

# EVALUATION OF INTERFERENCE BETWEEN UPLINK AND DOWNLINK IN UTRA/TDD

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## ABSTRACT

An ideal TDD system offers high capacity, dynamic asymmetry between uplink and downlink and no co-ordination requirements between operators and base stations. This paper studies the performance of UTRA/TDD and how close to the ideal TDD system UTRA/TDD could be. Since both uplink and downlink share the same frequency in TDD, those two transmission directions can interfere with each other. This interference can occur between two mobile stations or between two base stations within one carrier or between two operators. This interference scenario is evaluated here. The results show that for UTRA/TDD operation dynamic channel allocation, synchronization of base stations and co-operation between the operators is preferred to obtain the maximum performance. The most difficult interference situations occur between base stations within one operator's band and between two operators if they are not synchronized.

## 1. INTRODUCTION

In ETSI the chosen air interface for the 3<sup>rd</sup> generation system (UMTS Terrestrial Access, UTRA) is WCDMA for paired FDD (frequency division duplex) bands and TD/CDMA for unpaired TDD (time division duplex) bands. The technology selection and the refinement work has been moved to 3GPP (3<sup>rd</sup> Generation Partnership Project) for standard creation. UTRA/FDD suits for large coverage areas and it is also able to provide bit rates up to 2 Mbps in small cells. UTRA/TDD is particularly well suited for small cells and for asymmetrical traffic. The FDD and TDD components are harmonized to a large degree to ease the dual mode implementation. The

spectrum allocation for UMTS is shown in Figure 1: for FDD 2x60 MHz and for TDD 15+20 MHz.

This paper studies the performance of UTRA/TDD and how close to the ideal system UTRA/TDD could be. The effect of inter-cell interference and inter-operator interference on the UTRA/TDD performance is evaluated in this paper together with a few solutions to avoid and tackle the problems.

## 2. UTRA TDD PHYSICAL LAYER

The physical layer of UTRA/TDD is a combination of TDMA and CDMA access methods [1]. The 10 ms frame is divided into 15 time slots, each of which can support parallel CDMA spreading codes with a maximum spreading factor of 16. The channel estimation is based on the midamble code. The downlink frame and slot structure is shown in Figure 2. UTRA TDD physical layer has a support for asymmetrical capacity allocation between uplink and downlink. The maximum asymmetry is 13:2.

The UTRA/FDD and TDD components are harmonized to a large degree including the following common features:

- Chip rate 3.84 Mcps
- Slot length 2/3 ms, frame length 10 ms, multiframe 720 ms
- Modulation QPSK, pulse shaping root-raised cosine
- Similar coding and service multiplexing solutions
- Harmonized higher layer protocols
- Identical protocol termination points
- Frequency reuse 1

Harmonization of TDD with FDD eases the dual mode terminal implementation, especially RF parts and the dual FDD/TDD network implementation.

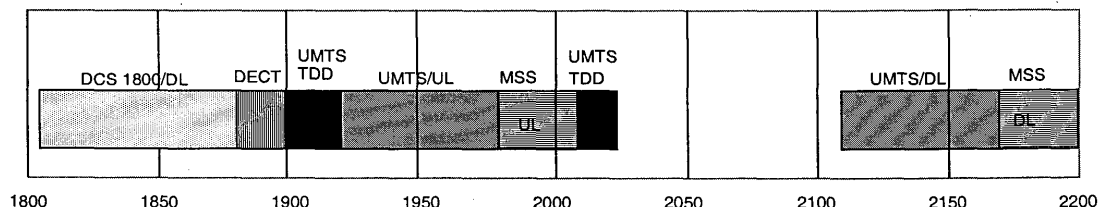


Figure 1. UMTS spectrum allocation, UL=uplink, DL=downlink, MSS=mobile satellite band

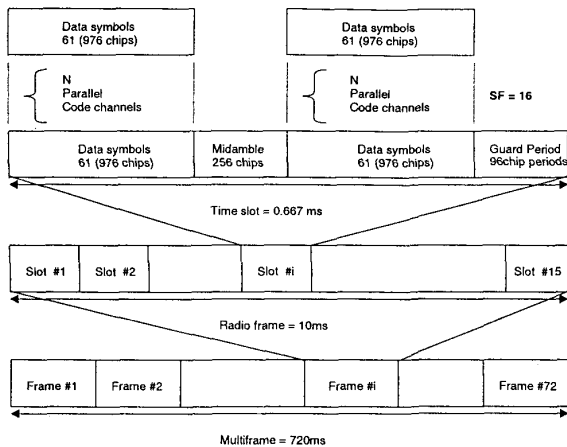


Figure 2. Downlink frame/slot structure

There are a few differences in the physical layers between UTRA/FDD (also denoted is Direct-Sequence (DS) mode in some publications) and TDD modes. Those differences are listed in Table 1.

Table 1. Differences between UTRA FDD and TDD modes

|                                 | FDD                                  | TDD                                                           |
|---------------------------------|--------------------------------------|---------------------------------------------------------------|
| Maximum power control frequency | 1.5 kHz                              | 100-800 Hz depending on service and asymmetry                 |
| Detection in the receiver       | Rake receiver                        | Support and need for JD                                       |
| TDMA component                  | No, continuous transmission          | Yes, DCA possible                                             |
| Resource allocation             | Variable spreading factor, 1-4 codes | Variable spreading factor, 1-9 codes and 1 or more time slots |
| Spreading factor                | 4..256                               | 1..16                                                         |

JD = Joint Detection

DCA = Dynamic Channel Allocation

### 3. IDEAL TDD SYSTEM

An ideal TDD system for an operator should have the following properties:

- High capacity
- Dynamic asymmetry between uplink and downlink capacities
- Cell and operator independent asymmetry without coordination
- No synchronization requirements between base stations and between operators
- Support for unlicensed operation

This paper studies how close to such an ideal TDD system UTRA/TDD can be.

### 4. INTERFERENCE BETWEEN UPLINK AND DOWNLINK IN TDD

Since both uplink and downlink share the same frequency in TDD, those two transmission directions can interfere with each other. This kind of interference occurs if the base stations are not synchronized. The interference is present also if a different asymmetry is used between uplink and downlink in adjacent cells even if the base stations are frame synchronized. Frame synchronization requires an accuracy of a few symbols, not an accuracy of chips.

The interference between uplink and downlink can also occur between adjacent frequencies. Therefore, the interference between uplink and downlink can take place within one operator's band, and also between two operators.

The interference between uplink and downlink can occur between two mobile stations and between two base stations. In FDD operation the duplex separation prevents the interference between uplink and downlink. The interference between a mobile station and a base station is the same both in TDD and in FDD operation, and that interference scenario is not considered in this paper.

#### 4.1. Mobile-to-mobile interference

Mobile-to-mobile interference occurs in Figure 3 if the mobile M2 is transmitting and the mobile M1 is receiving in the same (or adjacent) frequency in adjacent cells. Mobile-to-mobile interference is statistical because the locations of the mobiles cannot be controlled. Therefore, mobile-to-mobile interference cannot be avoided completely by the network planning.

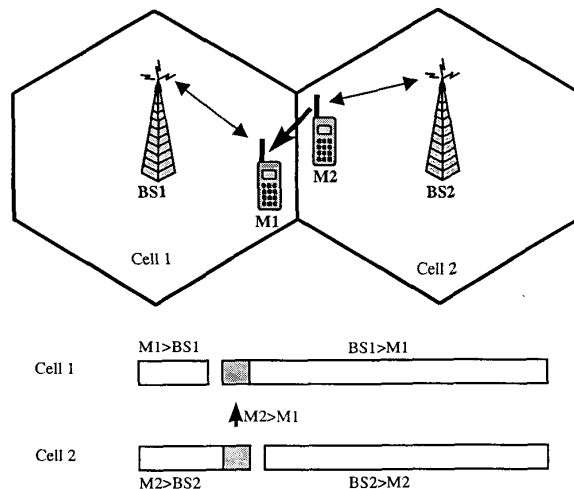


Figure 3. Mobile-to-mobile interference at the cell border

## 4.2. Base station-to-base station interference

Base station-to-base station interference occurs in Figure 4 if the base station BS1 is transmitting and the base station BS2 is receiving in the same (or adjacent) frequency in adjacent cells. Base station-to-base station interference depends heavily on the path loss between the two base stations, and therefore, the network planning greatly affects this interference scenario.

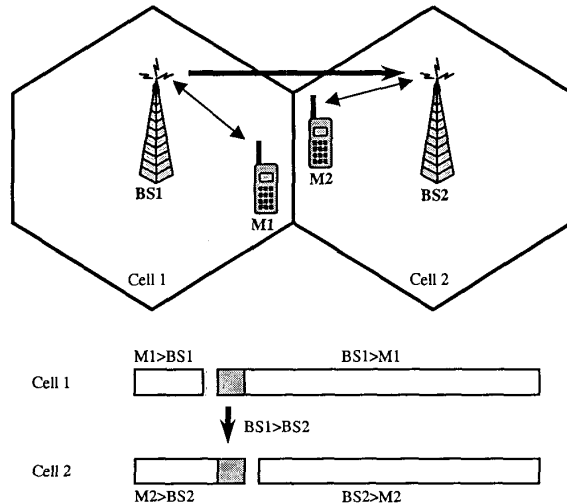


Figure 4. Base station-to-base station interference

## 5. INTRA-OPERATOR INTERFERENCE

A simulation platform was generated to evaluate the interference scenarios in TDD operation. The simulation first generates two cells, the cell causing the interference, and the one experiencing it. Hexagonal cells were used so that the two cells can be made adjacent without overlaps. A random distribution of the mobiles within the interfering cell was used. The simulation scenario is shown in Figure 5. In Figure 5 the left cell is the cell experiencing the interference and the right one includes a few random test locations where the test interference is generated. Each simulation run consists of a large number of test locations. A path loss exponent of 3.7 and slow fading with 12 dB standard deviation has been assumed both between the mobile stations and between the base stations. The outage probabilities are evaluated for those time slots where uplink and downlink transmission occurs at the same time in adjacent cells.

### 5.1. Mobile-to-mobile interference

Mobile-to-mobile interference within one operator's band occurs at the cell borders. Figure 6 shows the percentage of the cell area where the outage probability exceeds the required maximum levels (1%, 2%, 5% or 10%) as a function of the base station separation. In case of continuous coverage the base station separation is equal to the twice cell radius. Using that base station separation, an outage level of 2% is exceeded in about 8% of the cell area.

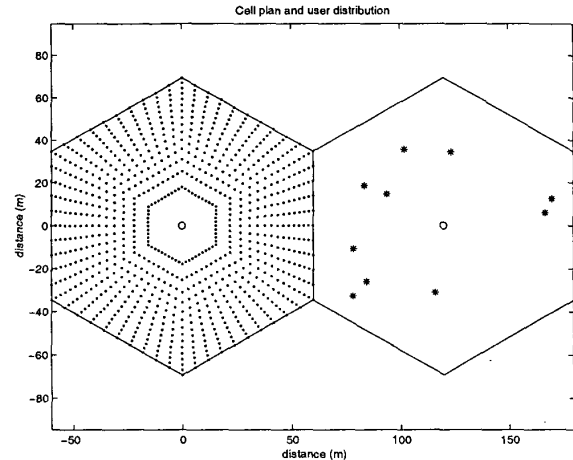


Figure 5. Simulation scenario

One solution for this problem is to use intelligent dynamic channel allocation (DCA) techniques. In DCA such time slots are selected for the connection where the interference levels are low enough. DCA can be applied because UTRA/TDD mode includes a TDMA component. DCA is used also, for example, in DECT system. It should be noticed that DCA is effective only if a few time slots are used for the connection, i.e. for low bit rate connections. DCA does not work properly for those connections where multiple time slots are used. The maximum bit rate with one slot in UTRA/TDD is 144 kbps.

If the TDD system is not targeted for providing a continuous coverage, the interference problems can be greatly reduced by keeping the base station separation large.

### 5.2. Base station-to-base station interference

The interference between base stations depends on the base station locations. In Figure 7 the outage probability is shown as a function of the base station separation. It is assumed that the path loss formula between two base stations is the same as between a base station and a mobile station. For continuous coverage (base station separation = 2 x cell radius) the outage probability is about 28%. Such a high outage probability indicates that the adjacent cells need to be synchronized and they need to have the same asymmetry.

By introducing an additional 12 dB protection between the adjacent base stations in Figure 7, the outage probability is reduced from 28% to 8%. The 12 dB protection is still not enough to bring the outage probability to reasonably small figures but more protection is desirable. This additional protection was assumed to be obtained by antenna direction or antenna tilting or by careful network planning.

The interference between base stations can be particularly strong if the path loss is low between the base stations. Such cases could occur, e.g. in macro cell, if the base stations are located in masts above the rooftops.

## 6. INTER-OPERATOR INTERFERENCE

### 6.1. Mobile-to-mobile interference

The inter-operator interference between mobiles can occur anywhere where two operators' mobiles are close to each other and transmitting with a fairly high power. An adjacent channel protection of 35 dB has been assumed in this work.

The percentage of the cell area where problems exist is only less than 0.5% if the required outage probability is 2%. The mobile-to-mobile interference between operators is not a problem if the mobiles are equally distributed over the cell area since the adjacent channel protection mitigates the problem. Mobile-to-mobile interference is more difficult within one carrier. Mobile-to-mobile interference, however, can be more difficult than shown here if the mobiles are not equally distributed but are close to each other, e.g. in meeting rooms.

### 6.2. Base station-to-base station interference

The interference between two TDD operators' base stations is shown in Figure 8. The outage probability increases to very high values if the different operators' base stations are located close to each other. If the base stations are co-located, the interference levels will be intolerable. These outage probabilities show that co-operation between TDD operators' network planning is required or the networks need to be synchronized and the same asymmetry need to be applied. Otherwise, the overall capacity for each user is, at best, effectively halved. Note that in FDD operation the inter-operator interference can be best avoided by co-locating the base stations.

One solution to avoid inter-operator interference is to use very high requirements for the adjacent channel filtering. With the technology level after a few years it is, however, not possible to considerably improve the filtering characteristics to obtain higher adjacent channel protection values than about 35 dB.

From the synchronization and co-ordination point of view, the higher the transmission power levels and the larger the intended coverage area, the more difficult will be the co-ordination for the interference management. Especially, macro-cell type of antenna locations easily result to a line-of-sight connection between base stations causing strong interference.

## 7. TDD OPERATION IN FDD UPLINK BAND

If there is less traffic in the uplink direction in UTRA/FDD than in downlink direction, part of the uplink spectrum could be utilized for TDD operation. According to [2] TDD operation should not be prohibited in FDD uplink band.

If TDD is used in FDD uplink, the TDD base station transmission can interfere the reception in FDD base station. The interference analysis can be taken from Section 6.2. Therefore, we can notice that the co-location of operator's TDD and FDD base stations is difficult if TDD is operated in FDD uplink band. It should be noticed

that DCA techniques are not effective against FDD interference since FDD transmission is continuous.

## 8. UNLICENSED TDD OPERATION

Unlicensed operation with UTRA/TDD is possible if DCA techniques are applied together with a TDMA component. DCA techniques cannot be applied for high bit rates since several time slots are needed. Therefore, unlicensed operation is restricted to low bit rates if there are several operators in the same area.

## 9. OPERATIONAL DIFFERENCES BETWEEN UTRA FDD AND TDD

UTRA/FDD and TDD are harmonized to a large degree on the physical layer. There are, however, a few differences in the operation of FDD and TDD networks.

In the TDD radio network planning more co-ordination between the operators is needed. Also, the TDD uplink range is shorter than in FDD and that need to be considered in the planning. The real time radio resource management algorithms are partly different between FDD and TDD: power control, handovers, dynamic channel allocation, resource allocation and load control are different. The synchronization requirements in TDD between operators and between adjacent cells have an effect on the network operation.

## 10. CONCLUSIONS

The interference between uplink and downlink in UTRA/TDD has been evaluated in this paper. This interference can occur between two terminals or between two base stations. The results show that within one carrier (one operator) both mobile-to-mobile interference and base station-to-base stations can cause problems. The solutions to tackle the problem include base station synchronization, careful network planning, antenna techniques and dynamic channel allocation.

The results showed also that between different operator's TDD networks, the most difficult interference occurs between base stations when the base stations are co-located or are in close proximity. That problem occurs also if TDD is used in FDD uplink band. This problem can be tackled by avoiding co-location and by co-ordination between operators including network planning, base station locations and common synchronization.

For UTRA/TDD operation dynamic channel allocation, synchronization of base stations and co-operation between the operators is preferred to obtain the maximum performance. The different interference scenarios are summarized in Table 2.

Table 2. UTRA/TDD interference summary

|                             | Outage <sup>1</sup> | Solutions                          |
|-----------------------------|---------------------|------------------------------------|
| Intra-operator:<br>MS-to-MS | High outage         | DCA                                |
| Intra-operator:<br>BS-to-BS | High outage         | Network planning,<br>antennas, DCA |
| Inter-operator:             | Low outage          |                                    |

| MS-to-MS                            |                                                           |                                                                     |
|-------------------------------------|-----------------------------------------------------------|---------------------------------------------------------------------|
| <b>Inter-operator:<br/>BS-to-BS</b> | High outage if<br>base stations<br>close to each<br>other | Co-ordination<br>between operators,<br>no co-location of<br>BS, DCA |

<sup>1</sup>without synchronization or with different asymmetry

BS=Base station, MS=Mobile station

## 11. REFERENCES

- [1] 3GPP RAN TS 25.221, Working Group 1 specification, "Physical Channels and Mapping of Transport Channels onto Physical Channels (TDD), v1.1.0, June 1999. <http://www.3gpp.org>
- [2] ERC/DEC/(99)HH. <http://www.ero.dk>

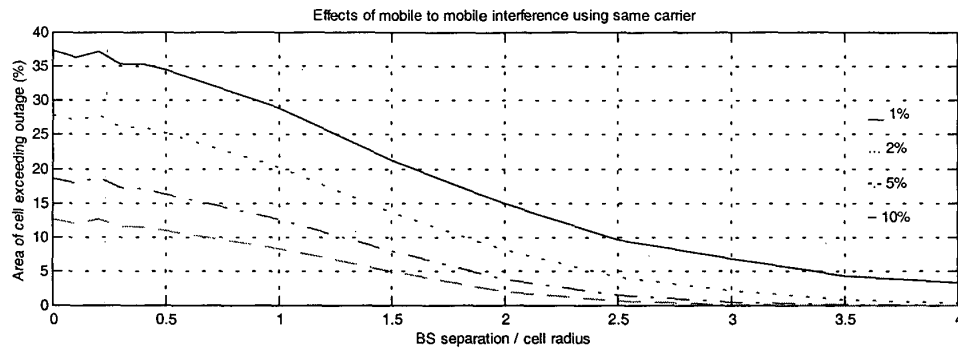


Figure 6. One operator, MS-to-MS interference, percentage of the cell area where the given outage probabilities are exceeded

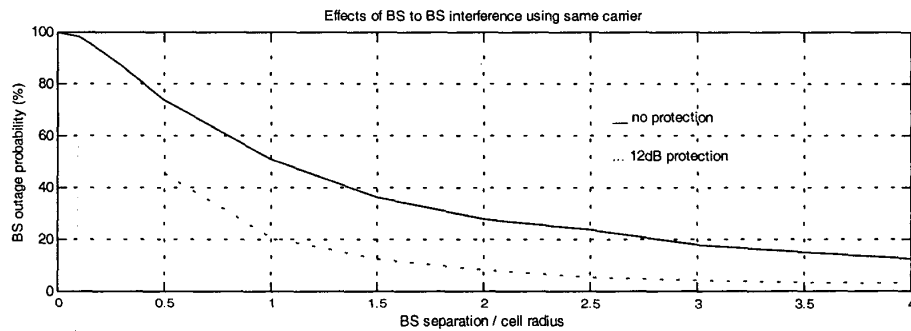


Figure 7. One operator, BS-to-BS interference, outage probability. 12 dB protection could be obtained e.g. by antenna techniques or by network planning

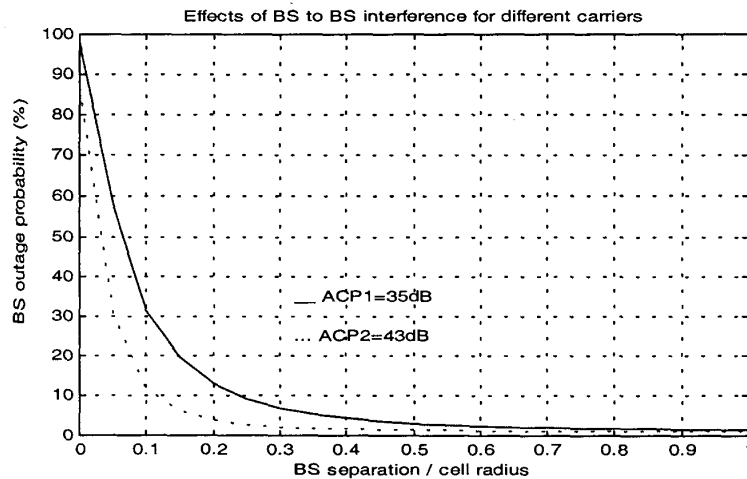


Figure 8. Inter-operator interference, BS-to-BS, outage probability. ACP1=adjacent carrier, ACP2=2<sup>nd</sup> adjacent carrier