells within the TDD system is also accounted for in this modelling.

We then describe the model used for quantifying the impact of TS-TS interference on a FDD terminal station. Here, we again assume the use of adaptive modulation and coding on the FDD downlink, and evaluate the levels of adjacent-channel interferer powers received based on the extent of time overlap between uplink TDD packets and downlink FDD packets. Co-channel downlink interference from a ring of adjacent cells within the FDD system is also accounted for in this modelling.

We subsequently show how the degradation in the FDD downlink SINR (and hence throughput) can be calculated as a function of the adjacent-channel interferer powers. This is performed by modelling the impact of a) adjacent-channel interference ratio (ACIR), b) receiver saturation, and c) inter-modulation products.

Note that we use WiMAX and UTRA-HSDPA as templates for the TDD and FDD technologies respectively.

2. Modelling of the TDD uplink

The results presented in Section (5) of this document quantify the impact of adjacent-channel interference originating from a number of TDD terminal stations radiating in frequency blocks #35 to #38 and #21 to #24, and located within a 25 m radius of a FDD terminal station that is tuned to receive in block #34.

In this sub-section, we describe in detail the methodology employed for the modelling of the above TDD terminal station transmissions. Note that the calculations presented in this sub-section apply to TDD terminal stations operating in a single frequency block, and as such, need to be performed for each of the TDD frequency blocks under investigation.

a) Adaptive modulation and coding in the TDD uplink

Modern radio access technologies invariably use adaptive modulation and coding (AMC), whereby the employed modulation order and forward error correction (FEC) coding rate are dynamically modified by the transmitter in response to variations in signal-to-interference-plus-noise ratio (SINR) at the receiver. This enables the transmitter to maximise its utilisation of the capacity offered by the radio link at any given instant in time.

In this study, we use Shannon's Capacity Theorem[39] to model the variation of data throughput as a function of SINR as made possible by the range of modulation orders and coding rates available for use in the TDD uplink.

Accordingly, if a TDD terminal station radiates continuously at the maximum permitted in-block EIRP of $P_{\max}$, then it can achieve (subject to zero demand from other TDD terminal stations in the cell) a maximum throughput of

$$C = \xi \, B \log_2\left(1 + \mathrm{SINR}_{\mathrm{UL}}\right) \quad \text{bits/s}, \qquad \text{(A4.1)}$$

[39] This describes the upper bound on the spectral efficiency of an additive white Gaussian noise (AWGN) channel. See, for example, *Digital Communications* by J.G.Proakis, 2000, McGraw-Hill.

Where B is the noise-equivalent channel bandwidth, $\mathrm{SINR}_{\mathrm{UL}}$ is the uplink signal-to-interference-plus-noise ratio, and the penalty factor ξ represents the inferiority of the link's spectral efficiency as compared to the Shannon Limit. Furthermore,

$$\mathrm{SINR}_{\mathrm{UL}} = \frac{G\,P_{\max}}{P_{\mathrm{N}} + P_{\mathrm{I,CC}} + P_{\mathrm{I,AC}}}, \tag{A4.2}$$

where G is the aggregate propagation gain (including receive antenna gain) from the TDD terminal station to the TDD base station, and $P_{\mathrm{N}} = kTB\,\mathrm{NF}_{\mathrm{BS}}$ is thermal noise power at the TDD base station receiver (k is Boltzman's constant, T is the ambient temperature, and $\mathrm{NF}_{\mathrm{BS}}$ is the receiver noise figure). $P_{\mathrm{I,CC}}$ and $P_{\mathrm{I,AC}}$ are the co-channel and adjacent-channel interference powers experienced by the TDD base station respectively. The computation of these last two terms is described in later sub-sections of this annex.

It should be noted that a TDD terminal station need not radiate at the maximum permitted EIRP in order to achieve maximum throughput in all circumstances. This is because, in practice, radio technologies only support a finite number of modulation and coding schemes, and as such, can not support indefinitely increasing throughputs as a function of increasing SINRs. In other words, there is no utility in achieving a SINR that is greater than an upper threshold, γ_{TH}, as defined by the highest-order modulation and highest-rate coding supported.

Therefore, if a TDD terminal station suffers from low levels of path loss or shadowing, then we may have $\mathrm{SINR}_{\mathrm{UL}} > \gamma_{\mathrm{TH}}$, in which case, the TDD terminal station's in-block EIRP can be reduced (so that $\mathrm{SINR}_{\mathrm{UL}} = \gamma_{\mathrm{TH}}$) with no loss in the achieved throughput. Consequently, we model a TDD terminal station's in-block EIRP, P, as

$$P = \begin{cases} P_{\max} & \text{if } \mathrm{SINR}_{\mathrm{UL}} \le \gamma_{\mathrm{TH}} \\ \dfrac{\gamma_{\mathrm{TH}}}{\mathrm{SINR}_{\mathrm{UL}}} P_{\max} & \text{if } \mathrm{SINR}_{\mathrm{UL}} > \gamma_{\mathrm{TH}} \end{cases}, \tag{A4.3}$$

which in turn means that the resulting uplink SINR and maximum throughput are given by Equation (A4.1) and Equation (A4.2), subject to the constraints that $\mathrm{SINR}_{\mathrm{UL}} \le \gamma_{\mathrm{TH}}$ and $C \le \xi\, B \log_2(1+\gamma_{\mathrm{TH}})$.

The above formulation implies that a TDD terminal station will always radiate at the minimum power level which would allow it to achieve (via the optimum combination of modulation order and coding rate) the highest uplink throughput possible. It is implicitly assumed that the terminal station transmitter has full knowledge of the uplink channel-state information for the purpose of selecting the most appropriate modulation and coding combination.

Figure 37 shows the variation of C/B with $\mathrm{SINR}_{\mathrm{UL}}$ used for the purposes of this study. The assumed value of $\xi = 0.6$ is typical of current state of the art in physical layer technologies[40].
The maximum spectral efficiency of 4.5 bits/s/Hz (via 64-QAM with ¾ rate coding, as used in WiMAX) is achieved at a SINR of $\gamma_{\mathrm{TH}} = 22.5$ dB. In short, a TDD terminal station backs off from radiating at maximum power if the resulting SINR at the TDD base station exceeds $\gamma_{\mathrm{TH}} = 22.5$ dB.

The throughput in Equation (A4.1) and the EIRP in Equation (A4.3) are used in the next sub-section to model the bursty structure of transmissions by individual TDD terminal stations.

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[40] See, for example, *Fundamentals of WiMAX* by J.G.Andrew *et al*, 2007, Prentice-Hall, where $\xi = 0.75$ for an AWGN channel.

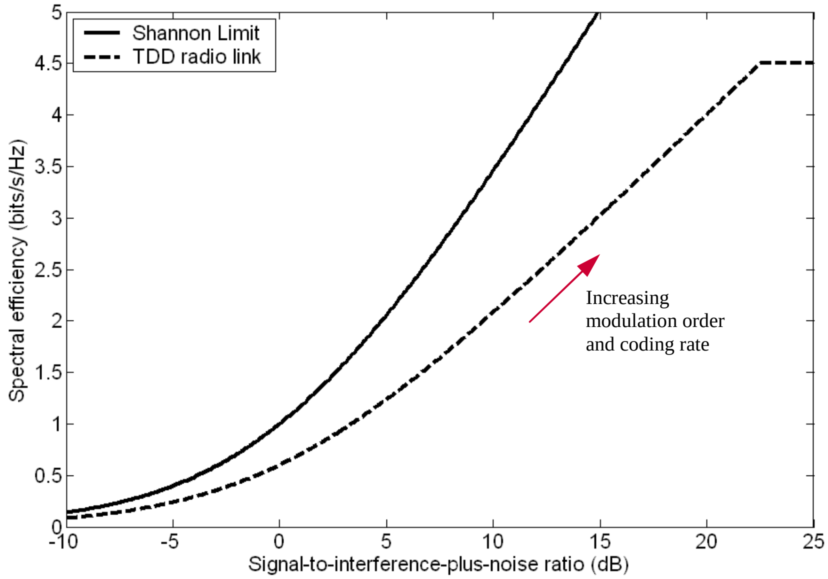

Figure 37: Model of spectral efficiency as a function of SINR for the TDD uplink

b) Bursty transmission and scheduling in the TDD uplink

Modern radio access technologies increasingly employ packet-based transmissions over the air-interface in order to better deal with the bursty nature of traffic, and to more efficiently utilise the radio resource by appropriately scheduling transmissions to and from those terminal stations associated with favourable radio link conditions at any given instant in time.

Consequently, the terminal stations in such systems transmit and receive data in bursts of finite duration. The durations and timing of such bursts are dependent on three factors, namely, a) the throughput that is available to each terminal station, b) the throughput that is required by each terminal station, and c) the manner in which the serving base station schedules communications with each terminal station.

In a TDD system, uplink transmissions only occur for a fraction, $u_{\mathrm{UL}} < 1$, of the time (i.e., during uplink sub-frames), with the remaining time dedicated to downlink transmissions (i.e., downlink sub-frames). Consequently, the maximum uplink throughput available to a TDD terminal station is equal to $C_{\mathrm{UL}} = u_{\mathrm{UL}} C$.

However, a TDD terminal station may not necessarily require the full uplink throughput available. Indeed, if the terminal station accesses a service which only requires a throughput, R_{S} , then it only needs to transmit using a fraction,

$$z = \frac{R_{\mathrm{S}}}{C_{\mathrm{UL}}} = \frac{R_{\mathrm{S}}}{u_{\mathrm{UL}} C} \le 1 , \qquad \text{(A4.4)}$$

of the time-frequency-code resource available in the uplink.

The precise nature of the multiple-access mechanism in an uplink sub-frame is not critically important for the purposes of this study. Nevertheless, it must be noted that if $z > 1$, then the service accessed by the terminal station can not be supported by the TDD network, as this would require more uplink resource than is available within the cell. Moreover, if there are K terminal stations in the cell, requiring fractions, $z_i \;\; i = 1 \cdots K$, of the uplink resource, only K' can be supported, where

$$\sum_{i=1}^{K'} z_i \le 1 . \qquad \text{(A4.5)}$$

The identities of the K' supported TDD terminal stations are decided by the TDD base station through a process of scheduling.

Many different scheduling algorithms exist. If fairness is the objective, the base station may schedule terminals in a round-robin fashion. If the objective is to maximize the uplink throughput, the base station may, at any given time, schedule the terminal(s) with the highest uplink SINR. If the objective is to maximize the number of satisfied customers, the base station may schedule terminals in order of ascending z_i.

For the purposes of this study, we are interested in the scheduling of TDD terminal stations only in so far as it impacts the levels of interference generated towards FDD terminal stations. For this reason, we use the latter scheduling algorithm described above in order to allow the largest number of TDD terminal stations to radiate during each scheduling interval.

To further clarify the scheduling model adopted, we present below an example based on the timing parameters of the WiMAX physical layer.

Example

Consider a scheduling interval of T_{Sch} = 20 ms containing N_{F} = 4 WiMAX frames of T_{F} = 5 ms duration each. Our assumption is that, in order to maintain real-time communication, a terminal station must be serviced (at an appropriate throughput) once every 20 ms. We have selected 20 ms, as this is the time epoch associated with the encoding interval of many audio and video compression technologies.

If $u_{\mathrm{UL/DL}}$ is the ratio of time reserved for uplink over that reserved for downlink, then

$$u_{\mathrm{UL}} = \frac{u_{\mathrm{UL/DL}}}{1 + u_{\mathrm{UL/DL}}}. \tag{A4.6}$$

A value of $u_{\mathrm{UL/DL}}$ = 1/3 is commonly quoted for WiMAX, in which case u_{UL} = 1/4. This means that each of the four 5 ms WiMAX frames in the 20 ms scheduling interval is divided into a downlink sub-frame of T_{DL} = 3.75 ms and an uplink sub-frame of T_{UL} = 1.25 ms. This is illustrated in Figure 38.

We next consider K' = 5 terminal stations requiring fractions z_1 = 0.1, z_2 = 0.1, z_3 = 0.2, z_4 = 0.2, and z_5 = 0.3, respectively of the available uplink resource over the scheduling interval.

Figure 38 shows the scheduling of the terminal stations in ascending order of required resources, z_i, over a scheduling interval of 20 ms. To appreciate the impact of scheduling on the nature of the TDD terminal stations as sources of interference, we focus on the case of the 3rd terminal station.

If the fraction, z_3, of the uplink radio resource required by this terminal station was equal to 0.25, and took up all the time-frequency-code resource within an otherwise unoccupied uplink sub-frame, one could conclude that the terminal station would radiate at an in-block EIRP level of P (as derived in Equation (A4.3)) over the relevant uplink sub-frame.

However, in the presented example, the fraction, z_3, of the uplink radio resource required by the 3rd terminal station is equal to 0.2, and is split into $z_{3,1}$ = 0.05 and $z_{3,2}$ = 0.15 between the 1st and 2nd uplink sub-frames respectively. One may then conclude that the 3rd terminal station effectively appears as an adjacent-channel interferer which radiates at in-block EIRP levels of (0.05/0.25) P and (0.15/0.25) P when averaged over each of the 1st and 2nd uplink sub-frames respectively.

Note that in the example of Figure 38, the demand for the TDD uplink radio resource is less than the supply, i.e., all terminal stations are serviced and there is still some uplink radio resource to spare in the 4th sub-frame. If demand exceeds supply, however, we ensure that all the available TDD uplink radio resource is utilised, even though this might mean that the last terminal station served in the scheduling interval is serviced only partially.

Expressing the previous example in general terms, we can see that when scheduling is performed over N_F uplink sub-frames, the k^{th} TDD terminal effectively *appears* as an interferer which radiates at an in-block EIRP level of

$$P_{k,n} = \alpha_{k,n} P_k \qquad \text{(A4.7)}$$

when averaged over the n^{th} uplink sub-frame, where

$$\alpha_{k,n} = \frac{z_{k,n}}{(1/N_F)}, \qquad \text{(A4.8)}$$

$z_{k,n}$ is the fraction of the uplink resource that is available in the n^{th} uplink sub-frame and which is required by the k^{th} terminal station, and P_k is the actual in-block EIRP level of the k^{th} terminal station as derived in Equation (A4.3).

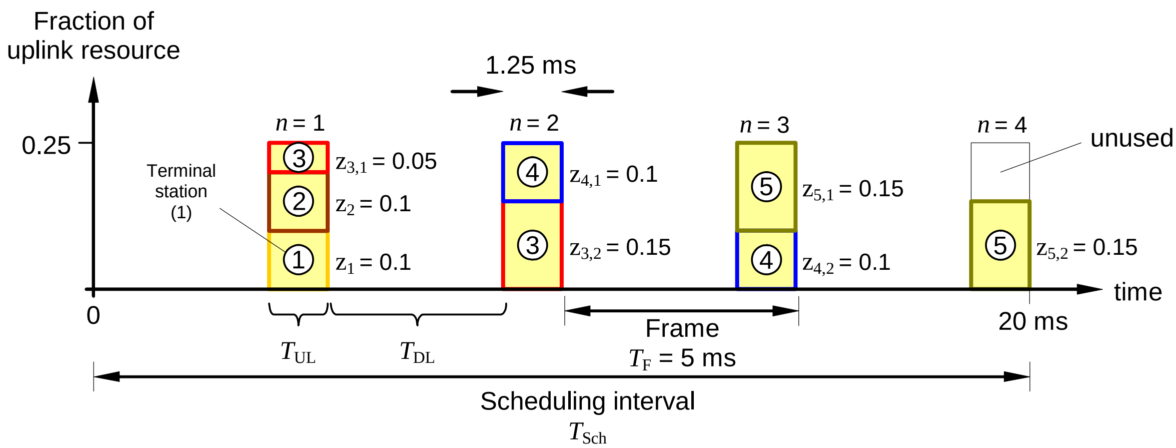

Figure 38: Example of uplink scheduling by a TDD base station of five terminal stations requiring fractions {0.1, 0.1, 0.2, 0.2, 0.3} of the uplink radio resource

The effective in-block EIRP values, $P_{k,n}$, derived in Equation (A4.7) will be used in Equation (A4.15) later in this annex to compute the adjacent-channel interference from TDD terminal stations to FDD terminal stations.

c) Co-channel interference in the TDD uplink

Co-channel interference at a TDD base station can, in principle, originate from both TDD base stations and TDD terminal stations of the same network.

In practice, however, it is highly likely that the uplink/downlink phases across the co-channel cells of a TDD network will be synchronised in order to avoid base-to-base and (particularly) TS-TS interference. In such a case, co-channel interference at a TDD base station would only originate from radiations of TDD terminal stations realised in the form of intra-cell and inter-cell interference. This has been assumed in our analysis.

<u>Intra-cell (multiple-access) interference</u>

In technologies such as WiMAX, the combined use of OFDMA and/or TDMA on the uplink implies a nominal absence of intra-cell (or multiple-access) interference. For this reason, we do not model intra-cell co-channel interference in our analysis, and assume this to be zero.

<u>Inter-cell interference</u>

A precise modelling of co-channel inter-cell interference on the uplink is complicated, as this requires the detailed characterisation of a large number of terminal stations in the adjacent cells, whose behaviour in turn depends on the interference environment in those cells. Simplified models are therefore often adopted.

For the purposes of this study, we model the co-channel inter-cell interference experienced at a TDD base station as the sum of received signals originating from single TDD terminal stations located randomly at the edge of each adjacent cell, radiating at the maximum permitted in-block EIRP, $P_{\max}$, and utilising all the radio resource available in every uplink sub-frame. This is illustrated in Figure 39 below.

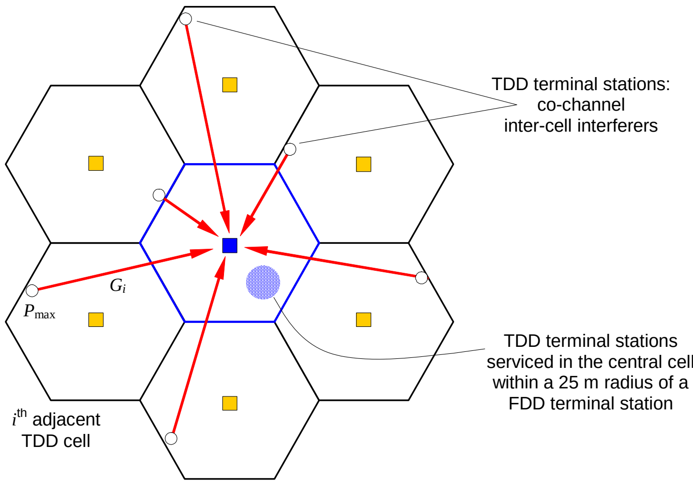

Figure 39: Model for co-channel inter-cell interference in the TDD uplink

The co-channel interference experienced by the central-cell TDD base station from radiations in M adjacent cells may then be written as

$$P_{\mathrm{I,CC}} = P_{\max} \sum_{i=1}^{M} G_i \,, \tag{A4.9}$$

where G_i is the aggregate propagation gain (including receive antenna gain) from the TDD terminal station in the i^{th} adjacent cell to the TDD base station in the central cell, and $P_{\max}$ is the maximum permitted terminal station in-block EIRP.

The uplink SINR at the central-cell base station can then be computed by substituting Equation (A4.9) into Equation (A4.2).

In practice, there will be instances when the TDD terminal stations in the adjacent cells do not radiate at the maximum permitted in-block EIRP (e.g., due to their proximity to the serving base station or low levels of shadowing). In such instances, the model of Equation (A4.9) would overestimate the amount of co-channel inter-cell interference experienced at the TDD base station.

On the other hand, there will be instances where more than a single TDD terminal radiates in each of the adjacent cells, and some of these may be located closer to the central cell than the single TDD terminal station we have considered. In such instances, the model of Equation (A4.9) would underestimate the amount of co-channel inter-cell interference experienced at the TDD base station.

Despite its limitations, the adopted model provides a reasonably accurate representation of the co-channel inter-cell interference experienced at a TDD base station.

In deriving the results presented in Section (5) of this document, we have assumed the model of Equation (A4.9) with a ring of M = 6 adjacent cells. Furthermore, $P_{\max}$ is set to 31 dBm/(5 MHz).

d) Adjacent-channel interference in the TDD uplink

Adjacent-channel interference at a TDD base station can, in principle, originate from the radiations of FDD or TDD terminal stations and base stations in adjacent frequency blocks.

Adjacent-channel interference from TDD terminal stations to TDD base stations is typically not a significant source of degradation in the uplink SINR (the exception being rare geometries where the interfering terminal station is extremely close to the victim base station). Also note that the TDD base stations of interest in this study operate in frequency blocks that are adjacent to the FDD downlink spectrum. Consequently, adjacent-channel interference from FDD terminal stations is not an issue.

Moreover, it is highly likely that the uplink/downlink phases of TDD radio links in neighbouring frequency blocks will be synchronised, particularly if they are managed by the same operator. Consequently, adjacent-channel interference from TDD base stations to TDD base stations is also unlikely in the frequency blocks of interest.

The only remaining source of adjacent-channel interference at the TDD base stations of interest is due to radiations by FDD base stations. Such interference can be effectively mitigated via adequate spatial separation between the base stations (100 m for a 1 dB desensitisation).

Given the above arguments, and for the purposes of this study, we make the simplifying assumption that the TDD uplink does not suffer from significant adjacent-channel interference, i.e., that $P_{\mathrm{I,AC}} = 0$ in Equation (A4.2).

3. Modelling of the FDD downlink

In this sub-section, we describe in detail the methodology employed for calculating the FDD downlink throughput, and for the modelling of collisions between TDD uplink packets and FDD downlink packets.

a) Adaptive modulation and coding in the FDD downlink

Following the same principles adopted for the TDD uplink, we use *Shannon's Capacity Theorem* to model the variation of data throughput as a function of SINR as made possible by the range of modulation orders and coding rates available for use in the FDD downlink. It is implicitly assumed that the base station transmitter has full knowledge of the downlink channel-state information for the purpose of selecting the most appropriate modulation and coding combination.

Accordingly, if a FDD base station radiates continuously at the maximum permitted in-block EIRP of $P_{\max}$, then it can potentially achieve a maximum downlink throughput of

$$C = \xi \, B \log_2\left(1 + \mathrm{SINR}_{\mathrm{DL}}\right) \quad \text{bits/s} \tag{A4.10}$$

where B is the noise-equivalent channel bandwidth, $\mathrm{SINR}_{\mathrm{DL}}$ is the downlink signal-to-interference-plus-noise ratio, and the penalty factor ξ represents the inferiority of the link's spectral efficiency as compared to the Shannon Limit. Furthermore,

$$\mathrm{SINR}_{\mathrm{DL}} = \frac{G \, P_{\max}}{P_{\mathrm{N}} + P_{\mathrm{I,CC}} + P_{\mathrm{I,AC}} + P_{\mathrm{I,IM}}}, \tag{A4.11}$$

where G is the aggregate propagation gain (including receive antenna gain) from the FDD base station to the FDD terminal station, and $P_{\mathrm{N}} = kTB \, \mathrm{NF}_{\mathrm{TS}}$ is thermal noise power at the FDD terminal station receiver (k is Boltzman's constant, T is the ambient temperature, and $\mathrm{NF}_{\mathrm{TS}}$ is the receiver noise figure). $P_{\mathrm{I,CC}}$, $P_{\mathrm{I,AC}}$, and $P_{\mathrm{I,IM}}$ are the co-channel, adjacent-channel, and inter-modulation interference powers experienced by the FDD terminal station respectively. The computation of these last three terms is described in later sub-sections of this annex.

Figure 40 shows the variation of C/B with $\mathrm{SINR}_{\mathrm{DL}}$ used for the purposes of this study. The assumed value of $\xi = 0.6$ is typical of current state of the art in physical layer technologies. The maximum spectral efficiency of 3 bits/s/Hz (via 16-QAM with ¾ rate coding, as used in UTRA-FDD HSDPA) is achieved at a minimum SINR of γ_{TH} = 15 dB.

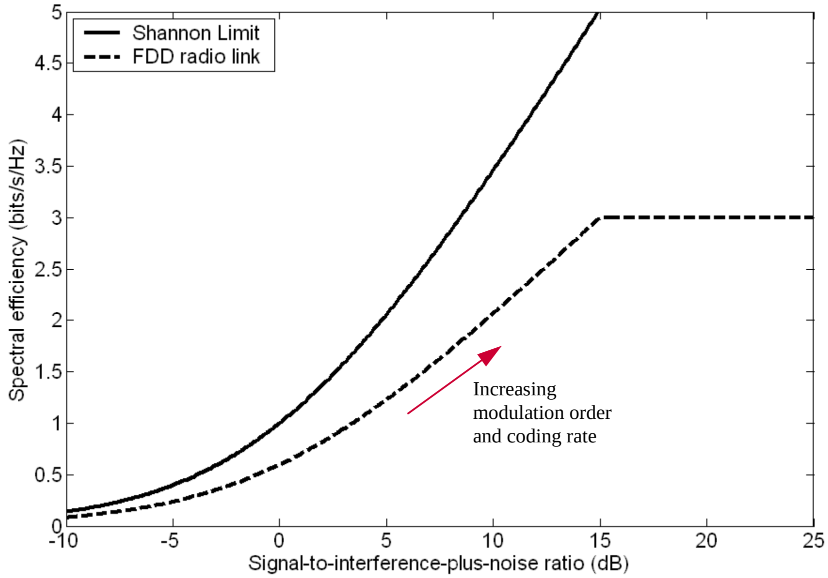

Figure 40: Model of spectral efficiency as a function of SINR for the FDD downlink

We assume that a FDD base station will always radiate at the minimum power level which would allow it to achieve (via the optimum combination of modulation order and coding rate) the highest downlink throughput possible. This means that a FDD base station backs off from radiating at full power if the resulting SINR at the FDD terminal station exceeds γ_{TH} = 15 dB (see Figure 40). In short, the resulting downlink SINR and maximum throughput are given by Equation (A4.10) and Equation (A4.11), subject to the constraints that $\mathrm{SINR}_{\mathrm{DL}} \le \gamma_{\mathrm{TH}}$ and that $C \le \xi B \log_2(1+\gamma_{\mathrm{TH}})$.

What is of particular interest in this study is the downlink throughput achieved by the reception at a FDD terminal station of a downlink radio packet of duration $T_{\mathrm{P,V}}$ over a scheduling interval T_{Sch}. The FDD downlink throughput averaged over the scheduling interval is then given by

$$C_{\mathrm{DL}} = \frac{T_{\mathrm{P,V}}}{T_{\mathrm{Sch}}} C \qquad \text{(A4.12)}$$

The cumulative probability distributions of FDD downlink throughput presented in Section (5) of this document correspond to the statistics of C_{DL} in Equation (A4.12) for $T_{\mathrm{P,V}}$ = 2.5 ms and T_{Sch} = 20 ms. Specifically, the statistics of C_{DL} are first computed with $P_{\mathrm{I,\,AC}}$ and $P_{\mathrm{I,\,IM}}$ set to zero in Equation (A4.11), representing the absence of TDD terminal station interferers. The impairments in FDD downlink throughput as a result of radiations by TDD terminal stations are then evaluated by including the computed values of $P_{\mathrm{I,\,AC}}$ and $P_{\mathrm{I,\,IM}}$ in the denominator of Equation (A4.11).

We next describe the computation of parameters $P_{\mathrm{I,CC}}$, $P_{\mathrm{I,AC}}$ and $P_{\mathrm{I,\,IM}}$.

b) Co-channel interference in the FDD downlink

Co-channel interference at a FDD terminal station originates from FDD base station radiations in the form of intra-cell and inter-cell interference.

Intra-cell (multiple-access) interference

In this study, we evaluate the maximum downlink throughput potentially available to a FDD terminal station due to the reception of a downlink radio packet. For this reason, we do not model any intra-cell (multiple-access) co-channel interference, and assume this to be zero.

Inter-cell interference

The inter-cell co-channel interference experienced by a FDD terminal station is caused by co-channel radiations from FDD base stations in adjacent cells (assuming universal frequency reuse). This may be written in a general form as

$$\sum_{m=1}^{M} G_m \eta_m P_m , \tag{A4.13}$$

where M is the number of adjacent-cell FDD base stations, G_m is the aggregate propagation gain (including receive antenna gain) from the m^{th} FDD base station to the receiving FDD terminal station, and P_m is the in-block EIRP of the m^{th} FDD base station. The interference scenario is illustrated in

Figure 41. Note that the FDD terminal station is always assumed to be serviced by the FDD base station associated with the lowest propagation loss. The significance of the multiplier η_m is described next.

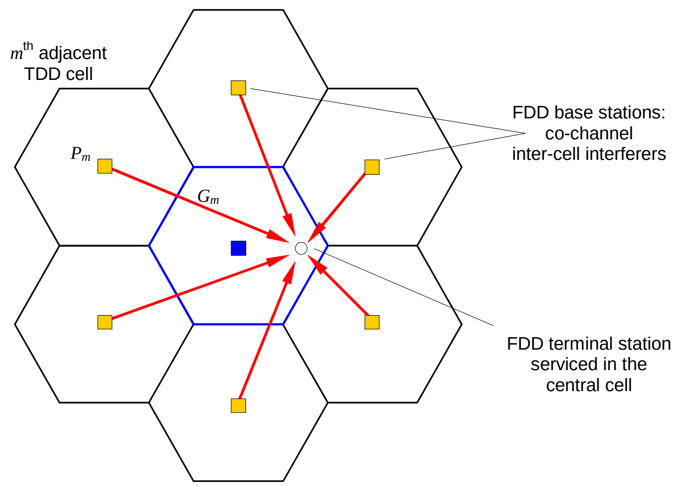

Figure 41: Model for co-channel inter-cell interference in the FDD downlink

To precisely model the inter-cell interference in a system such as UTRA-FDD HSDPA, one needs to account for the loading and traffic conditions in each adjacent cell. These influence a) the power radiated by each interfering base station, and b) the probability of collision between downlink radio packets in adjacent asynchronous cells.

At a coarse level, these effects may be expressed via the multiplier η_m. For the purposes of this study, we assume that all adjacent cells are fully loaded, to the extent that the corresponding FDD base stations radiate continuously and at the maximum permitted in-block EIRP, $P_{\max}$, so that $\eta_m = 1$ and $P_m = P_{\max}$ for $m = 1 \cdots M$. As a result, Equation (A4.13) may be re-written as

$$P_{\mathrm{I,CC}} = P_{\max} \sum_{m=1}^{M} G_m . \tag{A4.14}$$

The SINR at the FDD terminal station receiver (and hence the FDD downlink throughput) can then be computed by substituting Equation (A4.14) into Equation (A4.11).

In practice, the FDD base stations in adjacent cells do not always transmit data continuously, and in instances where they might transmit continuously, they would not necessarily do so at the maximum permitted EIRP (e.g., due to the proximity of the serviced terminal stations and/or low levels of shadowing). Therefore, the model of Equation (A4.14) represents an upper bound on the co-channel inter-cell interference experienced at a FDD terminal station.

In deriving the results presented in Section (5) of this document, we have assumed the model of Equation (A4.14) for a ring of M = 6 adjacent cells with $P_{\max}$ set to 57 dBm/(5 MHz).

c) Adjacent-channel interference in the FDD downlink

Adjacent-channel interference at a FDD terminal station can, in principle, originate from the radiations of TDD terminal stations and FDD or TDD base stations in adjacent frequency blocks.

Adjacent-channel interference from FDD base stations to FDD terminal stations is typically not a significant source of degradation in the downlink SINR (the exception being rare geometries where the victim terminal station is extremely close to the interfering base station). Furthermore, this type of interference is characteristic of all FDD cellular deployments and is in no way unique to the 2.6 GHz band. Moreover, adjacent-channel interference from TDD base stations is no greater (and, due to bursty transmissions, is typically lower) than that from FDD base stations.

For the above reasons, we do not model the adjacent-channel interference from base stations in our study of the FDD downlink throughput.

We instead focus on the potentially more significant adjacent-channel interference from TDD terminal stations (whose characteristics were described earlier in this annex).

Radiations by TDD terminal stations only cause interference towards a FDD terminal station if a received FDD downlink packet overlaps in time (i.e., collides) with the radiated TDD uplink packets. The extent of this interference is a function of the degree of overlap, the identities (and hence the proximities) of the TDD terminal stations involved, and their effective radiation powers in the relevant uplink sub-frames. To clarify the above issues, we present our model using the example below.

Figure 42 illustrates a scenario where a FDD downlink packet of duration $T_{\mathrm{P,V}}$ = 2 ms (as in UTRA-FDD HSDPA) partially collides with the n^{th} TDD uplink sub-frame of duration $T_{\mathrm{UL}} = 1.25\,\mathrm{ms}$ (as in WiMAX for $u_{\mathrm{UL/DL}}$ = 1/3) containing transmissions from $K = 3$ TDD terminal stations. As explained in Equation (A4.7), the *effective* in-block EIRPs of these terminal stations are $P_{k,n}$ for k = 1, 2, 3, where $P_{k,n} = \alpha_{k,n} P_k$.

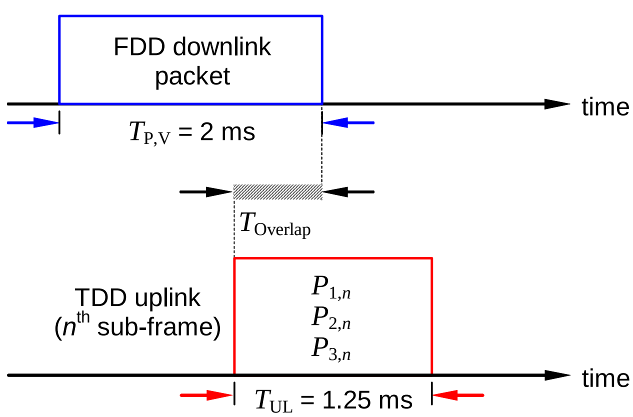

Figure 42: Example of collision between a FDD downlink packet and TDD packets in the n$^{\mathrm{th}}$ uplink sub-frame.

It is clear from Figure 42 that, when *averaged* [41] over the FDD downlink packet interval, the effective in-block EIRP of the k^{th} TDD terminal station is given by

$$\frac{T_{\mathrm{Overlap}}}{T_{\mathrm{P,V}}} P_{k,n} = \frac{T_{\mathrm{Overlap}}}{T_{\mathrm{P,V}}} \alpha_{k,n} P_k \,, \qquad \text{(A4.15)}$$

[41] This is a coarse model which does not take into account of the precise nature of the multiple-access mechanism within the TDD uplink sub-frame.

where T_{Overlap} is the overlap interval, $\alpha_{k,n}$ is the scalar derived in Equation (A4.8), and P_k is the actual in-block EIRP level of the k^{th} terminal station as derived in Equation (A4.3).

We assume that the arrival time of the FDD downlink packet within the scheduling interval, T_{Sch}, follows a uniform random distribution. As such, the FDD downlink packet may collide with any one of $N_{\text{F}} = 4$ TDD uplink sub-frames over a 20 ms scheduling interval.

The total power of the adjacent-channel interferers received at the antenna connector of the FDD terminal station is then given by

$$P_{\text{AC}} = \frac{T_{\text{Overlap}}}{T_{\text{P,V}}} \sum_{k=1}^{K} G_k \alpha_{k,n} P_k \ . \qquad \text{(A4.16)}$$

where K is the total number of TDD terminals stations radiating within the colliding n^{th} TDD uplink sub-frame and in the spatial proximity (e.g., within a 25 m radius) of the receiving FDD terminal station, and G_k is the aggregate path-gain (including receive antenna gain) from the k^{th} TDD terminal station to the receiving FDD terminal station.

Note that P_{AC} is the total received interferer power generated by the TDD terminal stations radiating in all the adjacent frequency blocks respectively. Synchronised uplink/downlink phases are assumed across the TDD blocks, with the base station scheduling phases randomised among different TDD blocks. The adjacent-channel interference experienced by the FDD terminal station may then be written as

$$P_{\text{I,AC}} = \frac{T_{\text{Overlap}}}{T_{\text{P,V}}} \sum_{k=1}^{K} \frac{G_k \alpha_{k,n}}{A_k} P_k \ , \qquad \text{(A4.17)}$$

where A_k is the adjacent-channel interference ratio (ACIR)[42] associated with the radio link from the k^{th} TDD terminal station to the FDD terminal station. This accounts for interferer radiation masks and non-ideal receiver frequency discrimination, and is a function of the frequency offset between interferer and victim (see Table 10).

The SINR at the FDD terminal station receiver (and hence the FDD downlink throughput) can then be computed by substituting Equation (A4.17) into Equation (A4.11).

The modelling of saturation and inter-modulation effects are described next.

Saturation

The components in the receiver chain of a FDD terminal station are unable to deal with arbitrarily large signal levels. If the absolute values of the received adjacent-channel signals are beyond a certain threshold the receiver will be overloaded or saturated. The performance of the receiver is difficult to model in such circumstances. In our model we assume that the saturation of the receiver would result in a zero radio link throughput.

As illustrated in Figure 21 of Section (5), the FDD terminal station's receiver is to some extent protected from certain adjacent-channel interferers by its front-end (duplex) filter. The extent of this protection depends on whether the adjacent-channel interferers fall within the pass-band, transition-band, or stop-band of the front-end filter. Based on this formulation, the FDD downlink throughput is assumed to fall to zero if

$$P_{\text{X}} = \frac{T_{\text{Overlap}}}{T_{\text{P,V}}} \sum_{k=1}^{K} G_k G_{\text{X},k} \alpha_{k,n} P_k \ > \ \Pi_{\text{Sat}} \, , \qquad \text{(A4.18)}$$

where $G_{\text{X},k} \leq 1$ is the gain of the FDD terminal station's front-end filter at the frequency of the k^{th} TDD terminal station interferer, Π_{Sat} is the adjacent-channel power threshold beyond which the FDD terminal station

[42] The ACIR is defined as the ratio of the power of an adjacent-channel interferer as received at the victim, divided by the interference power experienced by the victim receiver as a result of both transmitter and receiver imperfections.

can be assumed to be saturated, and P_X is the total adjacent-channel interferer power at the output of the front-end filter.

Measurements [6] of commercially available UTRA-FDD user equipment in the 2.1 GHz band suggest that Π_{Sat} is approximately −10 dBm in practice. This value is used in our modelling of saturation effects.

We account for the roll-off of the front-end filter via gains, $G_{X,k}$, of 0, −4, −8, and −12 dB for interferers in frequency blocks #24, #23, #22, and #21 respectively. Interferers in frequency blocks #35, #36, #37, and #38 fall within the pass-band of the front-end filter (which nominally spans from 2620 to 2690 MHz) and $G_{X,k}$ = 0 dB for interferers in these frequency blocks.

<u>Inter-modulation</u>

Let $P_{I,IM}$ be the interference power experienced by the FDD terminal station receiver as a result of co-channel third-order inter-modulation products generated by adjacent-channel interferers received at aggregate powers of P_{AC1} and P_{AC2}, and at frequency offsets Δf and $2\Delta f$ from the wanted signal carrier. It can be shown that

$$P_{I,IM} = \lambda P_{AC1}^2 P_{AC2}, \tag{A4.19}$$

where λ is a constant of proportionality.

Let us also assume that the third-order inter-modulation products generated by equal-power adjacent-channel interferers, each received at power Π_{AC}, and at frequency offsets Δf and $2\Delta f$ respectively from the wanted signal carrier, result in a 3 dB desensitisation of the receiver with respect to the receiver's reference sensitivity performance[43]. By definition, the 3 dB desensitisation implies that the inter-modulation interference power experienced by the receiver is equal to the thermal noise power, P_N; i.e., that,

$$P_N = \lambda \Pi_{AC}^2 \Pi_{AC} \tag{A4.20}$$

where $P_N = k\,T\,B\,\mathrm{NF}_{TS}$, k is Boltzmann's constant, T is the ambient temperature, B is the receiver's noise-equivalent bandwidth, and NF_{TS} is the receiver's noise figure.

Dividing Equation (A4.19) by Equation (A4.20), we have

$$P_{I,IM} = \left(\frac{P_{AC1}}{\Pi_{AC}}\right)^2 \left(\frac{P_{AC2}}{\Pi_{AC}}\right) P_N . \tag{A4.21}$$

In summary, Equation (A4.21) describes the experienced inter-modulation interference, $P_{I,IM}$, as a function of the aggregate adjacent-channel interferer powers, P_{AC1} and P_{AC2}, given the reference adjacent-channel power, Π_{AC}, and the thermal noise power P_N.

Note that the adjacent-channel interferer aggregate powers, P_{AC1} and P_{AC2} are computed by application of Equation (A4.18) in each of the relevant frequency channels respectively[44].

The interference power, $P_{I,IM}$, is substituted into the denominator of Equation (A4.11) in order to compute the downlink SINR at the FDD terminal station. In scenarios where interferers in more than two adjacent channels are involved (e.g., see Figure 21), we apply Equation (A4.21) to every pair of channel offsets which can give rise to inter-modulation products that are co-channel with the wanted signal, and then add the results prior to substitution into the denominator of Equation (A4.11).

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[43] Reference sensitivity performance refers to the case where the only source of degradation in the receiver is additive thermal noise.

[44] The interferer powers P_{AC1} and P_{AC2} are usually cited as measured at the antenna connector, and as such, strictly speaking, should be calculated via Equation A4.16. However, Equation A4.18 is more appropriate in the context of dealing with "out of band" interferers. This is because the front-end filter gains $G_{X,k}$ in Equation A4.18 correctly account for the fact that interferers in frequency blocks #21 to #24 are attenuated prior to their processing by the active elements of the FDD terminal station receiver.

The reference power, Π_{AC}, of the adjacent-channel interferers can be derived either from the relevant minimum requirement specifications in technical standards, or via direct measurement of FDD terminal station receivers.

For example, 3GPP TS 25.101 specifies that the inter-modulation characteristics of a FDD terminal station receiver should be such that the reception of two interferers, each at a level of –46 dBm and at frequency offsets of 10 and 20 MHz from the wanted carrier, should at most result in a 3 dB desensitisation with respect to the reference sensitivity performance; i.e., $\Pi_{AC} = -46$ dBm.

Measurements [6] of commercially available UTRA-FDD user equipment in the 2.1 GHz band suggest that Π_{AC} is closer to –30 dBm in practice. This value is used in our modelling of inter-modulation effects.

ANNEX 4: REFERENCES

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[4] ECC/DEC/(05)05 of 18 March 2005 on harmonised utilisation of spectrum for IMT-2000/UMTS systems operating within the band 2500-2690 MHz.

[5] R&TTE Directive, Directive 1999/5/EC, on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity.

[6] ERA Technology, "Measurements of UTRA-FDD user equipment characteristics in the 2.1 GHz band," final report, April 2008. Document is available at: http://www.ofcom.org.uk/consult/condocs/2ghzregsnotice/.

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[8] "TGn Channel Models (IEEE 802.11-03/940r2)," High Throughput Task Group, IEEE P802.11, 15 March 2004.