THE CAPACITY AND PERFORMANCE GAIN REACHABLE WITH LINK QUALITY CONTROL IN EGPRS NETWORKS

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ABSTRACT

In this paper a performance analysis of the Enhanced General Packet Radio Service (EGPRS) with the focus on radio network dimensioning for the mobile Internet access is presented. The impact of the new Modulation and Coding Schemes (MCSs) and the related Link Quality Control (LQC) functions defined in the EGPRS specifications on the overall system performance and the quality of service (QoS) for the non-real-time Internet applications WWW and E-Mail is examined. To achieve this, simulation results for EGPRS performance and system measures for different load situations are produced with the simulation tool GPRSim that models the traffic behaviour of an EGPRS network.

I. INTRODUCTION

Third-Generation (3G) mobile radio networks like the Universal Mobile Communication System (UMTS) in Europe will provide data services with higher data rates than presently available in second generation (2G) cellular systems. UMTS will realize net bit rates of up to 144 kbit/s with wide coverage, up to 384 kbit/s in hotspots, and up to 2 Mbit/s in indoor scenarios. A stepwise way towards 3G, however, will already be performed by the extension and further development of existing cellular systems. The advantage of such an evolution process is the faster availability of such services, since the infrastructure of existing systems can be applied. Furthermore there is the opportunity to prepare the customers to new, so called third-generation services. Enhanced Data Rates for Global Evolution (EDGE) is a further development of the GSM data services High Speed Circuit Switched Data (HSCSD) and General Packet Radio Service (GPRS) [10, 9] and is suitable for circuit- and packet-switched services. The EDGE data services are called Enhanced GPRS (EGPRS) and Enhanced CSD (ECSD). Applying modified modulation and coding schemes EGPRS reaches raw bit rates of up to 69.6 kbit/s per GSM physical channel. If a user utilizes all 8 time slots in parallel, the theoretical maximum raw bit rate is 556.8 kbit/s. The maximum net bit rate reachable rises to about 384 kbit/s [5].

In the context of radio network dimensioning and capacity planning issues the focus lies on mobile Internet applications like WWW and E-Mail, since these are the applications predicted for GPRS and EDGE phase 1. While these system concepts will be suitable for non-real-time applications, EDGE phase 2 with its common evolution of GSM, TDMA/136 and EDGE towards GSM/EDGE Radio Access Networks (GERAN) [1, 2] will be mainly related to packet-based real-time applications.

This paper presents characteristic EGPRS performance and system measures for different cell configurations and load situations based on a simulative performance analysis. They are directly usable for radio network dimensioning and system optimization regarding non-real-time applications. The performance evaluation is considering both the detailed EGPRS protocol implementation and protocol specific traffic generation for Internet applications, including TCP modelling.

In the first section the new Modulation and Coding Schemes together with the Link Quality Control (LQC) functions, namely Link Adaptation (LA) and Incremental Redundancy (IR) defined in the EDGE specifications will be introduced. After that the simulation model that is the basis for the performance evaluation is presented. This will be followed by simulation results for the mean throughput per user during data transmission, the mean packet delay, the system throughput per radio cell, and the channel utilization for different cluster and cell sizes and different LQC capabilities.

II. EVOLUTION FROM GSM TO EDGE

The mayor changes in the GSM standard are made at the radio interface. The modulation scheme named 8-Phase-Shift-Keying (8-PSK) is introduced which will not replace the current Gaussian Minimum Shift Keying (GMSK), but coexist. With 8-PSK it is possible to provide a higher bit rate which is necessary to support bandwidth extensive data applications. The modifications concern the RLC/MAC layer and the physical layer. Since these protocols are implemented in the Mobile Station (MS) and the Base Station (BS), both have to be modified. Since 8-PSK is more sensible to bad channel quality, Link Quality Control (LQC) is introduced in EGPRS, which allows Link Adaptation (LA) to react on a changing radio link quality. Additionally, soft information can be stored during retransmissions to enable Incremental Redundancy (IR). The RLC/MAC proto-

Scheme	Code rate	Header Code rate	Modulation	RLC blocks per Radio Block (20ms)	Raw Data within one Radio Block	Family	BCS	Tail payload	HCS	Data rate kb/s
MCS-9	1.0	0.36	8PSK	2	2x592	A	2x12	2x6	8	59.2
MCS-8	0.92	0.36		2	2x544	A				54.4
MCS-7	0.76	0.36		2	2x448	B				44.8
MCS-6	0.49	1/3		1	592 *544+48*	A	12	6		29.6 27.2
MCS-5	0.37	1/3		1	448	B				22.4
MCS-4	1.0	0.53	GMSK	1	352	C				17.6
MCS-3	0.80	0.53		1	296 *272+24*	A				14.8 13.6
MCS-2	0.66	0.53		1	224	B				11.2
MCS-1	0.53	0.53		1	176	C				8.8

NOTE: the italic captions indicate the padding.

Table 1: EGPRS Modulation and Coding Schemes and Coding Parameters

col structure and retransmission mechanism proposed for EGPRS is based on the GPRS standard. An LLC frame is divided into a number of RLC blocks. The duration of a radio block comprising one or two RLC blocks is 20 ms, its information content ranges from 176 to 1184 bits, depending on the Modulation and Coding Scheme (MCS) that is used (see Table 1). MCS-1 to MCS-4 use GMSK as modulation scheme similar to the coding schemes used in GPRS providing bit rates up to 17.6 kbit/s. MCS-5 to MCS-9 use the 8-PSK modulation scheme enhancing the bit rate up to 59.2 kbit/s per time slot. The MCSs are classified in three different MCS families consisting of different basic payload sizes. An RLC block is created depending on the MCS family currently used. For a detailed discription see [3, 4]. Through transmitting a different number of payload units within a 20 ms block, different code rates are achieved, resulting in bit rates of 8.8 kbit/s up to 59.2 kbit/s per time slot. According to the link quality, an initial MCS is selected for each RLC block. For retransmission, it is allowed to use the same MCS or to switch to another MCS of the same MCS family. In order to perform the most efficient LA, measurements of the radio channel quality are the basis of the choice of the MCS. The operation of LQC relies on measurements of the link quality, depending on C/I values, frequency errors, time dispersion, interleaving gain due to frequency hopping, velocities and bit error probability. In IR mode three different puncturing schemes (PS1-3) are used for retransmitted blocks. PS-1 is sent at first and if decoding is unsuccessful, PS-2 will be sent. The IR functionality saves soft information of PS-1 and performs a joint decoding with PS-2 after the received retransmission with PS-2. Stealing bits are used to indicate the code rate and puncturing scheme used by the sender. More detailed information about the EDGE capabilities is given in [9].

III. SIMULATION

For this study a simulation tool named GPRSim was used. This simulation environment allows to ascertain and to optimize properties of different protocols of the EGPRS transmission plane. In addition, it gives the possibility of

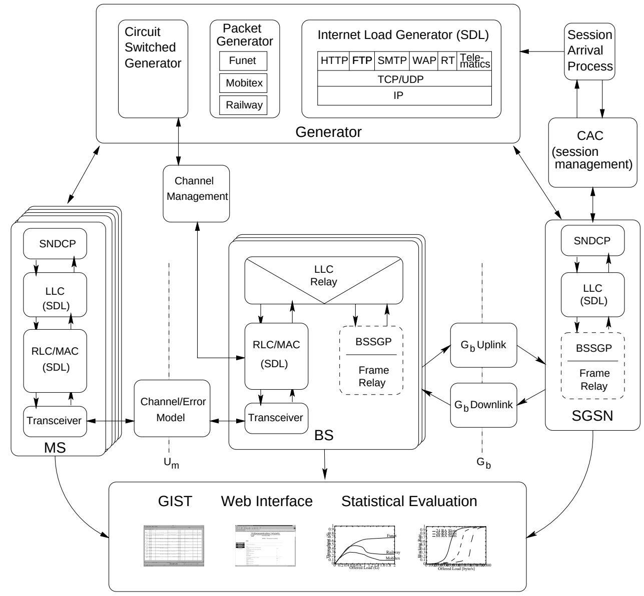

Figure 1: The GPRS/EGPRS Simulator GPRSim

network capacity and quality of service planning by performance evaluation in certain simulation scenarios. The GPRS/EGPRS Simulator GPRSim is developed as a pure software solution in the programming language C++. Up to now in the GPRS architecture 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 implementation of the simulation model in C++ the Communication Networks Class Library (CNCL) [6], which was developed at the Chair of Communication Networks, 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 based on GPRS/EGPRS Release 99, and the Internet Load Generators including TCP/IP and UDP/IP are specified with the Specification and Description Language (SDL), are translated to C++ by the Code Generator SDL2CNCL [7] 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 to study the behaviour of EGPRS in a realistic way.

The RLC/MAC layer that was implemented for GPRS was extended by the new MCSs and the LQC functions LA and IR. The choice of the MCSs is based on the results from [5] to optimize the throughput for LLC data.

The channel/error model determines, if a radio block transmitted in the simulator is erroneous. With the distance between MS and BS that is calculated by a mobility model, the radio propagation model, which models the statistical behaviour of the radio channel, determines the signal-to-interference ratio at the receiver. This value can be

Table 2: Model parameters of Internet applications (HTTP and SMTP)

HTTP 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
Amount of SMTP data	**Distribution**	**Mean**
E-Mail Size [byte]	$\log_2$-normal	10000
base quota [byte]	constant	300

mapped onto a block error probability (BLEP) as described in [11, 12]. With the comparison of the BLEP with a generated value from a descrete random process the error decision is made. More information about the mobility, radio propagation model and the BLEP mapping can be found in [9].

IV. Simulation Results

A. Simulation Scenarios

The cell configuration is given by the number of PDCHs available for GPRS/EGPRS. Here 4 fixed PDCHs are used. The channel conditions are determined by the cell and cluster size that are the basis for the C/I calculation. Cluster size 3 and 7 and cell sizes with a radius of 300 and 3000 meters are regarded.

LLC and RLC/MAC are operating in acknowledged mode. The multislot capability is 4 uplink and 4 downlink slots. The MAC protocol instances in the simulations 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. 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. The session interarrival time is set to 30 seconds. The Internet traffic (see [8]) is composed of 70 % E-Mail sessions and 30 % WWW sessions (see Table 2).

B. Maximum Performance of the EGPRS MCSs

First the maximum IP throughput per user during transmission periods reachable with the EGPRS MCSs focusing on Internet applications WWW and E-Mail is regarded in comparison to GPRS. This measure is the QoS paramter that is noticed by the user for these kind of applications, i.e., the IP data rate when the user is waiting for a web page. Additionally the IP delay, the system IP throughput per radio cell and the PDCH utilization for the different MCSs are examined. For this an optimal, errorfree channel is assumed. Figure 2 shows the mean downlink IP throughput per user during transmission periods over the number of active EGPRS users for different fixed MCSs. The EGPRS MCSs 1-3 are reaching nearly the same performance as the corresponding coding schemes in GPRS (see Figure 3). This is plausible since the payload size of the corresponding schemes in GPRS and EGPRS is similar. The performance of MCS-4 differs from CS-4. Since the payload size of MCS-4 is smaller than CS-4 the throughput of CS-4 is higher. Under optimal conditions, i.e., if only one user is active, MCS-9 is used and an errorfree channel is assumed, an EGPRS user can reach a maximum mean IP data rate of 66 kbit/s for the chosen application mix. This is an improvement of ca. 50 % compared to the throughput for CS-4 in

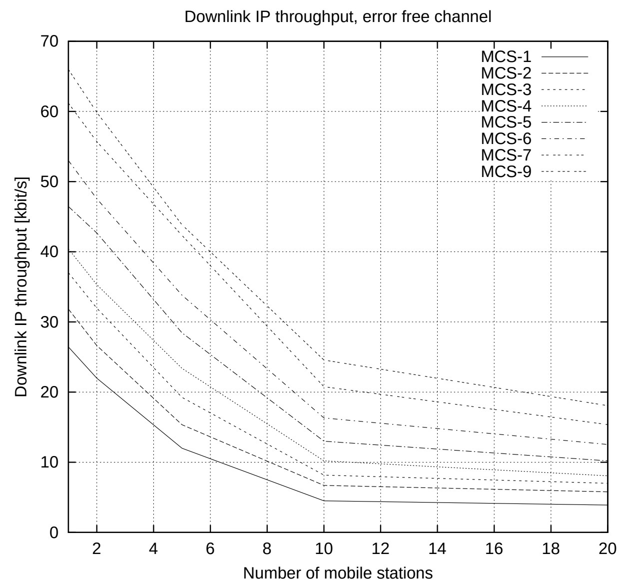

Figure 2: Mean downlink IP throughput per user for EGPRS

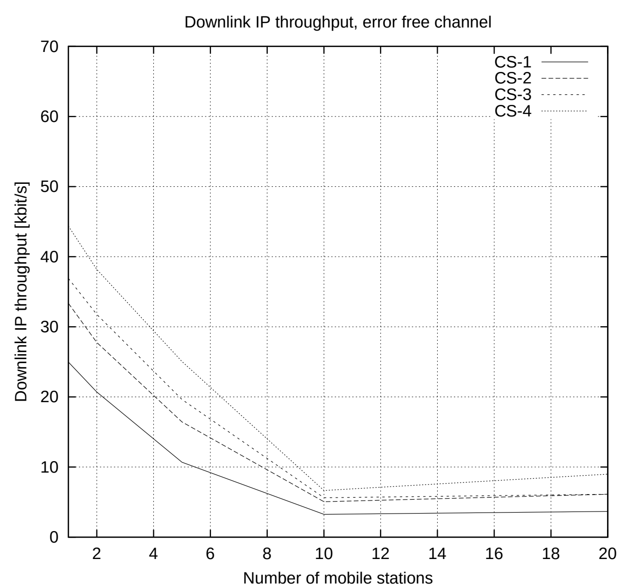

Figure 3: Mean downlink IP throughput per user for GPRS

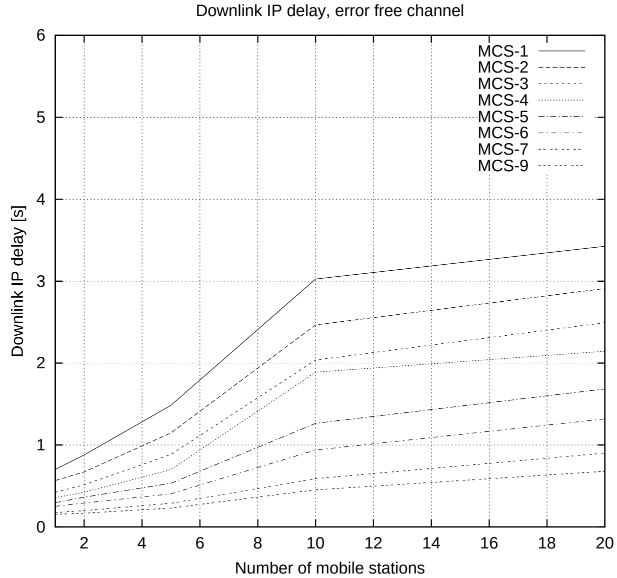

Figure 4: Mean IP packet delay

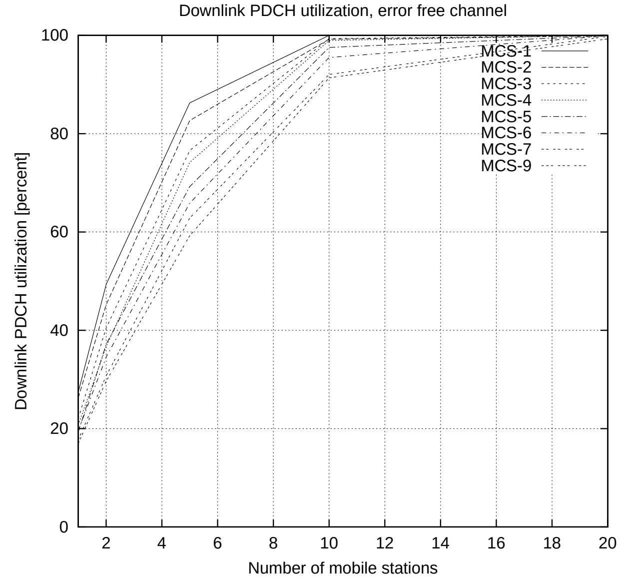

Figure 6: Mean downlink PDCH utilization

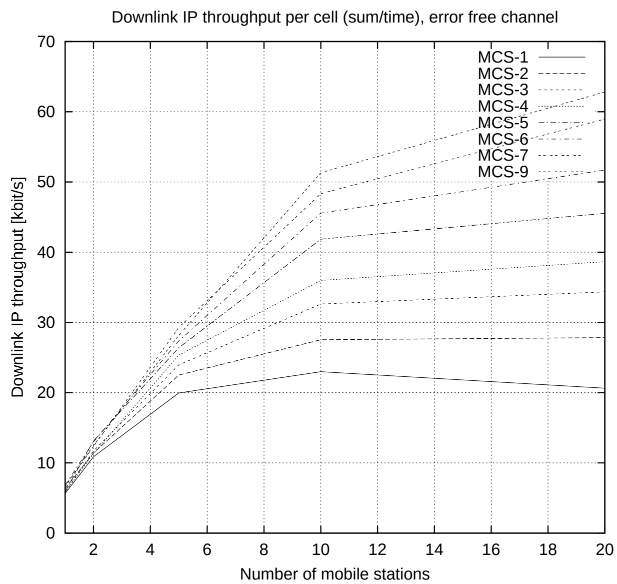

Figure 5: Mean IP system throughput per radio cell

GPRS, but regarding 10 users the performance gain reachable with EGPRS MCSs gets more noticeable, here the gain rises over 100 %. Figure 4 shows the IP packet delay for the different MCSs in EGPRS. Furthermore the EGPRS system measures are showing the traffic behaviour. Figure 5 shows the mean downlink system throughput of all connections per radio cell. In Figure 6 the mean downlink PDCH utilization is presented. Utilization is defined by the number of downlink radio blocks carrying data or control information devided by the total number of transmitted radio blocks. The graphical presentation shows that with ten active MSs the mean utilization of the PDCHs is nearly 100 % for all GMSK schemes. The two highest EGPRS MCSs (MCS 7-9) let some capacity reserves for further users. As expected, the maximum values of the mean cell throughput are measured for MCS-9. The value lies between 40 % for ten mobiles up to ca. 62 % for twenty MSs higher compared to MCS-4.

The presented results within this section do not indicate the maximum throughput generally achievable with EGPRS and 4 PDCHs, since the measured values depend on the application mix and the characteristics of e.g. the WWW sessions.

C. The Effects of LQC on the Performance

Now the performance and system measures, especially the IP throughput performance, are regarded considering the EGPRS LQC functions LA and IR compared to fixed MCSs.

First a scenario with cluster size 3, cell radius of 300 m and an MS velocity of 6 km/h is regarded. Simulations have shown that fixed MCS-5 reaches the best performance for this scenario compared to other fixed MCSs. Additionally the performance is plotted for LA without IR and LA with IR. The last one represents full LQC capability. Figure 7 shows that the performance with LA is increased by up to 20 % compared to the fixed MCS-5. If additionally IR is used, the performance gain is not significant to LA without IR.

In Figure 8 the mean downlink IP packet delay is presented. Compared to the operation with the well chosen fixed MCS-5, IR is able to decrease the delay by up to 10 %. LA achieves a delay performance gain of even 20 to 25 %, while the additional use of IR does not change the delay performance significantly. The LQC functions do not have a major effect on the system throughput per cell compared

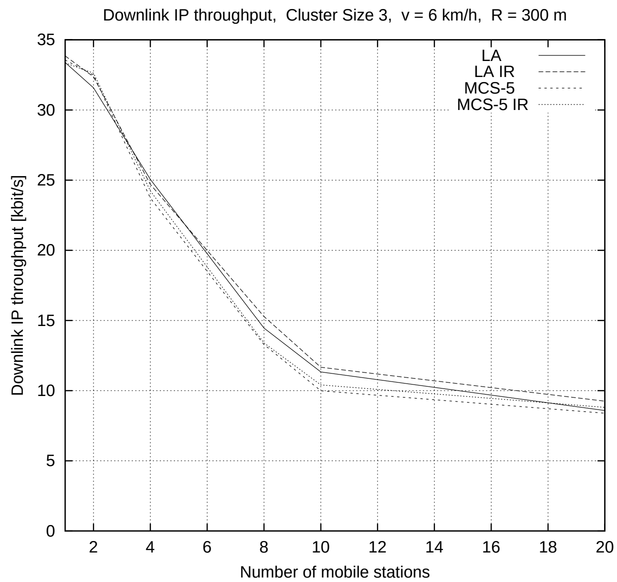

Figure 7: Mean downlink IP throughput per user for LQC and MCS-5

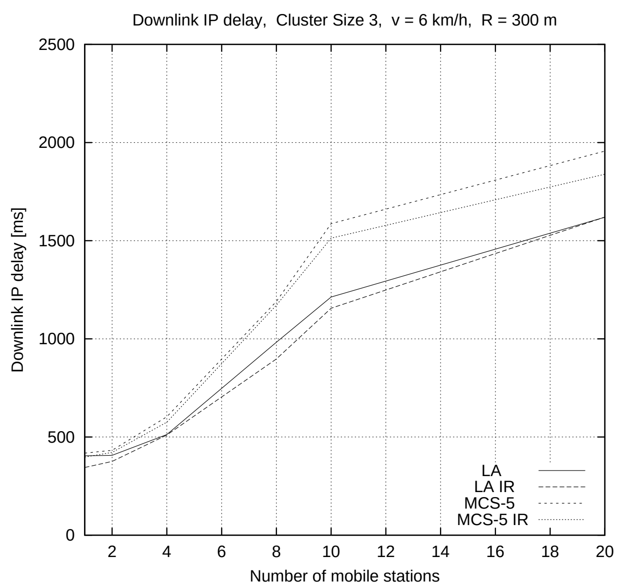

Figure 8: Mean downlink IP packet delay for LQC and MCS-5

to the well chosen fixed MCS-5 (see Figure 9). In the range of 10 to 20 MS the cell throughput ranges between 37 and 41 kbit/s.

Now the throughput performance from the user's point of view is discussed regarding the LQC functions in comparison to a less robust fixed MCS chosen. If LA is not used and a less robust MCS is chosen, e.g. MCS-6, the throughput performance can be increased with IR. Figure 10 shows a gain of up to 30 %. If the MCS is chosen even more aggressively, e.g. MCS-9 (see Figure 11), the performance cannot be fully recorvered compared to fixed MCS-5.

Finally the throughput performance considering different cluster and cell sizes is discussed. Figure 12 shows that the mean downlink IP throughput per user during transmission periods reaches up to 45 kbit/s in the scenario with cluster size 7 and 3000 m cells. While the performance gain in this scenario compared to the scenario regarded above ranges between 15 and 30 % in low load situations, an increase of up to 45 % is reached in high load situations. The throughput does not fall below 14 kbit/s for the scenario with cluster size 7 even with 20 MS being active in the cell.

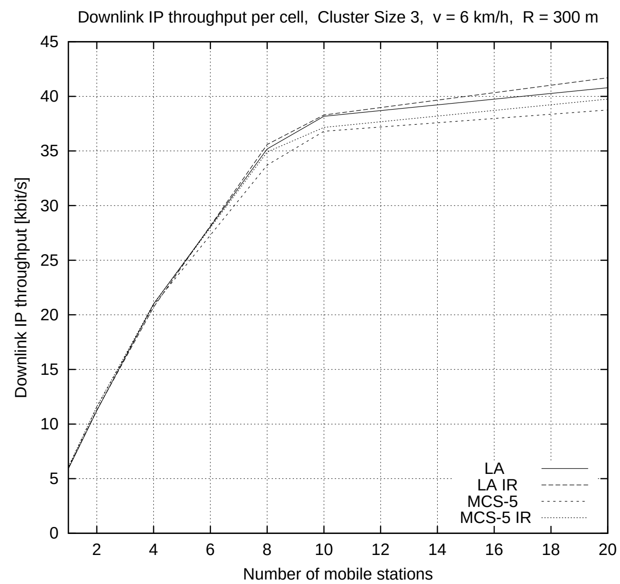

Figure 9: Mean downlink IP system throughput per cell for LQC and MCS-5

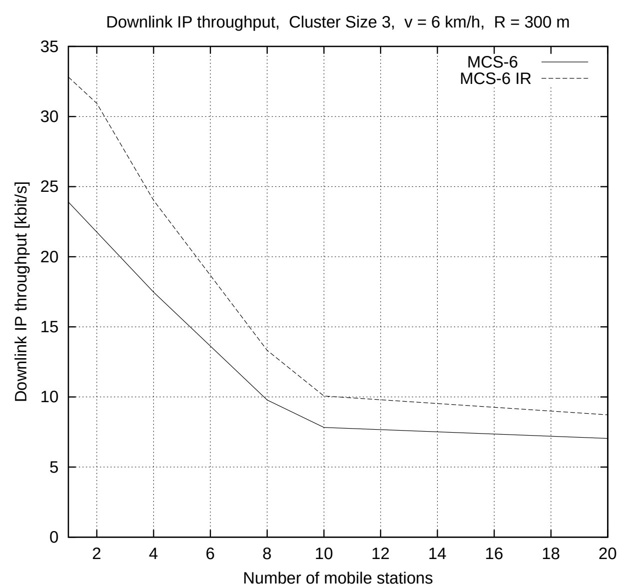

Figure 10: Mean downlink IP throughput per user for MCS-6 with and without IR

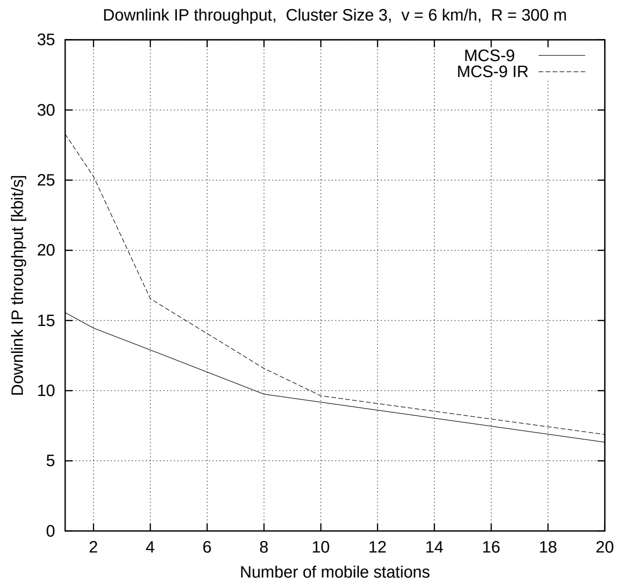

Figure 11: Mean downlink IP throughput per user for MCS-9 with and without IR

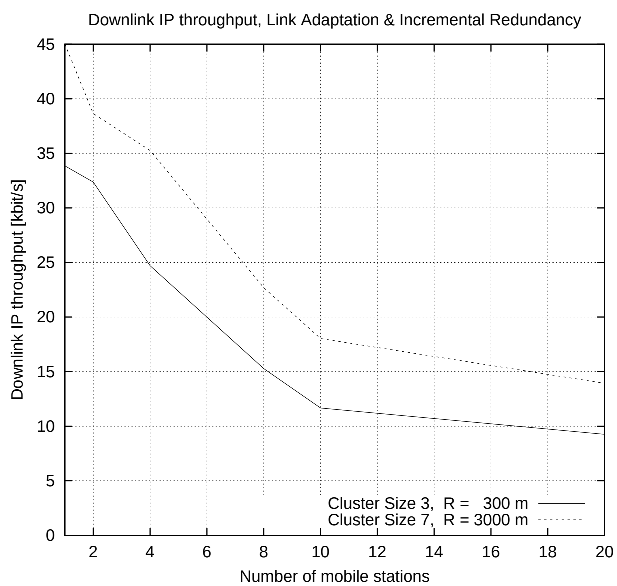

Figure 12: Mean downlink IP throughput per user for different cluster and cell sizes

V. CONCLUSIONS

In this paper the performance and system measures of EGPRS regarding non-real-time Internet applications are presented. Different LQC functions and their impact on the overall performance are examined. For the regarded traffic mix (30 % WWW, 70 % E-Mail), a throughput performance gain of up to 100 % compared to GPRS is reachable with the new MCSs in EGPRS. A maximum downlink IP data throughput per user during transmission periods of about 66 kbit/s is reachable for this traffic mix with 4 PDCHs available and the multislot capability of 4 slots in up- and downlink. Additionally LA and IR are enabling performance gains in comparison to a fixed chosen MCS. Although the gain through LA compared to a well chosen fixed MCS is not dramatic, LA should be used in EGPRS networks. The reason is that without LA, a fixed MCS would have to be chosen for every site. This cannot be simply realized in realistic radio coverage planning processes.

VI. REFERENCES

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