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Name:	Ulrich Fornefeld, Peter Stuckmann, Adolfo Bayo and Rosalino Critelli
Affiliation:	Communication Networks Aachen University of Technology
Address:	Kopernikusstr. 16 D–52074 Aachen, Germany
Phone:	+49 241 80 7916
Fax.:	+49 241 88 88242
E-mail:	{ufo|pst}@comnets.rwth-aachen.de

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Analysis of the Influence of Packet-data and Voice Traffic on the Interference Situation in Multi-cellular GSM/(E)GPRS Networks

Ulrich Fornefeld, Peter Stuckmann, Adolfo Bayo and Rosalino Critelli

Communication Networks
Aachen University of Technology
Kopernikusstr. 16
D–52074 Aachen, Germany
Phone: +49 241 80 7916
E-mail: {ufo|pst}@comnets.rwth-aachen.de

Abstract

In this paper a first approach of examining large multi-cellular **E**nhanced **G**eneral **P**acket **R**adio **S**ervice (EGPRS) scenarios is done. To obtain this, a mixed GSM/(E)GPRS traffic mix is generated to observe the influence of voice traffic on packet data traffic and vice versa. Special emphasis is put on the modeling of a realistic simulation environment concerning traffic generation, positioning and radio propagation. The burst level approach provides the possibility to examine the dynamic allocation of radio block periods by the GPRS RLC/MAC layer in detail.

1 Introduction

In the context of the evolution towards 3rd Generation (3G) mobile radio networks, packet-switched data services like the General Packet Radio Service (GPRS) and the Enhanced GPRS (EGPRS) are presently introduced into GSM and TDMA/136 systems worldwide.

In GPRS networks a radio cell may allocate resources on one or several physical channels in order to support the GPRS traffic. Those channels shared by the GPRS mobile stations are taken from the common pool of GSM physical channels available in the radio cell. The allocation of physical channels to circuit-switched services and GPRS is done dynamically according to the "capacity on demand" principle [1]. The operator can decide to dedicate permanently or temporarily physical channels for the GPRS traffic. In this context GSM physical channels that are allocated permanently for GPRS are called *fixed* **P***acket* **D***ata* **Ch***annels (PDCHs)*, channels that are allocated temporarily for GPRS are called *on-demand PDCHs*.

Obtaining the maximum possible bandwidth from a PDCH is not possible without optimum usage of power control and link adaptation algorithms. To develop and to evaluate optimized algorithms, a suitable simulation environment, operating at radio block level in detail, is introduced within this paper.

In order to examine the interference situation in multi-cell EGPRS scenarios in general, an approach using averaging models for the fast fading process, frequency hopping and mapping of the **c**arrier to **i**nterference **r**atio (CIR) to the **b**it **e**rror **r**atio (BER) might be sufficient. In this case, the packet arrival process might be approximated by a simple distribution and the calculated average BER will be near reality.

However, a more detailed approach is necessary if also the protocol behaviour shall be investigated in detail. Especially the 'fast' **r**adio **r**esource **c**ontrol (RRC) algorithms for power control and link adaptation - acting on radio block level - demand frequent measurements on burst level and consideration of correlated effects such as fast fading. Although the evaluation of RRC algorithms is not within the scope of this work, the basis for these investigations shall be developed in this paper. A proven simulation environment, the **S***DL*-**G***eneric* **O***bject-*

Oriented **S**imulation **E**nvironment (S-GOOSE, [2, 3]) is used for these examinations as it provides the mentioned exact modeling of physical effects and also supports the measurement collection on the physical layer. It is connected to the **GPRS** protocol **sim**ulator (GPRSim) which is well-known for exact performance evaluations on capacity parameters of the (E)GPRS protocol stack [4, 5]. Both systems are based on the **S**ystem **P**erformance **E**valuation **T**ool **C**lass **L**ibrary (SPEETCL, [6]). The protocol stack has been specified in the **S**pecification and **D**escription **L**anguage (SDL) and has been translated to SPEETCL-conformable C++-classes with the code generator SDL2SPEETCL [7].

Sec. 2 provides the basic ideas for the simulations. In Sec. 3, the setup of the performed simulations and the main aspects for the environmental model are provided. Sec. 4 explains the details of the modelling concepts for the protocol stack, in Sec. 5 the simulation results on examinations of the CIR distribution in EGPRS systems are presented and discussed. A summary is provided in Sec. 6.

2 Scope

The focus is set on the examination of the CIR measurements for mixed scenarios. While the carrier strength is similar for both, voice and packet data, the interference caused by both traffic families is quite different. Three interference situations can be observed, Fig. 1:

- For a circuit-switched interferer, permanent interference occurs during the session in both, uplink and downlink. Only noise occurs if no session is active on the reused frequency.
- For a packet-switched interferer, almost permanent interference occurs on the downlink during the busy hour. As the **u**plink **s**tate **f**lag (USF) has to be transferred on a downlink PDCH whenever an uplink **t**emporary **b**lock **f**low (TBF) is active, the downlink is sending permanently except for the rare case that no mobile has an active TBF in the cell. This case is even more improbable as the TBF context is ended some seconds after the last data have been transferred. Channel combination 13 [8] is selected and downlink dummy control block filling is enabled [9] so that the downlink is sending permanently. On the uplink, non-contiguous interference can be observed, the interference situation is therefore better than for the downlink.
- For multiplexed packet-switched interferers, the downlink situation remains as mentioned for a single packet-switched interferer, the uplink interference increases with the utilization.

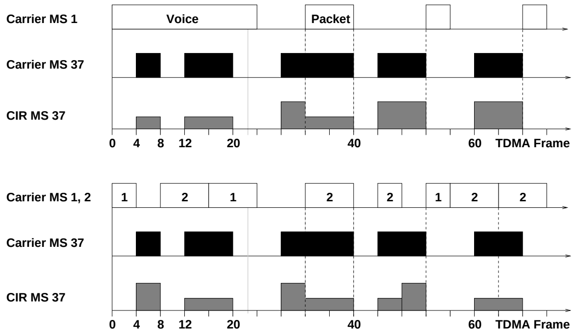

Figure 1: Influence of different kinds of traffic on the interference situation, Uplink

For the downlink of the PDCH, only the geometrical situation influences the CIR. The source of interference is always in the center of the interfering cell. The propagation loss is modeled using the UMTS 30.03 propagation model for vehicular participants [10], $h_{MS} = 2m, \quad h_{BS} = 45m$, each cell site is equipped with one omnidirectional antenna. The propagation loss is

$$L_p = 112.726 + 32.8\, log_{10}\left(\frac{d}{km}\right)$$

for 945 MHz transmitter frequency.

The carrier strength and the interference strength are calculated separately in order to give some statements about non-contiguous traffic later. The transmitter power P_{TX} is set to 45 dBm. As the mobile stations (MS) are distributed uniformly over the scenario, the mean distance to the neighbouring **b**ase **s**tations (BS) is 1500 m. Regarding the cluster size k = 9, the cell radius is obtained [11].

$$\begin{aligned} D &= 3 * \text{MS\_BS\_Distance} = 4500\, m \\ Q &= \frac{D}{R} = \sqrt{3 \cdot k} \rightarrow \\ R &= 866\, m \end{aligned}$$

The average intra cell MS-BS distance, influencing the carrier strength, can be approximated by the radius of a circle covering half of the cell area.

$$R_{ave} = \sqrt{\frac{A_{Hex}}{2 \cdot \pi}} = \sqrt{\frac{\frac{3}{2}\sqrt{3}R^2}{2 \cdot \pi}} = 556.8\, m$$

The average carrier strength is obtained with the average distance R_{ave}.

$$\begin{aligned} \bar{C} &= P_{TX} - \bar{L}_{p,C} = 45\, dBm - 104.38\, dB \\ &= -59.38\, dBm \qquad for \\ \bar{L}_{p,C} &= 112.726\, dB + 32.8\, log_{10}\left(\frac{R_{ave}}{km}\right)\, dB \\ &= 104.38\, dB \end{aligned}$$

Using a cluster size of $k = 9$, the mean MS - BS interferer distance of $R_i = 4500\,m$ leads to a mean interference strength of

$$\begin{aligned}\bar{I} &= P_{TX} - \bar{L}_{p,I} = 45\,dBm - 134.15\,dB \\ &= -89.15\,dBm \qquad for \\ \bar{L}_{p,I} &= 112.726\,dB + 32.8\,log_{10}\left(\frac{R_i}{km}\right)\,dB \\ &= 134.15\,dB\end{aligned}$$

The interference is provided n = 6 times by the first tier of interfering base stations contiguosly, so the total interference strength is increased by a cochannel multiplier $CCM_n = 10\,log_{10}(n)\,dB$.

$$\begin{aligned}CCM_6 &= 10\,log_{10}(6)\,dB = 7.78\,dB \\ \bar{I}_6 &= \bar{I} + CCM_6 = -81.37\,dBm\end{aligned}$$

The expected mean CIR is therefore

$$\begin{aligned}CIR_{mean} &= \bar{C} - \bar{I}_6 \\ &= -59.38\,dBm - (-81.37\,dBm) \\ &= 21.98\,dB\end{aligned}$$

For non-contiguous voice traffic, seven interference states might be observed with 0 - 6 active interferers. If it is possible to estimate the probability of the states, it is also possible to calculate the CIR with the expression

$$CIR_{mean,voice} = \bar{C} - \sum_{n=0}^{6} p_n * \bar{I}_n$$

active interferers n	interference strength $\bar{I}_n$
0	Noise only, -116 dBm
1	$\bar{I} = -89.15\,dBm$
2	$\bar{I} + CCM_2 = -86.14\,dBm$
3	$\bar{I} + CCM_3 = -84.38\,dBm$
4	$\bar{I} + CCM_4 = -83.13\,dBm$
5	$\bar{I} + CCM_5 = -82.17\,dBm$
6	$\bar{I} + CCM_6 = -81.37\,dBm$

The probabilities for 0 - 6 active interferers might be obtained from the offered traffic using the Erlang state distribution formula with $A_{channel} = 0.875\,Erl$ per interfering channel, leading to a total interferer traffic of $A = 6 \cdot A_{channel} = 5.25\,Erl$ [11].

$$p_x = \frac{\frac{A^x}{x!}}{\sum_{i=0}^{n} \frac{A^i}{i!}}$$

This approach is possible only if the four available TCH channels per cell are allocated randomly, otherwise correllation between the interferers might increase the total interference.

x	p_x
0	0.0072
1	0.0380
2	0.0998
3	0.1746
4	0.2292
5	0.2406
6	0.2106

$$\begin{aligned}CIR_{mean,voice} &= -59.38\,dBm + 83.51\,dBm \\ &= 24.13\,dB\end{aligned}$$

The uplink calculation is done equally with $P_{TX} = 33\,dBm$. As the scenario is interference-limited (p(0) < 1 %), the CIR is almost the same in uplink and downlink.

For bursty packet streams, a theory for calculating the state probability of the interference situation is not present yet, therefore stochastical simulations have to be used to obtain the CIR.

3 Simulation Scenario

A square scenario area of 10 km length covers 37 cells using a cluster size of 9, Fig. 2. The distance of neighbouring base stations is 1.5 km. All base stations use omnidirectional antennas, diversity antennas are not modelled.

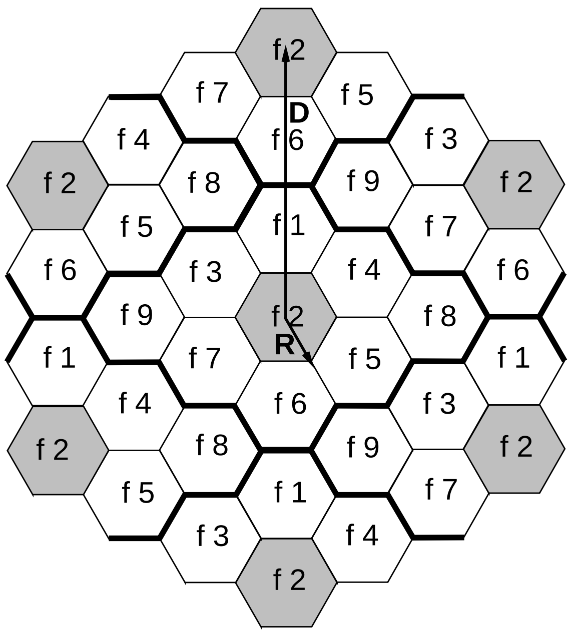

Figure 2: 37 Cells using cluster size 9

The participants move according to the molecular movement model of Brown. A user speed of $3\frac{km}{h}$ provides sufficient fading lengths. A random, uniformly distributed initial positioning is used. All mobiles are placed within 1 km distance to the next base station

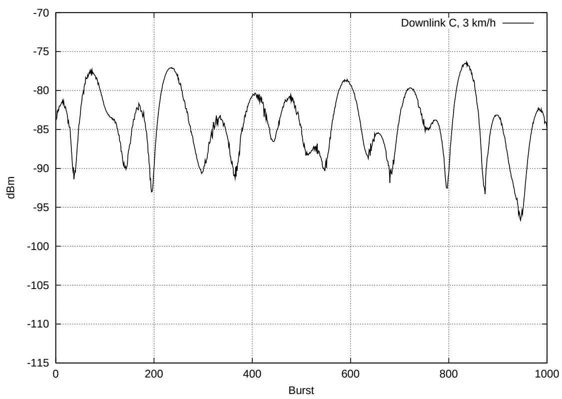

Figure 3: Fading process for the downlink carrier, $v_{ped} = 3km/h$

in order to avoid coverage problems. All measurements are obtained exclusively from the participants attached to the center cell. No power control and no link adaptation is applied.

There are the following two settings to be examined:

For the GSM simulations, 1260 mobiles with a voice activity of 10% (call duration: 120s, inter arrival time: 1200s, poisson process) are placed uniformly distributed in the outer 36 cells of the scenario. This results in an average traffic of 3.5 Erl per cell. In the inner cell, two GPRS mobiles with the capability to allocate four consecutive PDCH time slots in downlink and one in uplink are regarded.

For the GPRS simulations, one GPRS mobile of the mentioned type is present in each cell. Load generators [12] provide a bursty packet stream on the user plane of OSI layer 4. To investigate multiplexing, two mobiles per cell have been regarded. A larger number of participants would be desirable, but is not possible at present time due to hardware limitations.

Bejond these usual modellation methods, the following detailed approaches are used:

3.1 Fast Fading

A correlated fast fading process is generated from a fading pattern that is shifted with the user speed, Fig. 3.

Especially for slow-moving users, the fading duration is longer than one radio block and influences the fast power control and the link adaptation algorithm. The measurement algorithm calculates the mean and the standard deviation of the BER for the four measurements made during one radio block. While the mean BER might be modeled well with an uncorrelated fading process (e.g. drawn randomly from a distribution function), the standard deviation of the BER is smaller for a correlated process than for an uncorrelated process.

3.2 CIR calculation on burst level

The CIR is calculated once per burst. Only the cochannel interferers are considered in the interference calculation. For the downlink PDCH, sending contigously, a dummy sender is used for the modellation of control-only blocks. The calculations for carrier strength and CIR are averaged over one SACCH period for classical RRC algorithms (slow power control, cell selection). In addition, a weighted averaging over one radio block is performed for fast RRC algorithms (link adaptation and fast power control) as described in ETSI GSM 05.08, sec. 10.2. [13]

4 Protocol Stack

To be able to generate a realistic GPRS traffic behaviour, the protocol simulator GPRSim was integrated into the SGOOSE.

The (E)GPRS Simulator GPRSim [4] is a pure software solution based on the programming language C++. Up to now models of Mobile Station (MS), Base Station (BS), and Serving GPRS Support Node (SGSN) are implemented. The simulator offers interfaces to be upgraded by additional modules.

For the implementation of the simulation model in C++ the SDL Performance Evaluation Tool Class Library (SPEETCL) [14, 6] is used. This allows an object oriented structure of programs and is especially applicable for event driven simulations.

The complex protocols like LLC, RLC/MAC, the Internet traffic load generators and TCP/IP are specified formally with the Specification and Description Language (SDL) and are translated to C++ by means of the Code Generator SDL2SPEETCL [14] and are finally integrated into the simulator.

Different from usual approaches to building a simulator, where abstractions of functions and protocols are being implemented, the approach of the GPRSim is based on the detailed implementation of the standardized protocols. This enables a realistic study of the behaviour of EGPRS and GPRS. The real protocol stacks of (E)GPRS are used during system simulation and statistically analyzed under a well-defined traffic load.

The block structure of the combined simulation environment is shown in Fig. 4.

LLC and RLC/MAC are operating in acknowledged mode. The multislot capability is 1 uplink and 4 downlink slots. The MAC protocol instances are operating with three random access subchannels per 52-frame. All conventional MAC requests have the radio priority level 1 and are scheduled with a FIFO strategy. Ongoing TBFs in uplink and downlink are served with a Round Robin strategy with a Round Robin depth of 10 radio blocks. LLC has a window size of 16 frames. TCP/IP header compression in SNDCP is

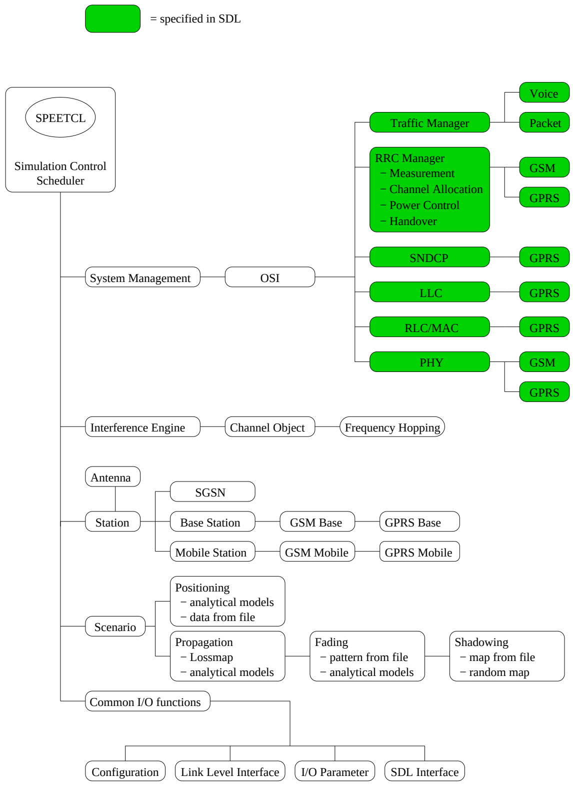

Figure 4: Basic simulator structure

performed. TCP is operating with a maximum congestion window size of 8 Kbyte and a TCP Maximum Segment Size (MSS) of 536 byte. The transmission delay in the core network and externel networks, i.e. the public Internet is neglected. This corresponds to a scenario where the server is located in the operator's domain.

In order to perform network capacity planning, the system behaviour during the busy hour has to be regarded. The Internet traffic [15] is composed of 70 % e-mail sessions and 30 % WWW sessions. The inactive period between two sessions is set to 12 seconds. One radio frequency channel per link direction is available, carrying 4 fixed PDCH. Frequency hopping does not occur.

5 Simulation Results

The voice call scenario, as discussed in Sec. 2, shows a mean CIR of 23.4 dB (UL and DL), Fig. 5. As this scenario is interference-limited, uplink and downlink are performing equally. In the packet-data scenario, a different behaviour can be observed: The downlink, now being disturbed by a contiguous sender, shows a lower mean CIR (21.3 dB) whilst the uplink is performing much better (32.7 dB). This is helpful as the uplink is the weaker link - considering radio link problems - because the sending power is limited to the battery capabilities of the mobile station. However,

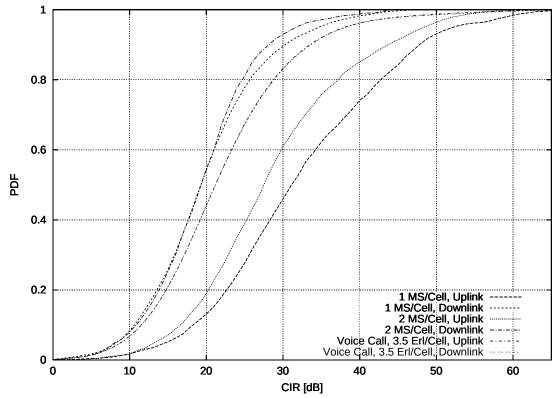

Figure 5: CIR distributions for voice and packet traffic

the larger bandwith demands occur in the downlink. With a low CIR, coding scemes with a small bandwith have to be used.

In this scenario, only one mobile station was assigned to a base station. For two assigned mobile stations, the uplink CIR decreases (29.7 dB) due to the effects mentioned above. The downlink CIR does not change for multiplexed mobile stations as the packet stream is already contiguous (20.9 dB due to short run time).

Due to hardware limitations, a higher accuracy for the packet-data scenarios is not possible at this moment. Larger scenarios will follow in future.

From the obtained results, the conclusion can be drawn, that the separation of frequencies to services is not helpful. While symmetrical connections like voice calls either have equal CIR in each direction or suffer from a worse uplink quality, caused by the sending limitations of the mobile station, the packet channels provide heavy interference on the downlink. Therefore, a mixture of both traffic types should be achieved: The traffic channel provides little interference on the uplink, which improves the voice call quality. On the same time, it worsens the situation on the downlink by heavy interference. However, a mean CIR of 21.3 dB is sufficient for a voice call. On the other hand, the packet traffic takes advantages of the voice call interferer. The Uplink quality of 32.7 / 29.7 dB is not necessary on the uplink and a CIR of 23.4 dB is sufficient for a **m**odulation and **c**oding **s**cheme (MSC) of 8 and a data rate of 48 kbit/s per time slot [16]. The downlink quality of 21.3 dB allows an MSC of 8 and a data rate of 43 kbit/s. Here, any improvement is welcome as the downlink is carrying the bigger load normally. In the simulated scenario, the interference with voice calls allows an MSC of 8 (23.4 dB) and a data rate of 48 kbit/s. It should be examined if the contiguous sending in downlink direction can be avoided if not TBF is active as this would decrease interference.

6 Summary

A first multi-cell EGPRS scenario has been evaluated concerning the CIR distribution on uplink and downlink. A comparison to a voice call scenario showed an improvement of the CIR situation on the uplink and a degradation on the downlink. The simulations show that benefits can be drawn if voice and packet data are using cochannels. In future, the existing architecture should be improved to allow larger scenarios. The feedback to the link adaptation and fast power control algorithm should be finished to investigate different algorithms.

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