3 GPP TSG RAN WG4#3 Tdoc 96/99
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Title: TDD/FDD co-existence investigation – summary of results

1 Introduction

Within the ETSI SMG2 L1 group detailed investigations were made in order to determine the ACP requirements for the FDD mode based on the assumption that 5 MHz carrier spacing is used. In particular [1] gives detailed recommendations on carrier spacing in FDD mode for the intra- and inter-operator case. First results for TDD/FDD co-existence were presented in [8]. This contributions aims to give a more complete set of results based on extensive simulations, that have been carried out to determine the probability of coupling losses in different environments (macro, micro, pico), cf. [2], [3]. The results address the FDD/TDD scenarios $MS_{FDD} \rightarrow MS_{TDD}$, $MS_{FDD} \rightarrow BS_{TDD}$ and $MS_{TDD} \rightarrow BS_{FDD}$ case. To give a more comprehensive picture in addition TDD/TDD co-existence was simulated for the $MS_{TDD} \rightarrow BS_{TDD}$ case and finally FDD/FDD co-existence was simulated for the $MS_{FDD} \rightarrow BS_{FDD}$ case. Results show the cumulative density function (CDF) of C/I.

2 Simulation description

2.1 General

As mentioned in the introduction the implemented method is not exactly the same as in [1]. A fixed carrier spacing of 5 MHz is applied in all cases. The spectrum masks for BS and MS have been assumed for both TDD and FDD mode as given in the following pictures:

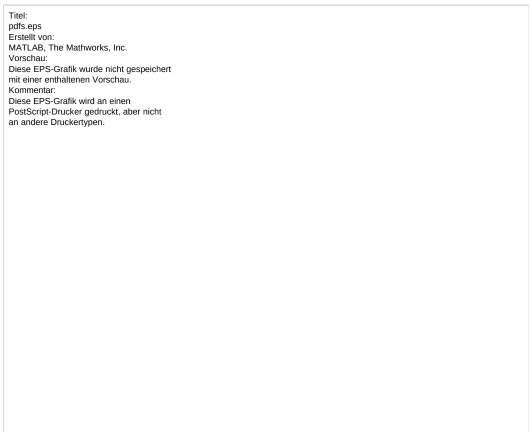


*Figure **Error! Unknown switch argument.** BS and MS spectrum mask I*

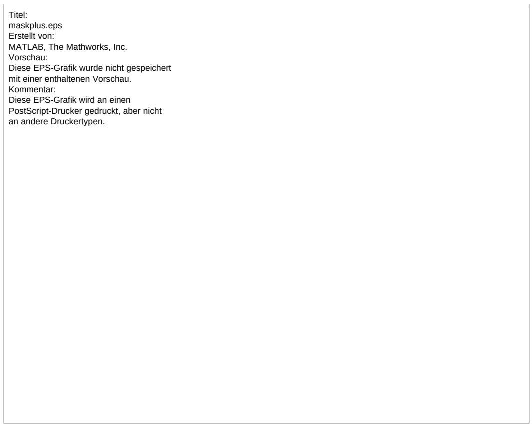


*Figure **Error! Unknown switch argument.** BS and MS spectrum mask II*

During the February Turin meeting WG4 agreed a definition to characterise the power leakage into adjacent channels caused mainly due to transmitter non-linearities. The agreed definition is:

Adjacent Channel Leakage power Ratio, ACLR = The ratio of the transmitted power to the power measured after a receiver filter in the adjacent RF channel. Both the transmitted power and the received power are measured within a filter response that is nominally rectangular, with a noise power bandwidth equal to the chip rate.

Following the above definition the ACLR for the spectrum mask I and II in figure 1/2 are:

$ACLR_{MS,\ mask\ I}$ = 40.38 dB $ACLR_{MS,\ mask\ II}$ = 35.39 dB

$ACLR_{BS,\ mask\ I}$ = 55.35 dB $ACLR_{MS,\ mask\ II}$ = 35.39 dB

Furthermore maximum the transmit powers for BS and MS are suggested as given in the following table. The figures are defined according to the three environments assuming that a speech user occupies one slot and one code in TDD and one frame and one code in FDD.

Table ***Error! Unknown switch argument.*** *BS and MS transmit power*

Scenario	**TDD**		**FDD**	
	MS	**BS**	**MS**	**BS**
Pico	21 dBm	27 dBm	14 dBm	20 dBm
Micro	21 dBm	27 dBm	14 dBm	20 dBm
Macro	30 dBm	36 dBm	21 dBm	27 dBm

On the receiver side an ideal RRC filter (α = 0.22) has been implemented according to [4]. The transfer function H(f) of the filter is given in the following picture:

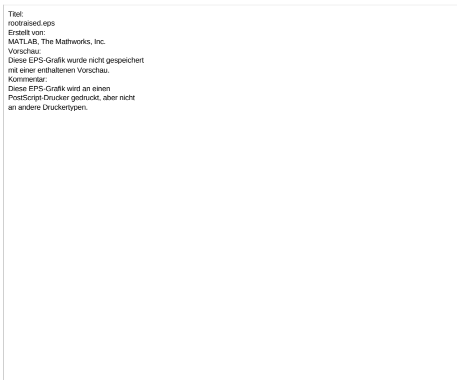


Figure ***Error! Unknown switch argument.*** *Transfer function of the receive filter*

WG4 agreed on an Adjacent Channel Selectivity (ACS) definition during it's Turin meeting as follows:

Adjacent Channel Selectivity, ACS: Adjacent Channel Selectivity is a measure of a receiver's ability to receive a signal at its assigned channel frequency in the presence of a modulated signal in the adjacent channel. ACS is the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent channel frequency. The attenuation of the filter on the assigned and adjacent channels is measured with a filter response that is nominally rectangular, with a noise power bandwidth equal to the chip rate.

Following the above definition the ACS becomes infinity with the implemented filter since an ideal root-raised cosine was used. The implementation of real filters is foreseen in the next step of simulation runs.

Simulation results with and without power control are included. In the first step a simple C based power control algorithm has been used. The PC algorithm controls the transmit power in the way to achieve sensitivity level at the receiver. The power control range is assumed to be 80 dB in the uplink and 30 dB in the downlink, respectively. The power control step size is 1 dB for both MS and BS.

2.2 Macro cell scenario

2.2.1 Evaluation method

Since for the macro scenario a hexagonal cell structure is assumed, a Monte-Carlo method has been chosen for evaluation. Each Monte-Carlo (MC) calculation cycle starts with the positioning of the receiver station (disturbed system) by means of an appropriate distribution function for the user path. The interfering (mobile) stations are assumed to be uniformly distributed. The density of interferers is taken as parameter. To start up we assume that only the closest user of the co-existing disturbing system is substance of the main interference power. However to judge the impact of more than the one strongest interferer, some simulation cases are performed with the 5 strongest interferer stations. In simulations behind it was shown that taking into account more than 5 will not change the simulation results. In addition (compared to the coupling loss analysis in[2] and [3]) a transmitter station in the disturbed system and a receiver station in the interfered system are placed, i.e. communication links in both systems are set up. At each MC cycle the pathloss between the disturbed receiver and the next interfering station as well as the pathloss for the communication links are determined according to the pathloss formula given in the next section. Depending on the use of power control the received signal level C at the receiver station in the disturbed system is calculated. Finally the interference power I is computed taking into account the transmit spectrum mask and the receiver filter. C/I is then substance to the staistical evaluation giving the CDF.

2.2.2 Pathloss formula

The pathloss formula for the **Macro Vehicular Environment Deployment Model** is implemented to simulate the MS ↔ BS case (10 dB log-normal standard deviation, see B.1.6.4.3 in [5]). Both 2000m and 500m cell-radii are considered. The simulation does not support sectorised antenna patterns so an omnidirectional pattern is used. However [5] was generated before the evaluation phase of different concepts for UTRA, which were all FDD based systems. Therefore [5] does not name propagation models for all possible interference situations. E.g. considering TDD the mobile to mobile interference requires a model valid for transmitter and receiver antennas having the same height. In order to cover this case the outdoor macro model in [3] was used. The model is based on path loss formula from H. Xia considering that the height of the BS antenna is below the average building height. This is seen as reasonable approximation of the scenario. Furthermore it has to be considered that mobiles might be very close to each other, i.e. in LOS condition, which leads to considerably lower path loss. To take this effect into account LOS and NLOS is randomly chosen within a distance of 50m (100m) for MS – MS (BS – MS) interference whereas the probability for LOS increases with decreasing distance. Details can be found in [3].

2.2.3 User density

The user density of the TDD system is based on the assumption that 8 slots are allocated to DL and UL, respectively. Considering 8 or 12 codes per slot this yields 64 / 96 channels per carrier corresponding to 53.4 / 84.1 Erlang (2% blocking). Taking into account that users are active within only one slot and that DTX is implemented we reach effective user densities of 5.14/km² / 8.10/km² for the 500m cell radius (cell area = 0.649 km²) and 0.32/km² / 0.51/km² for the 2000m cell radius (cell area = 10.39 km²), respectively. Note that these figures "sound" rather small, since we concentrate on one slot on one carrier. However if an average traffic of 15mE per user is assumed, these figures lead to 5484 real users per km² / 8636 real users per km². It should be emphasised that this investigations regards user on a single carrier at adjacent frequencies, since users on the second adjacent frequency will be protected by higher ACP figures. In addition one TDD carrier per operator is a very likely scenario at least in the first UMTS start-up phase.

The user density of the FDD system is based on the ITU simulation results given in [6]. For the macro environment 88 Erlang per carrier lead to an effective user density of 4.23/km² and 67.7/km² for the 200m cell and 500m cell respectively. Note that in FDD all users are active during the entire frame.

2.3 Micro cell

2.3.1 Evaluation method

For the **Micro Pedestrian Deployment Model**, a Manhattan-grid like scenario has been generated. A 3x3 km² area with rectangular street layout is used. The streets are 30m wide and each block is 200m in length. This is in accordance to B.1.6.4.2 in [5].

In the microcellular environment evaluation a detailed event-driven simulation tool is used. A street-net is loaded into the simulator (according to [5]). A given number of mobiles is randomly distributed over the street-net with a randomly chosen direction. These mobiles move with a maximum speed of 5 km/h along the streets. If they come to a crossing there is a probability of 0.5 for going straight across the crossing and a probability of 0.25 for turning left and right respectively. If there is another mobile in the way, a mobile slows down to avoid a collision. This results in a distribution of the speed that comes close to the one described in [5]. Mobiles coming from the right may cross a crossing first. The model simulates the behaviour of cars and pedestrians in a typical Manhattan-grid layout. Based on the observed coupling loss the received signal C and the interference power I are determined in the same way as described for the macro scenario.

2.3.2 Pathloss formula

Using the propagation model presented in [7] by J.E.Berg, only one corner is considered, i.e. propagation along more than one corner results in an attenuation above 150 dB and is therefore negligible. The log normal standard deviation used is 10 dB.

2.3.3 User density

Starting again from 64 and 96 users per slot for TDD, we reach an effective user density of 129.36 per km² and 203.73 per km2, respectively (e.g. 64 users → 53.4 Erlang → 6.675 Erlang per slot → 258.72 Erlang per km² (cell area = 0.0258 km², due to 72 BSs covering the streets) → 129.36 effective users (DTX)). Assuming on average 25mE per user this will lead us to 82791 and 130388 users per km², which might be slightly too high in a real scenario. For that reason simulation cases for 10000, 5000 and 1000 user per km² are added.

2.4 Pico cell

2.4.1 Evaluation method

The third scenario studied is the **Indoor Office Test Environment Deployment Model**. This scenario is referenced as the **Pico**-scenario. It is implemented as described in B.1.6.4.1 of [5]. The office rooms give in principle a cell structure similar to the macro environment case, because only one floor without corridors is implemented. For that reason the evaluation method used is the same as in macro based on Monte-Carlo simulations.

2.4.2 Pathloss formula

The indoor path loss formula given in [5] was implemented (log-normal standard deviation 12dB). However it is taken care that the coupling loss is not less than 38 dB, which corresponds to a 1m free-space loss distance.

2.4.3 User density

Some reasonable assumptions have been made on the user density in the pico cell scenario. If we take straight forward the ITU simulation results based on [5] e.g. for FDD, we reach 220000 active users per km² (88 Erlang per BS, BS serves two rooms, i.e. 2*10m*10m = 0.0002 km² with DTX = 0.5 → 220000 active users per km²). Assuming further on average 300mE per user, there should be 29.333.333 users per km², which is not very realistic. For the simulations we added a 10000 active users per km² case in FDD.

Starting from a realistic scenario we assumed that each user in a room occupies 10m² yielding 10 user per room or 100000 user/km². For TDD we get 100000/8 *0.5 (DTX) = 6250 users per slot, which leads under the assumption of 100mE per user to 625 active users per km². This is the lowest user density referred to in the simulation results section. To judge the impact on the results the user density is increased up to almost 10000 active users per km².

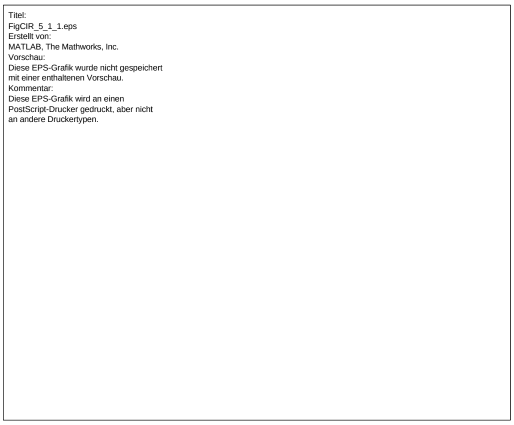
3 Simulation results for TDD/FDD co-existence

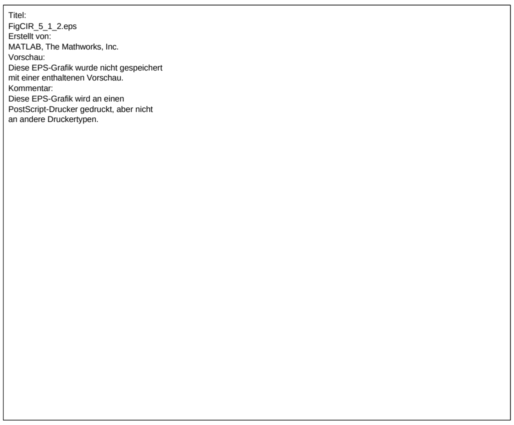
3.1 Macro cell scenario

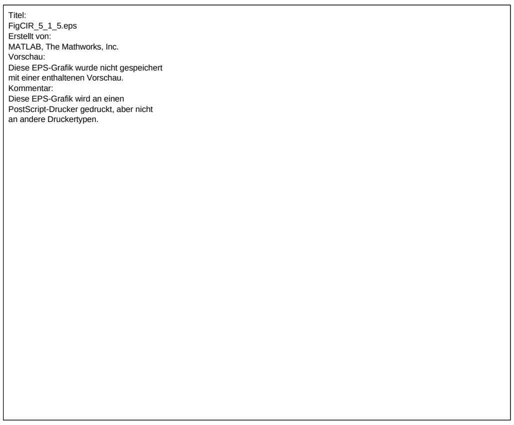
For the macro environment all simulations cases were run with the spectrum mask II, cf. section General.

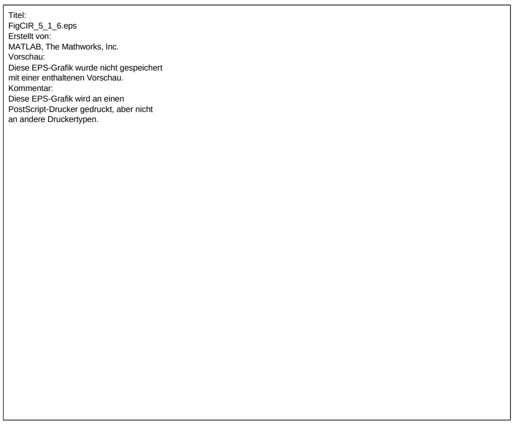
3.1.1 MS_{TDD} interferes BS_{FDD}

In the following the results with and without power control are given for both cell sizes.









Certainly power control improves the results. However in all cases the probability that the BS_{FDD} experiences C/I lower than -23 dB (requirement for the speech service in the uplink) is very low.

In addition simulations were run to take into account the five strongest interferer stations for the small cell size (with and without power control).

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FigCIR_5_5_1.eps
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The impact is visible at higher C/I figures, e.g. if we compare the no PC case, the probability of C/I figures higher than 0 dB increases from 16% to about 20% (medium subscriber density) if more than the one strongest interferer is taken into account. However if we look to the shape of the curves at low C/I figures (close to those required for the speech service) the difference can hardly be noticed.

3.1.2 MS_{FDD} interferes MS_{TDD}

In the following the results with and without power control are given for both cell sizes.

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Again power control improves the results. According to the ITU simulation results a TDD receiver needs about C/I = –5dB for speech. The probability of smaller figures is very low.

3.2 Micro cell scenario

For the micro cell scenario spectrum mask I, cf. section General, was used. In any case the strongest interferer was subject to the statistical evaluation of C/I.

3.2.1 MS_{TDD} interferes BS_{FDD}

In the following the results with and without power control are given.

Titel:
Fig1.eps
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Variations due to the implemented event-driven model are more visible at lower user densities. However no critical C/I figures are observed.

3.2.2 MS_{FDD} interferes MS_{TDD}

In the following the results with and without power control are given.

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Results show high C/I at all user densities, since statistics are relevant to both TDD and FDD MS. Furthermore the output power of the disturbing entity (MS_{FDD}) is low compared to the MS_{TDD}.

3.3 Pico cell scenario

For the pico environment all simulations cases were run with the spectrum mask II, cf. section General.

3.3.1 MS_{TDD} interferes BS_{FDD}

In the following the results with and without power control are given.

Titel:
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Obviously the power control impact is very high in this scenario, since cell sizes and thus transmit powers become very small. However even without power control C/I is more than sufficient at all user densities.

3.3.2 MS_{FDD} interferes MS_{TDD}

In the following the results with and without power control are given.

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The results are much better (even without power control) than in the $MS_{TDD} \leftrightarrow BS_{FDD}$ case, because the MS_{FDD} transmit power is lower than the MS_{TDD} transmit power and the sensitivity of the BS_{FDD} is better than the MS_{TDD} sensitivity.

Again in addition simulations were run to take into account the five strongest interferer stations (with and without power control).

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The probability for C/I lower than 45 dB (with power control at highest user density) is increased from 16% to about 30%. However even taken into account 5 interferer does not lead to C/I figures below the required ones.

4 Simulation results for TDD/TDD co-existence

4.1 Macro cell scenario

4.1.1 MS_{TDD} interferes BS_{TDD}

In the following the results with and without power control are given for both cell sizes.

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In particular for the no power control case rarely C/I lower than –5 dB occurs. Note that in TDD to TDD interference it is possible to change/allocate a different time slot, i.e. to avoid high interference in the time domain.

4.2 Micro cell scenario

4.2.1 MS_{TDD} interferes BS_{TDD}

In the following the results with and without power control are given.

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Again the impact of the power control is significant and the “nature” of the event driven simulation tool can be seen at lower user densities. C/I figures lower than –5 dB as required for speech services don’t occur at all.

4.3 Pico cell scenario

4.3.1 MS_{TDD} interferes BS_{TDD}

In the following the results with and without power control are given.

Titel:
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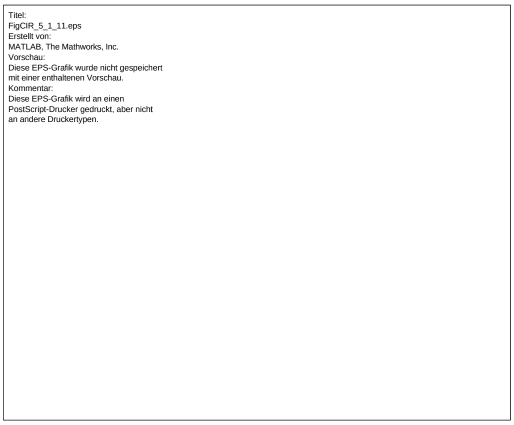
No critical C/I figures occur even not at high user densities and without power control.

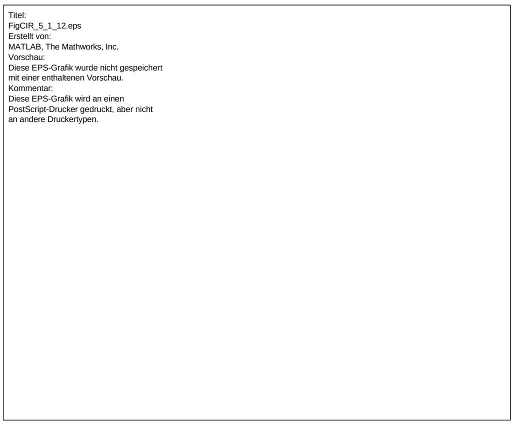
5 Simulation results for FDD/FDD co-existence

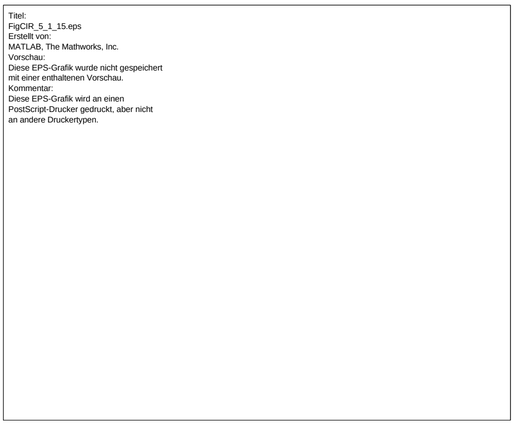
5.1 Macro cell scenario

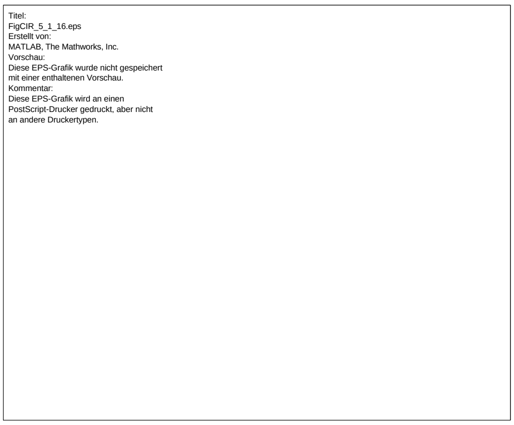
5.1.1 MS_{FDD} interferes BS_{FDD}

In the following the results with and without power control are given for both cell sizes.







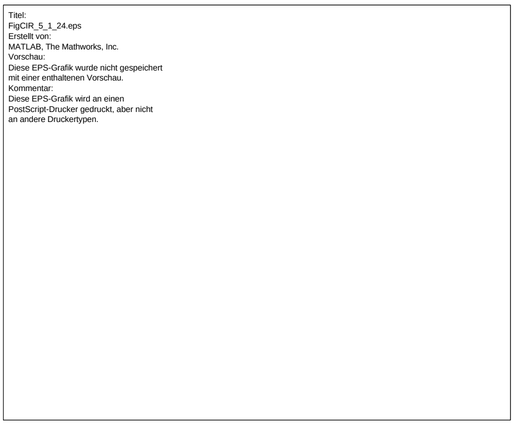


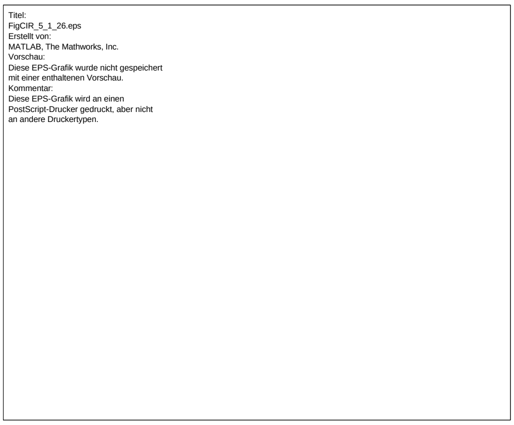
The impact of the power control is rather small in the 2000m cell radius case, since this cell size requires high powers for most users.

5.2 Pico cell scenario

5.2.1 MS_{FDD} interferes BS_{FDD}

In the following the results with and without power control are given.





6 Conclusion

Detailed simulations have been carried out to investigate the FDD/TDD co-existence interference. All interference scenarios simulated so far showed that co-existence with 5MHz spacing between FDD and TDD is possible. However the BS – BS scenario is missing, since this is independent of any statistical investigation. A separate investigation is needed to cover this particular topic.

7 Outlook

It is intended to continue the work by implementing a more sophisticated power control algorithm (C/I based). Furthermore comments received during the discussion at TSG RAN WG4#2 will be considered as far as possible, e.g. the implementation of non-ideal receive filter.

8 References

[1]: SMG2 UMTS L1 Tdoc 562 " Summary of UKTAG Document on FDD Guard Bands", UKTAG
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[3]: SMG2 UMTS L1 Tdoc 679/98 "Coupling loss analysis for UTRA – additional results", Siemens
[4]: SMG2 UMTS L1 XX.05 v 0.6.0 "UTRA FDD, spreading and modulation description"
[5]: ETSI TR 101 112 V3.2.0 UMTS 30.03
[6]: Evaluation Report for ETSI UMTS Terrestrial Radio Access (UTRA) ITU-R RTT Candidate (September 1998), Attachment 5
[7]: J.E. Berg, "A Recursive Model For Street Microcell Path Loss Calculations", International Symposium on Personal Indoor and Mobile indoor Communications (PIMRC) '95, p 140 – 143, Toronto
[8]: TSG RAN WG4#2 Tdoc 53/99 "TDD/FDD co-existence investigation", Siemens