Dimensioning GSM/GPRS Networks for Circuit- and Packet-Switched Services

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Abstract

In this paper radio network dimensioning rules for GSM/GPRS networks focussing on Internet applications are presented. Taking simulation results for GPRS introduction and evolution scenarios as the basis, the radio resources needed for a given offered traffic and for given quality of service requirements can be estimated. Both circuit-switched voice traffic and packet-switched Internet traffic sources are considered that are sharing the radio resources available in a GSM radio cell. To achieve this, the simulation tool GPRSim is used that comprises a prototypical implementation of the standardized GPRS protocols.

Keywords

GPRS, Internet Applications, Dimensioning, on-demand PDCHs, stochastic simulation.

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. For network operators, equipment vendors, and system integrators dimensioning rules have to be developed to plan and estimate the radio capacity that is needed for the predicted amount of user data, when the radio resources are shared between circuit- and packet-switched services.

For circuit-switched networks the Erlang-B-Formula has been successfully applied over decades, while for packet-switched networks such an applicable capacity model is still missing. The analytical discription of statistical multiplexing and Internet and Multimedia traffic modelling are more complex than for circuit-switched networks and have risen to a great challenge in traffic engineering.

Several papers concerning GPRS performance analysis were published in the last years [1, 2, 3]. They do not contain results for on-demand channel configurations with coexisting circuit-switched traffic sources, which are the typical configurations in GPRS introduction and evolution scenarios. Publications about on-demand channels like [4, 5], do not focus on higher layer traffic performance and do not consider the complete Internet stack with TCP.

In Section 2 after this introduction the problem of GPRS radio network dimensioning is introduced. After the description of the simulation environment GPRSim in Section 3, GPRS dimensioning rules are presented for fixed and on-demand channel configurations in Section 4.

2. Radio Network Dimensioning

A suitable dimensioning approach for the busy hour is based on the number of active users and the corresponding applications and user behaviour. These parameters characterize the offered traffic that has to be served by the network. Second the quality of service, which the operator wants to offer his customers has to be defined. Giving these two dimensioning criteria as the input parameters to an adequate capacity model the needed radio capacity can be determined.

2.1. Methodology

Although analytical and algorithmic models for the performance analysis of packet-switched radio networks are under development, the full detail of the GPRS protocol architecture and the Internet protocols including TCP cannot be described simply by formulas or equations usable in practice. Since GPRS networks are presently introduced, performance results are needed very fast, so that capacity and performance estimations can be done for GPRS introduction and evolution scenarios.

Producing performance results by measurements in the existing GPRS networks is not easily possible, since scenarios with well-defined traffic load are hard to set-up, the calculation of performance and system measures are very limited, and the analysis of different alternative protocol implementations is not possible with the existing network equipment.

Therefore computer simulation with prototypical implementation of the standardized GPRS protocols and the Internet protocols, traffic generators for the regarded applications and a simple model for the radio channel is chosen as the methodology to get the needed results rapidly.

2.2. GPRS Radio Resources

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 [6]. The operator can decide to dedicate permanently or temporarily physical channels for the GPRS traffic. In this context GSM physical channels allocated permanently for GPRS are called *fixed Packet Data Channels (PDCHs)*, channels allocated temporarily for GPRS are called *on-demand PDCHs*.

Simulation results [7] have shown that the performance for GPRS-based services does not increase dramatically, when few fixed instead of on-demand PDCHs are used. If the cell capacity

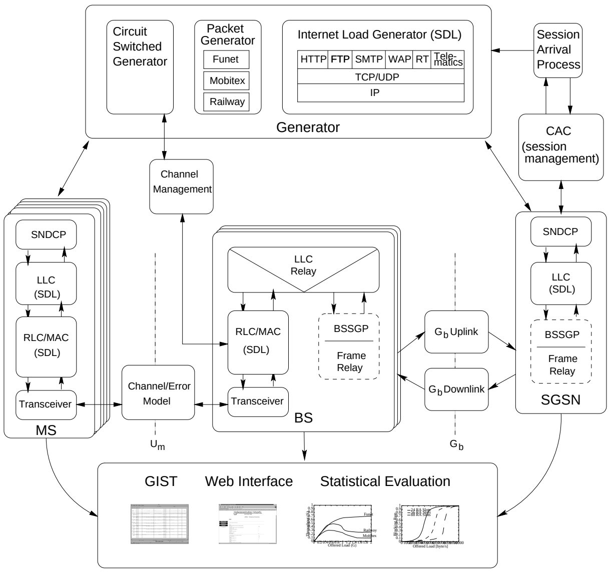

Figure 1: The GPRS/EGPRS Simulator GPRSim

is dimensioned with a low blocking probability, e.g., 1 %, for voice services, the use of on-demand PDCHs makes sense. This is plausible, since the probability that more than 2 channels are unused by voice services is around 90 %. On the other hand operators might allocate fixed PDCHs to be able to guarantee the availablity of GPRS. So dimensioning rules for both fixed and on-demand configurations as well as for mixed configurations with a combination of fixed and on-demand PDCHs have to be developed.

3. Simulation Environment

The capacity model for this examination is represented by the GPRS Simulator GPRSim, which was developed at the Chair of Communication Networks and models a GSM/GPRS network with its protocol architecture, the radio channel attributes and protocol specific traffic sources. Based on this model it is possible to create dimensioning graphs with the paradigm of Erlang-Tables and the Erlang-Formula, so that network dimensioning can be performed.

The (E)GPRS Simulator GPRSim [8] 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 (see Figure 1).

For the implementation of the simulation model in C++ the Communication Networks Class Library (CNCL) [9] is used that is a predecessor to the SDL Performance Evaluation Tool Class Library (SPEETCL) [10, 11]. This allows an object oriented structure of programs and is especially applicable for event driven simulations.

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 complex protocols like LLC, RLC/MAC based on GPRS/EGPRS release 99, 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 SDL2CNCL [10] and are finally integrated into the simulator.

3.1. Packet Traffic Generators

Internet sessions consist of the applications World Wide Web (WWW) and electronic mail (e-mail) running the TCP/IP protocol stack. Therefore Internet traffic models are necessary for simulative examinations of the performance of data services of mobile radio networks.

In the following, model parameters of these two applications and their distributions for generating protocol specific traffic are presented. Related documentation can be found in [12] and [13]. The parameters of these models are updated by parameters given by ETSI/3GPP suppositions for the behaviour of mobile Internet users [14] (see Table 1).

3.1.1. WWW Model

WWW sessions consist of requests for a number of *pages*. These pages consist of a number of *objects* with a dedicated *object size*. Another characteristic parameter is the delay between two pages depending on the user's behaviour to surf around the Web [12, 14]. Table 1 gives an overview of the WWW parameters. The small number of objects per page (2.5 objects), and the small object size (3700 byte) were chosen, since Web pages with a large number of objects or large objects are not suitable for thin clients such as PDAs or smart phones.

3.1.2. E-mail Model

The e-mail model describes the traffic arising with the transfer of a message downloaded from a mail server by an electronic mail user. The only parameter is the amount of data per e-mail. A constant base quota of 300 byte is added to this size [13]. The parameters of this distribution are shown in Table 1. The value of 10000 byte as the e-mail size is chosen, since it is assumed that no e-mails with large attachments will be downloaded on mobile devices.

3.1.3. Wireless Application Protocol (WAP) Model

A WAP traffic model was developed and applied in [15]. The main characteristics of the model are very small packet sizes (511 byte) approximately following a log2-normal distribution and a limited value of the packet size (1400 byte).

Table 1: Model parameters of Internet applications (WWW and e-mail)

WWW Parameter	Distribution	Mean
Pages per session	geometric	5.0
Intervals between pages [s]	negative exponential	12.0
Objects per page	geometric	2.5
Object size [byte]	$\log_2$-Erlang-k	3700
e-mail Parameter	**Distribution**	**Mean**
e-mail size [byte]	$\log_2$-normal	10000
Base quota [byte]	constant	300

Since one of the main cognitions was that one PDCH can serve more than 20 WAP users with an acceptable QoS, WAP traffic is not critical for dimensioning issues compared to the classical Internet applications like WWW and e-mail. Due to the small packet sizes WAP traffic can be multiplexed seamlessly with the Internet traffic.

Therefore, WAP traffic is not further regarded in this paper. A worst case estimation can be done by the allocation of one more fixed PDCH for WAP traffic.

3.2. Transmission Control Protocol (TCP)

Classical TCP is implemented based on the description in [16] including slow start and congestion avoidance. It is assumed that for each HTTP object a new TCP connection is set-up. Although in HTTP version 1.1 a TCP connection can be reused to transmit the following HTTP objects, several TCP connections are set-up in parallel for the first HTTP objects. Since in this model a small number of objects is regarded, the probability for separate TCP connections for each object is high. Additionally HTTP objects may be located on different servers, i.e., seperate TCP connections are needed.

3.3. Circuit-switched Traffic Generator

The circuit-switched traffic generator generates events with an interarrival time determined by a negative-exponential distribution. These events correspond to calls initiated in a cell. The traffic value in Erlang is given by the two configurable mean values of the call interarrival and the call duration times.

3.4. Air Interface Error Model

Within the air interface error model the decision is made if a received data or control block is either errorfree or defective. To decide this a set of mapping curves is used. These curves are gained from link level simulations and allow the mapping of C/I values onto the corresponding block error probabilities (BLEPs) for every radio block [17, 18, 19]. In Figure 2 the BLEP versus C/I reference function, which is taken from link level simulations, is shown. The TU3 (Typical Urban) channel model in GSM 05.05 was used in all link level simulations.

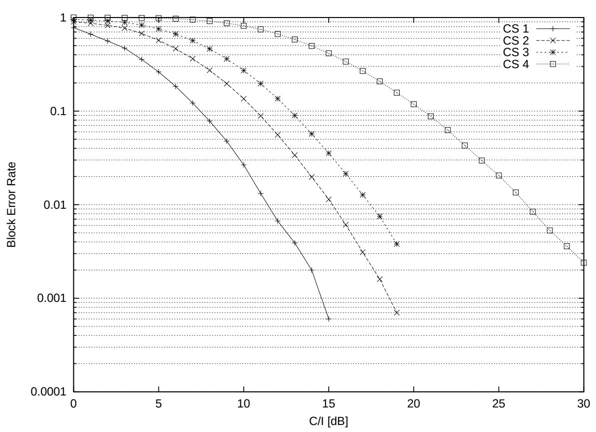

Figure 2: BLEP over C/I reference function used for the air interface error model

4. Dimensioning Rules

4.1. Simulation Scenarios

The cell configuration is defined by the number of GSM single-carrier transmitter-receiver units (TRXs) and the number of PDCHs allocated fixed or on-demand for GPRS.

The air interface error model is characterized by a constant RLC/MAC block error probability of 13.5 % corresponding to a C/I of 12 dB. This parameter corresponds to a typical coverage planning value widely used by operators for GSM networks. As the coding scheme for user data CS-2 is used. Since CS-2 is a relatively robust Coding Scheme and the average C/I of 12 dB is a worst case estimation, capacity limitations caused by co-channel interference in high load conditions can be neglected.

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 3 random access subchannels per 52-frame. All conventional MAC requests have the radio priority level 1 and are scheduled with a FIFO strategy. Ongoing Temporary Block Flows (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 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. The focus lies on the radio network and not on the core network, since radio resources are scarce and representing the system bottleneck assuming that the core network is well dimensioned.

The inactive period between two sessions is set to 12 seconds. The Internet traffic [20] is composed of 70 % e-mail sessions and 30 % WWW sessions (see Table 1).

For simulations with coexisting circuit-switched (CS) traffic, the maximum number of on-demand PDCHs is 8. On-demand PDCHs are used for both GPRS and CS services, with the restriction that CS has a higher priority and can pre-empt the on-demand PDCHs. The parameters for the CS traffic sources that are used for different blocking probability values have been calculated based on the Erlang-B-Formula. For the call blocking probability the term Grade of Service (GoS) will be used in the following. For details of the protocol implementations and traffic models see Section 3 or [8].

4.2. Performance and System Measures

As the performance measure the average downlink IP throughput per user during transmission periods is regarded. During an ongoing download of a Web page or e-mail the downlink IP throughput for each user for each TDMA frame is evaluated. From these values the mean value is calculated. The simulations are run until a confidence interval of 10 % is reached [21].

This QoS measure is the most important measure for WWW and e-mail applications and is chosen here as the dimensioning criterion. The same dimensioning approach can be done with delay or throughput quantile measures. Comprehensive simulation results for other performance and system measures such as delay, utilization and system throughput can be found in [22, 23].

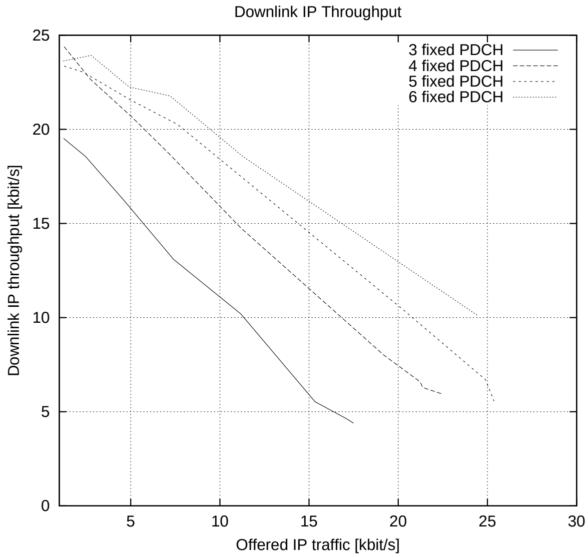

Figure 3: Mean downlink IP throughput per user

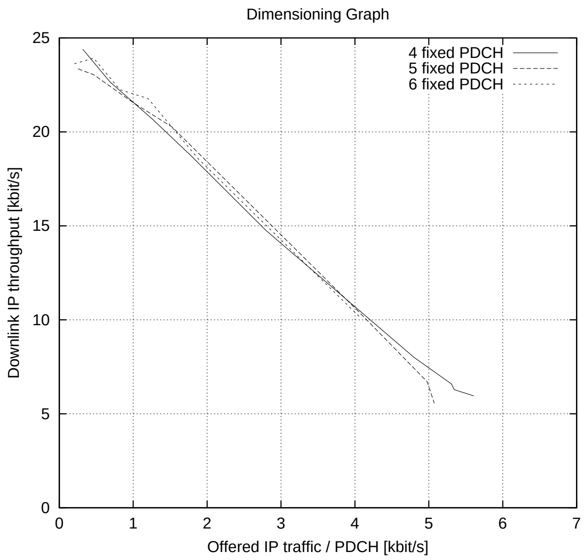

Figure 4: Dimensioning graph for fixed PDCH configurations

4.3. Fixed PDCH Configurations

If GSM radio cells have high capacity reserves, i.e. an acceptable blocking probability for voice calls can be guaranteed even if traffic channels are withdrawn, GSM physical channels can be allocated as fixed PDCHs to ensure the guaranteed availability of GPRS-based services. Figure 3 shows the mean downlink IP throughput per user during transmission periods over the IP traffic offered to the GPRS bearer for different numbers of PDCHs. If the x-axis is transformed dividing the offered traffic by the number of fixed PDCHs, the curves for more than 3 fixed PDCHs become equal (see Figure 4). With this dimensioning graph gained from the GPRSim, capacity planning can be performed following the next five steps.

- define the desired QoS
- estimate the number of users per cell
- define the offered IP traffic per user and calculate the offered traffic per cell
- determine the acceptable traffic per PDCH with the desired QoS from the dimensioning graph
- calculate the needed number of PDCHs with:

$$\mathrm{PDCH} = \frac{\text{estimated traffic}}{\text{acceptable traffic per PDCH}} \tag{1}$$

To visualize the dimensioning procedure introduced above, the following example is given. With a desired downlink IP throughput of 12.5 kbit/s, a given offered traffic per user of 540 kbyte/h, and 10 users per radio cell the needed number of PDCHs can be estimated following the next four steps.

- define the desired average QoS. Here the mean downlink IP throughput of 12.5 kbit/s is the QoS limit that is desired.
- estimate the average number of users per cell: user $= 10$
- calculate the total offered IP traffic per cell for the regarded scenario:
  offered traffic/user $= 540\,\mathrm{kbyte/h} = 1.2\,\mathrm{kbit/s}$
  total offered traffic $= 10 \cdot 1.2\,\mathrm{kbit/s} = 12\,\mathrm{kbit/s}$
- gain the accetable traffic per PDCH from the respective dimensioning graph:
  acceptable traffic/PDCH $= 3.5\,\mathrm{kbit/s/PDCH}$
  needed PDCHs $= 3.4$

Finally it is necessary to round off the calculated number of PDCHs. In this example 4 fixed PDCHs have to be provided.

4.4. On-demand PDCH Configurations

Since GSM networks are dimensioned for a low blocking probability for voice calls, the probability that a few channels are unused by voice services is high. On the other hand in GPRS introduction scenarios the offered data traffic will be comparatively low. As a result the use of on-demand PDCHs that are shared between voice and data services lead to an efficient radio resource utilization [7].

4.4.1. Estimating on-demand PDCH configurations with equivalent fixed PDCH configurations

A simple dimensioning approach for on-demand PDCH configurations as proposed in [24] and by other manufacturers is to calculate the usable bandwidth, namely the average number of PDCHs, that is left open by voice services with the Erlang-B-formula and take this number of PDCHs for capacity estimation in an equivalent fixed PDCH configuration.

The average number of GSM physical channels that are available for GPRS can be calculated, with *PDCH* as the average number of available PDCHs and *TCH* as the total number of GSM traffic channels in the radio cell:

$$\mathrm{PDCH} = \mathrm{TCH} - \text{offered voice traffic} \cdot (1 - \mathrm{GoS}) \tag{2}$$

To show that this approach is not accurate enough for dimensioning, simulation results for an on-demand example scenario and fixed PDCH scenarios are compared. In the regarded example scenario with a GoS of 0.5 % the average number of unused GSM TCHs that are available on average for GPRS is higher than 7 after Equation 2. That means that an equivalent configuration with 7 or 8 PDCHs should be taken.

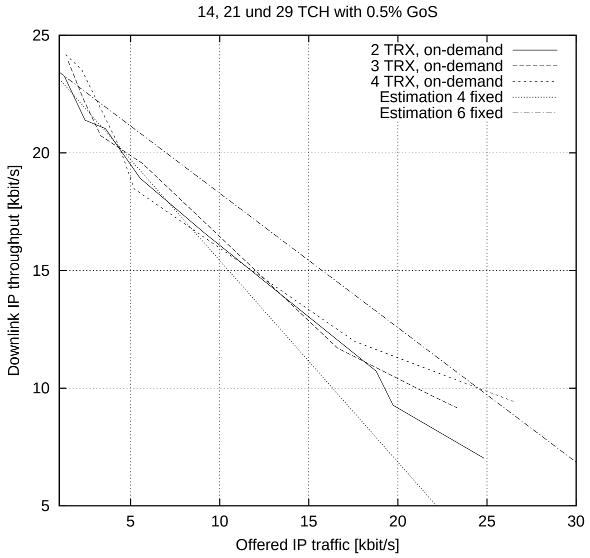

Figure 5: Estimation with an equivalent fixed PDCH configuration

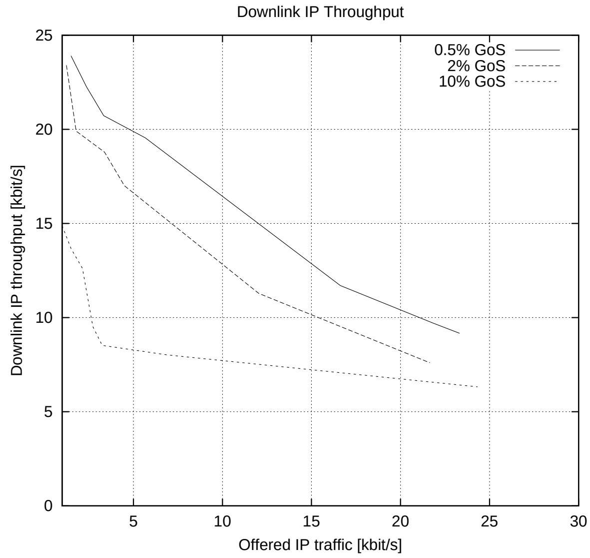

Figure 6: Dimensioning graph for on-demand PDCH configurations

However, the simulation results presented in Figure 5 show that the performance in this on-demand scenario both for 2, 3, and 4 TRXs is up to 25 % worse than in a scenario with 6 fixed PDCHs especially in the range of higher traffic load. That means that the regarded on-demand scenarios can not be estimated precisely with an equivalent scenario with 7 or 8 PDCHs. As the result of this comparison an equivalent fixed PDCH scenario with the average number of TCHs, which are available for GPRS in an on-demand configuration, can not genarally be applied for precise dimensioning of on-demand configurations.

4.4.2. Using simulation results for on-demand configurations

More precise capacity planning for on-demand configurations can be done by taking a dimensioning graph for an existing TRX scenario as the basis and finding the acceptable coexisting CS traffic (corresponding to a GoS value) so that the GPRS performance for a given offered IP traffic can be guaranteed. As an example based on the 3 TRX scenario (see Figure 6) this can be performed after the following steps with the same example values as in Section 4.3:

- estimate the GoS for the related TRX scenario for CS traffic, which is expected for the planning scenario. Here 1.5 % GoS is assumed as an example value.
- estimate the number of GPRS users per cell:
  user $= 10$
- calculate the total offered traffic per cell:
  offered traffic/user $= 540\,\mathrm{kbyte/h} = 1.2\,\mathrm{kbit/s}$
  total offered traffic $= 10 \cdot 1.2\,\mathrm{kbit/s} = 12\,\mathrm{kbit/s}$
- define the desired average user performance the operator wants to guarantee (here 12.5 kbit/s).
- regard the operating point p defined by the desired user performance on the y-axis and the total offered traffic on the x-axis and choose the adequate GoS curve as the next that lies above this operating point p. Here p equals (x = 12 kbit/s, y = 12.5 kbit/s).

If the offered CS traffic corresponding to this GoS is predicted to be exceeded a new TRX should be added. Here p is just below the 2 % GoS curve that means that coexisting CS traffic corresponding up to 2 % GoS for this scenario is acceptable. Since a GoS of 1.5 % is assumed an additional TRX is not necessary in this example.

4.5. Remarks to mixed configurations with fixed and on-demand PDCHs

To be able to guarantee the availability of GPRS-based services an operator might provide 1, 2 or more fixed PDCHs and the rest up to 8 as on-demand PDCHs. In these cases the pure on-demand configurations can be taken as a worst case estimation, since the probability that the first PDCHs are used by CS traffic are quite low (under 10 %) [7].

If 4 or more fixed PDCHs are provided and the rest up to 8 are on-demand, there are two possibilities. If another TRX is integrated to reduce the blocking probability for CS calls, the on-demand channels will not be highly utilized. Here the capacity can be estimated taking a configuration with 8 fixed PDCHs. If no further TRX is provided, the utilization of the on-demand PDCHs will be very high. In this case the capacity can be estimated by a configuration with the allocated number of fixed and no on-demand PDCHs.

5. CONCLUSIONS

In this paper dimensioning rules for GPRS networks for fixed and on-demand PDCH configurations were presented.

The dimensioning graph for fixed PDCH configurations is based on simulation results for different load scenarios and profits by nearly linear correlation between downlink IP throughput and the offered IP traffic in the radio cell. With this dimensioning graph the relationship between desired QoS, offered traffic and needed radio capacity can be estimated.

Regarding on-demand PDCH configurations, dimensioning graphs based on taking the average number of available PDCHs as an equivalent number of fixed PDCHs, can not be applied.

For on-demand configurations dimensioning graphs based on the simulation results for different CS load scenarios can be used to determine, if a new TRX has to be installed to serve the GPRS traffic with a desired QoS.

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