Evaluating Inter-System-Interference for the Spectral Coexistence of EDGE and UMTS in a Hybrid Scenario

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***Abstract*: This paper presents a receiver model for software simulation suitable to evaluate the influence of asynchronous interferers on parameters like system capacity and Quality of Service (QoS). This model is applied and implemented into the simulator Generic Object-Oriented Simulation Environment (GOOSE) developed at the Chair of Communication Networks, RWTH Aachen.**

In the course of this work, simulations have been performed to validate the developed receiver model. As example, a possible coexistence scenario where a Universal Mobile Telecommunication System (UMTS) and an Enhanced Data Rates for GSM Evolution (EDGE) system simultaneously operate in the same frequency band (hybrid network) is examined.

1. Introduction

The enormous growth of world-wide mobile wireless markets during the last years - coupled with advances in communications technology - leads to the rising need for integration of multiple services on mobile platforms and therefore the ever rising need of transmission bandwidth. Given the financial constraints and limited availability of radio spectrum, efficient spectrum usage is key to the economic success of third generation cellular systems.

Currently, the available radio spectrum is divided into fixed and non-overlapping blocks assigned to different services and standards. Guard bands are introduced between frequency bands of different systems to prevent interference due to out-of-band emissions. However, since the available radio spectrum for mobile radio networks has become a narrow resource, it is likely that independent systems with different air-interfaces e.g. different time-slot and frame structure coexist at the same time in adjacent or even the same frequency bands. A possible coexistence scenario would be to simultaneously operate **UMTS and EDGE systems in the same frequency band** (hybrid network). This option is regarded an advantageous way of migration between current 2^{nd} generation networks and the UMTS.[1] For details on burst- and frame-structure of EDGE and UMTS respectively, see [6]. Another approach to increase spectral efficiency is using dynamic, adaptive allocation of spectrum and assigning different types of traffic to the different radio systems, since each of the available radio systems is developed and optimized for a different type of traffic.

To determine the influences caused by the spectral coexistence of different systems on parameters like system capacity and quality of service, it is necessary to regard the flow of information over the radio interface and through the physical layer of the respective protocol stack, since this is where the different mechanisms for error detection and correction are performed.

While other work performed using GOOSE was restricted to simulations of single systems ([2, 5]), the novelty in this paper is simulating the coexistence of asynchronous[2] systems. The differentiating element between the simulations performed in this work and those presented in [3] is the application of a refined receiver model explained later in this paper and a more detailed modelling of the scenario with sectorized cells instead of omnidirectional cells.

Traditional methods, which evaluate QoS-parameters like Radio Link Failure (RLF) and Bit Error Ratio (BER) based on the average Carrier to Interference Ratio (C/I)–ratio during one burst or even one frame lead to erroneous calculation of the Bit Error Ratio because the relation between the received interference power and the ratio of disturbed bits is greatly non-linear cf. [4]. This raises the question what influence a more accurate measurement of the received interference will have on Bit Error Ratio (BER) calculation in comparison to calculating the BER from the averaged C/I–ratio.

The purpose of this work was to develop a receiver model, which considers the configuration of the physical channel as well as the different error protection mechanisms as input parameters, to investigate the influence of asynchronous interferers on quality of service parameters.

To illustrate a possible application of the developed model, the aforementioned coexistence case between UMTS and EDGE is exemplarily simulated and key results are presented.

The next section gives an overview about the principle of the mentioned receiver model and validation simulations. Section 3. describes the example coexistence scenario between EDGE and UMTS and its simulation parameters, while Section 4. presents key results from the simulations. Section 5. concludes the paper and gives an outlook on interesting future research topics.

[1] For further information about the spectral coexistence of UMTS and EDGE mobile radio networks, see [3].

[2] The interference between systems of different time-slot structure is so-called asynchronous interference.

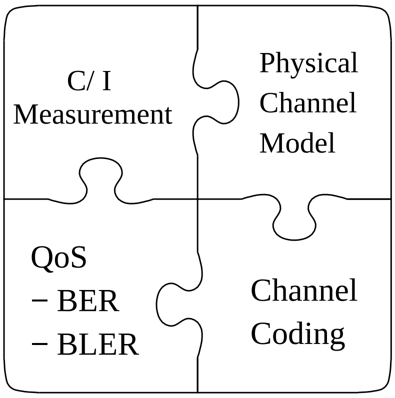
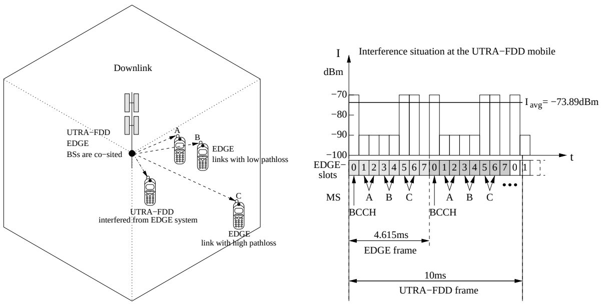


Figure 1: Properties of the receiver model



(a) Example scenario UTRA-FDD/EDGE

(b) Downlink interference situation

Figure 3: Sampling of the C/I in asynchronous systems

2. Modeling the Interference

A prerequisite for the receiver model to evaluate the effects of asynchronous interferers on the QoS of the victim system is to consider the configuration of the physical channel as well as the different error protection mechanisms i.e. channel coding (visualized in 1).

Figure 3(b) shows how the experienced interference at the location of a UMTS Terrestrial Radio Access (UTRA)-Frequency Division Duplex (FDD) mobile can vary during one frame (10 ms duration, consisting of 15 separate slots) for a constellation of interferers and victims as shown in Figure 3(a).

In the following we present the approach chosen in this paper to provide an interference calculation mechanism with variable time resolution.

When the interference power is calculated between any asynchronous systems like for example between a GSM/EDGE interferer and an UTRA-FDD-victim, the following steps are taken:

1. The MobileStation in the simulator contains a data structure for both Uplink (UL) and Downlink (DL) direction to store a finite number of interference power values received during one time-slot. The number of values stored per time-slot (i.e. the time resolution) is also referred to as *number of bins* and can be chosen according to the needs of the scenario.

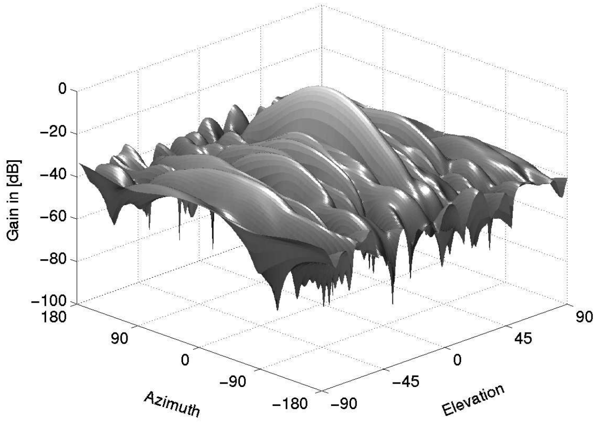


Figure 4: Antenna pattern

2. An Interference-Calculation-Engine determines if there is any collision between two transmissions at any point in time.

3. If a collision is detected, the total overlapping time between the victim slots and the slots in the interfering system is calculated. Furthermore the exact point in time, measured from the beginning of the victim slot, is calculated. Both the point in time and the duration are stored for each collision to determine the right bins for storing the interference.

4. After all collisions within the current victim-frame have been detected, the sum of the received interference power is stored into the bins. Utilizing the point in time and the duration for each collision, it is possible to determine the bins being interfered. The received interference power is added to these bins according to equation (1).

$$I_{bin}(t) = \frac{1}{T_{bin}} \cdot \int_{t}^{t+T_{bin}} I(x)\, dx \qquad (1)$$

Hence, as the result of this approach the sampled interference power level over the victim slot duration is available and can be used for further evaluation in the simulator.

Then, for each interference sample $I(k)$ the appropriate BER after demodulation and before channel decoding (also referred to as "raw" BER) is determined. For this purpose, first the C/I ratio is calculated and the raw BER is returned by utilizing a Mapping Interface. The mapping of the C/I-values to the raw BER after demodulation can be done in separate simulations, which assess the receiver performance.

Since the physical layer includes two interleaver stages with block interleavers, it is fair to assume that the bit errors resulting after demodulation are uniformly distributed within each slot. Thus, the raw BER for the current victim slot can be deter-

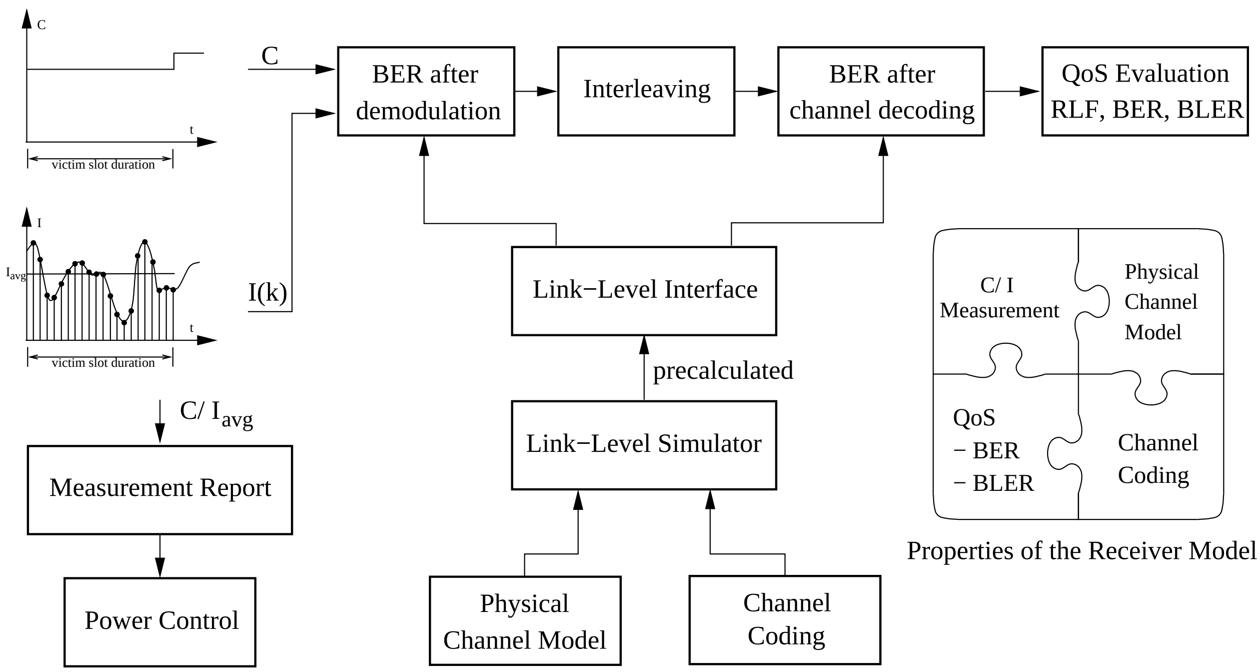


Figure 2: Receiver model structure

mined by averaging the entire BER–values.

$$\overline{\mathrm{BER}}_{raw} = \frac{1}{n} \cdot \sum_{i=0}^{n-1} \mathrm{BER}_{raw}(i) \qquad (2)$$

where n is the number of interference samples (number of bins) per slot.

Now having calculated the raw BER, it is possible to calculate the BER after channel coding (also referred to as ”user” BER). But first, the raw BER is averaged over the last n radio frames, since the physical layer provides a second interleaver stage.

Then, similarly to determining the raw BER, the user BER (i.e. the residual BER after decoding is supplied by a mapping interface using results yielded by link level simulations, which consider the channel coding scheme which is predetermined by the utilized traffic channel and its parameters.

Finally, the evaluation of QoS parameters like Radio Link Failure (RLF), BER and Block Error Ratio (BLER) can be performed. Figure 2 shows the overall structure of the developed receiver model.

3. Scenario

This section introduces the scenario and important parameters (see Tables 1, 2 and 3[3]) chosen for simulation of coexistence between EDGE and UMTS radio networks. The environment presented is designed to investigate the in-band-coexistence of UMTS- and EDGE-networks.

The simulator GOOSE is a dynamic, event-driven simulation environment. Terminals are created dy-

[3]DL Code Crosstalk in the table refers to the percentage of power transmitted on other channelizetion codes, which is regarded as interference due to the loss of orthogonality.

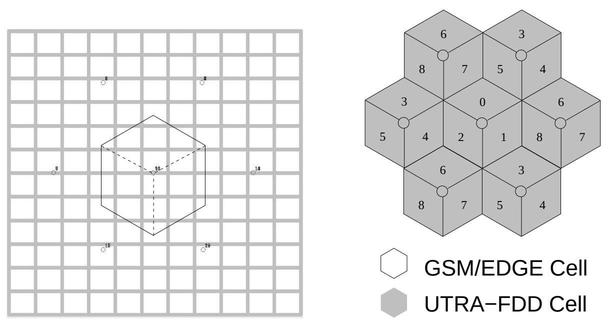


Figure 5: Sectorized cell structure and roadmap

Table 1: EDGE parameters

Fixed Parameter	Value
Carrier Frequency	UL: 1921.6 MHz DL: 2111.6 MHz
Carrier Spacing	200 kHz
Number of Frequencies	9
Number of TRX per Sector	1
Number of sectorized Cells	7
Sectors per Cell	3
Cell Radius [r]	500 m
BS maximum Power	40 dBm
MS Dynamic Range	0 dBm – +33 dBm
MS/BS Multislot Class	2
Backgruond Noise	-114 dBm
Power Control	GSM 05.08
Service-Type	EGPRS (HTTP)
Scheduling Period	500 ms
Mobility	3 km/h

Table 2: HTTP session according to [1]

Parameter	Distribution	Mean
Num. of Packets	Geometric	5
Packet Size	Geometric	12 kBytes
Reading Time	Geometric	12 s

Table 3: UTRA-FDD parameters

Fixed Parameter	Value
Carrier Frequency	UL: 1920 MHz
	DL: 2110 MHz
Carrier Spacing	5 MHz
Number of sectorized Cells	7
Sectors per Cell	3
Cell Radius [r]	500 m
BS maximum Power	43 dBm
MS Dynamic Range	-44 dBm-+21 dBm
Receiver Noise	-100 dBm
Power Control	C/I-based
C/I-target	-17.5 dB in UL+DL
Service-Type	Speech: 12.2 kbit/s
Discontinuous Transm. (DTX)	Yes
Channel Allocation	fixed
Spreading Factor	UL: 64
	DL: 128
Mobility	3 km/h
DL Code Crosstalk	30 %
variable Parameter	**Range**
Speech Traffic per Sector	10. . .60 Erlangs

namically, with both speech and Web-browsing sessions following independent Poisson arrival processes within the Manhattan Scenario (cf. Parameters in Tables 2 and 3, according to the proposals made by [1]).

Figure 5 depicts the cell structure and the base station deployment of the two systems. The Base Stations (BSs) of the two systems are co-sited since sites are rare and expensive resources of the network operators. The Mobility of the terminals is modeled by a roadmap which forms a rectangular grid, similar to Manhattan–like urban models. The block size is 200 m×200 m resulting in a simulation area of 7,1424 km^2. Measurements are taken at the middle hexagonal cell because the interference situation is expected to be the worst there. In the figure, the numbers from 0 to 8 denote the frequency numbers of the EDGE-system (1 Transceiver (TRX) per sector).

The calculation of pathloss values was performed identically in both systems and based on the Okumura-Hata model proposed by [1] for suburban open scenarios. The pathloss L_P was calculated according to equation (3)

$$L_P = 124.6\,\text{dB} + 36.2\,\text{dB} \cdot \log_{10} R \qquad (3)$$

where R is the distance in km between transmitter and receiver. The shadowing is lognormal distributed with mean zero and 4 dB Standard Deviation.

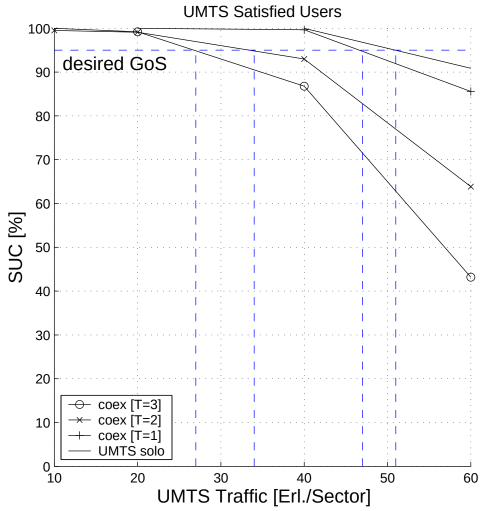


Figure 6: Satisfied User Criterion (SUC) of the UMTS-system in the presence of EDGE-traffic

The effects of 120° sectorized antennas was also taken into account. The antenna pattern shown in figure 4 gives the attenuation values relative to a gain of 18 dBi in the main beam direction. In the scenario, Lognormal Shadowing with mean $\mu = 0$, variance $\sigma^2 = 4$ dB was assumed. In the EDGE-network, Link Adaptation (LA) but no Incremental Redundancy (IR) was used, Enhanced General Packet Radio Service (EGPRS) is the mode of operation regarded. The traffic was modeled after the Hypertext Transfer Protocol (HTTP)-proposals from [1] (see table 2). Each Mobile Station (MS) represents one HTTP-session. The throughput achieved during this session is then evaluated as the sum of the data from all packets divided by the cumulative duration of the different Temporary Block Flows (TBFs). Calculating with the mean values, each single Mobile Station (MS) represents an average offer of $(5 \cdot 12\,\text{kByte})/(4 \cdot 12\,\text{s}) = 10\,{}^{kbit}/_{s}$, assuming that the packet transmission time is short compared to the reading time. The real offer is slightly lower, especially for high interference situations, where the Link Adaptation has influence on the throughput each user experiences and thus on the time it takes to transmit a packet.

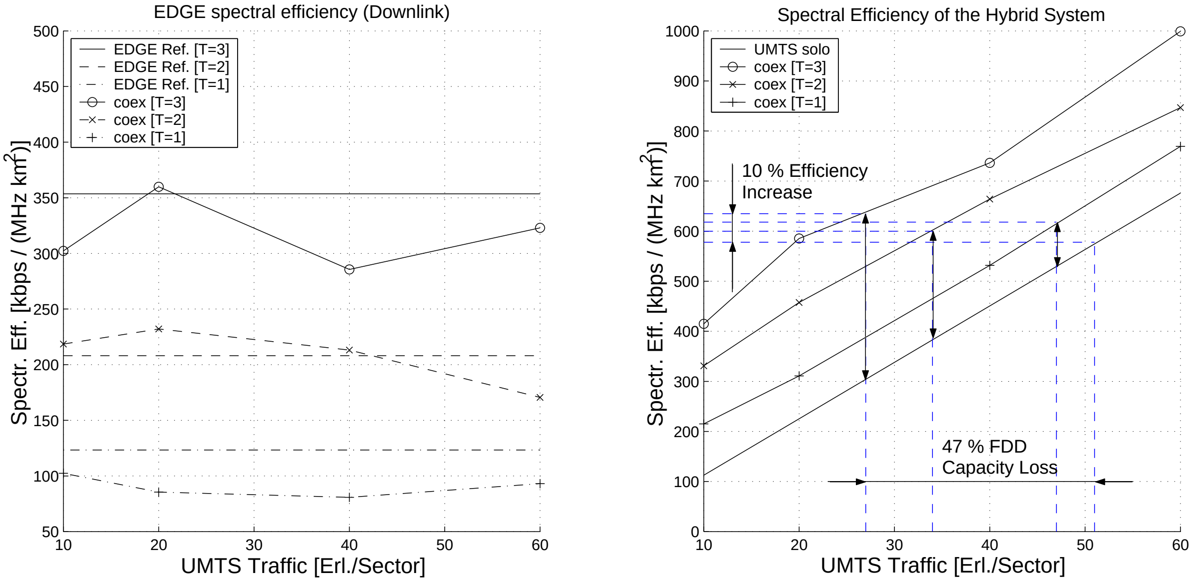
4. Performance and Capacity Analysis

This section presents the calculation of the spectral efficiency the regarded systems exhibit in the simulated scenario. The results are displayed in Figure 7(a).

The mean throughput of the EDGE-sectors is calculated as follows:

1. With the values from table 2 we find that the average requested data in one session is

$$5 \cdot 12\,\text{kByte} \cdot 8\,\frac{\text{bit}}{\text{byte}} = 480\,\text{kbit}.$$



(a) Spectral Efficiency for EDGE (Downlink)

(b) UMTS and combined Spectral Efficiency

Figure 7: Spectral efficiency in a hybrid system

The transmission time of the data can be calculated dividing it by the mean data throughput (TP) per user. In the case of the undisturbed EDGE-system (EDGE Reference with traffic load factor $T = 3$), this was 48.45 kbit/s. The total transmission duration for all packets of the sessions then becomes

$$t_{trans} = \frac{480\,\text{kbit}}{48.45\,{}^{kbit}/_{s}} = 9.91\,\text{s}.$$

2. The transmission time added to the sum of the reading intervals is the total duration of a session.

$$t_{total} = 4 \cdot 12\,\text{s} + 9.91\,\text{s} = 57.91\,\text{s}$$

3. The total data divided by the total session duration is the average offer one session represents. For the example:

$$\text{Offer} = \frac{480\,\text{kbit}}{57.91\,\text{s}} = 8.289\,{}^{kbit}/_{s}.$$

4. The sector throughput (TP) can then be determined as described above by multiplying the offer per session with the mean number of simultaneous sessions at one sector of a BS.

$$\text{Sector TP} = 46.17 \cdot 8.289\,{}^{kbit}/_{s} = 382.703\,{}^{kbit}/_{s}.$$

The spectral efficiency of the different systems is calculated dividing the total sector throughput by the product of allocated bandwidth and the sector area. The sector throughput of the UMTS system is calculated from the number of users and the data rate of their speech channel, as displayed in 7(b). This figure also shows the spectral efficiency of the hybrid system consisting of both UMTS and EDGE compared to the spectral efficiency of the single, undisturbed EDGE-system.

In a first step, the capacity of the regarded networks was determined. Figure 6 shows that the UMTS alone can carry a maximum of ca. 51 Erlang at a desired Grade of Service (GoS) of 95 %. In the presence of EGPRS traffic in the same frequency band, this figure diminishes to roughly 27 Erlang in the case of $T = 3$. In EGPRS, the influence of rising traffic in the coexisting UMTS on the maximum traffic that can be carried seems to be rather small, as Figure 7(a) shows. The next step is to calculate the resulting sum of the spectral efficiencies of the two systems running in parallel. This is done in Figure 7(b). At 95 % GoS, we have ca. 51 Erlang (corresponding to a spectral efficiency of ca. 560 kbit/s/MHz·km²) in the UMTS reference case. Adding EGPRS with 3-fold traffic load ($T = 3$) makes the 95 %-GoS efficiency of UMTS go down to about 300 kbit/s/MHz·km², but the added EDGE-system brings the total capacity up to a sum of ca. 650 kbit/s/MHz·km².

5. Conclusion

In this paper, a receiver model suitable to investigate the influence of asynchronous inter-system-interference on parameters like system capacity and QoS is presented. It provides a means to investigate coexistence scenarios of asynchronous systems (e.g. UTRA-FDD and -Time Division Duplex (TDD)) as well as–in a next version–coexistence of different systems in unlicensed spectra.

Using the described model, simulations regarding the spectral coexistence of EDGE and UMTS mobile radio networks in a hybrid radio access architecture were performed. The evaluation of the simulations comprises impacts on QoS and spectral efficiency.

In our simulation the maximum capacity decrease in one of the participating systems is 47 %, while at the same time the spectral efficiency of the combined hybrid system increases by approximately 10 %, which proves that EDGE could serve to enhance UMTS capacities and that a combined system can have a higher spectral efficiency than one single UMTS or EDGE system. In comparison to the investigations done in [3], we can state that due to the utilization of the developed model, the sectorized cells and the improvement of the power control mechanisms the combined spectral efficiency increases.

Finally we can remark that if this deployment option is seriously considered, it calls for a spanning control of services, traffic load and thus of interference which could be managed by an "Integrated Radio Resource Management" for both systems.

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