COMPARISON OF DATA THROUGHPUT PERFORMANCE IN GPRS, EGPRS, AND UMTS

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Abstract: *The expected growth in mobile data communications requires efficient spectrum usage. GSM has been evolved towards the 2.5G systems GPRS (General Packet Radio Service) and EGPRS (Enhanced EGPRS, often called EDGE) to support packet data, while UMTS (Universal Mobile Telecommunications System) provides a completely new, flexible air interface. The performance of these approaches depend on the environment, e.g. Rural, Suburban, or Dense Urban.*

Simulators have been developed at Alcatel to study the downlink system performance of 2G, 2.5G and 3G air interface technologies. Many different scenarios and configurations have been investigated to show the respective advantageous areas of operation.

The presented studies show that in case of tri-sectored cells EGPRS performs typically 2-2.7 times *better than GPRS. Assuming small cells in Dense Urban or Suburban environments UMTS utilises the spectrum again up to 1.75 (indoor), 1.4 (outdoor) and 1.1 (in-car) times more efficient than EGPRS. However, in Rural environments or using larger cells UMTS suffers from the fact that the transmission power is shared between all users, and EGPRS turns out to be the technology with the better bandwidth efficiency. Generally it can be observed that the UMTS cell size has to be set quite carefully.*

1 Introduction

Second generation (2G) systems like GSM were mainly developed to handle voice calls. Besides, simple data communication is possible in circuit switched mode. For better adaptation to the important class of bursty data traffic GPRS was introduced with increased radio resource efficiency. EGPRS is the consistent evolution with improved utilisation of good radio channel conditions by higher order modulation and new coding schemes (cf. [1]).

Third generation systems were designed to open up additional radio transmission resources for various kinds of future data services, even for high speed mobile data access. UMTS as a 3G system was therefore especially designed under consideration of the special properties of data communications (cf. [1], ..., [4]).

As the amount of data traffic to be carried on mobile networks is expected to grow significantly in the next years, most operators have to invest quite a lot in their radio transmission infrastructure to participate in this market segment. Both, EGPRS and UMTS technology are now ready to be introduced and, depending on the operators strategic network evolution plans, these systems might compete in some scenarios. Operators are strongly interested in technical performance evaluations as basis for their strategic decisions.

This document presents simulations to compare the bandwidth efficiency of GPRS/EGPRS/UMTS radio access network technology considering downlink packet traffic. More or less advantageous areas of operation can be identified for each system. The results presented here are limited to tri-sectorised base station configurations and only the 1800 MHz band is considered for GPRS/EGPRS. Additional simulations were carried out in the scope of this work but are not presented here.

Of course bandwidth efficiency is just one system requirement out of many. In UMTS much effort has been spent to design a very flexible system open for future data applications. This leads to a high system complexity. EGPRS is already an optimised system, while UMTS stands at the beginning of its evolution. Plans for further UMTS improvements (e.g. High Speed Downlink Packet Access, HSDPA) are already available. This has to be taken into account if the possibilities of the two systems shall be compared.

This paper is organized as follows: After giving a short overview about data traffic in mobile networks in chapter two, chapter three covers the modelling aspects of the two systems and how they are realised in the simulations. In chapter four the parameterisation of the simulations and the investigated scenarios are presented. Furthermore the obtained results in terms of throughput vs. distance and overall spectral efficiency of the system are shown. Finally chapter five summarises some general conclusions from these studies.

2 Data Traffic in Mobile Networks

Packet data transfer via mobile networks may be conveyed over various air interface channel types. Often data traffic uses dedicated channels with a guaranteed but rather low throughput, e.g. the Traffic Channel (TCH) of GSM. These dedicated channels are set up at the beginning of a packet data service session and are held during the whole lifetime of the session. In this case, due to the dynamic nature of packet data traffic, bursts in the traffic stream are delayed while during silence phases the valuable air interface resource is wasted. Furthermore, dedicated channels operate in non acknowledged mode, i.e. transmission errors have to be corrected by higher layer protocols.

"Bandwidth on demand" channels are better adopted to the dynamic nature of packet data traffic. They assign transmission capacity as soon as data is ready for transmission in the base station (for downlink data transfer) or in the mobile (for uplink data transfer). They segment the data to be transferred into small radio blocks. Examples for this type of channel are the Downlink Shared Channel (DSCH) of UMTS and the Packet Data Traffic Channel (PDTCH) of GPRS and EGPRS. These channels can be operated in the acknowledged mode and, consequently, they offer a well protected transport channel. Another important advantage of these bandwidth on demand channels is that they offer the so called "always on" feature. As an example users who register for mobile packet data services using these packet data air interface channels do not have to retrieve their E-mails manually but they receive them as soon as they arrive.

Nevertheless, systems like GPRS, EGPRS, and UMTS using DSCH also have some drawbacks. The required protocols for the "on demand" bandwidth allocation introduce additional delays, so that all incoming data bursts have to be stored until transmission capacity is available. This problem is slightly easier to solve for the downlink because media access of downlink packet data streams can be easily controlled by central instances while for the uplink all mobiles willing to transmit first have to signal their bandwidth requirements. In the latter case, additional delays cannot be avoided.

Moreover, all offered transmission capacity is shared between all users. Hence, the bandwidth offered for every individual data transfer varies depending on the dynamic, unpredictable behaviour of all data transfers.

Due to the varying radio channel conditions, the radio block error rate is not constant and, consequently, again varying transmission delays and transmission rates are induced. Furthermore, in GPRS/EGPRS but also in HSDPA the so called Link Adaptation (LA) protocol adopts the redundancy of radio blocks as well as the modulation scheme (except for GPRS) to the present channel conditions: If the channel condition is good, a higher modulation scheme is used and the number of redundancy bits is decreased and vice versa. On the one hand a radio access network with LA better utilises the available channel bandwidth, but, on the other hand, additional delay and throughput variations are introduced.

3 Modelling

3.1 Data Service

The service model assumed in these investigations is a simple data service model. All users are attached to the same service with 100% activity. There is a continuous data flow dedicated to each user. Neither the connection set up phase nor the release of a connection is considered. The measured user bit rate takes into account retransmissions of corrupted radio blocks. This model fits best with a FTP download. The measurements are taken between layer 2 and 3 in the protocol stack, i.e. higher layer aspects (e.g. TCP/IP interaction) are not covered.

This kind of service model may be less suited to achieve realistic performance indicators from a single user perspective, but it is helpful to find the maximum capacity of the respective radio access technology.

3.2 UMTS simulator

The UMTS simulations are based on the Monte-Carlo principle. A given network configuration is loaded with a random user distribution. The service is 64 kbps packet traffic. With this user configuration the power control algorithms are applied for all links, i.e. considering the respective link attenuation (incl. path loss, fading etc.), noise and the mutual user influence in form of interference it is tried to reach a given signal to noise ratio (*Eb/N0* target) for each user. This requires some convergence period.

In contrast to conversational and streaming applications interactive and background services do not depend as strictly on a bit error rate threshold. The overall system throughput may be increased with lower *Eb/N0* targets and therefore with reduced effective user throughput if considerably more users can be served. The target *Eb/N0* value was therefore considered as simulation parameter and the actual value was chosen under the constraint to maximise sector throughput.

The power control algorithms take into account the limitations for the maximum output power per sector, per

TCH and a reserved CCH part. Soft and softer handover is controlled by a handover threshold (3dB) and each user can have a maximum of 3 sectors in its active set.

The resulting *Eb/N0* values are mapped to the actual link performance in terms of *BLER* for each user in a measurement period. This mapping is done by the means of link level simulation results (cf. [5]). The percentage of users being satisfied is observed to decide whether the actual user density can be served or not (98% of the users are supposed to get more than 10% of the nominal bit rate). By sweeping the user density the maximum system capacity can be found (cf. [6]).

UMTS	Monte-Carlo simulations
Simulation area	90 sectors + wrap around
Bandwidth	5 MHz
Tx power	20 W (43 dBm) total 2 W (33 dBm) CCH 1 W (30 dBm) max per link
Tx antenna	18 dBi, 60° HPBW
nom. service bit rate	64 kbps
TTI	20 ms
Spreading factor	32
Orthogonality α	0.06 Pedestrian A 0.4 Vehicular A
MS noise figure	8 dB
(E)GPRS 1800	event-by-event simulations
Bandwidth	200 kHz, 8 timeslots
BCCH overhead	1/16
Tx power	35 W
Tx antenna	17 dBi, 65° HPBW
Cluster size	12 (DU, SU), 9 (RU)
MS noise figure	8 dB

Table 1: Some simulation parameters

Thereafter these steps are iterated many times with new user distributions to ensure statistically correct measurements independent from the actual user constellation. Furthermore a wrap around technique is applied to avoid asymmetric influences at the border of the simulation area. Therefore the simulation area can be seen as a toroidal surface.

The transport channels for user data are modelled as Dedicated Channels (DCH). These channels are best suited to handle large amounts of data with quite constant bit rate (e.g. FTP application). The 64 kbps service is realised with a spreading factor of 32. 30 codes under the primary scrambling code are used for user data. In case of code shortage further codes can be assigned using secondary scrambling codes, but with strongly increased interference due to the lack of orthogonality. A soft handover overhead of approximately 1.4 links per user was observed.

For very bursty traffic common or shared channels (e.g. DSCH) seem to be better adapted. With a DSCH part of the radio resource code power is shared between several users in a time division manner. I.e. the DSCH helps to utilise radio resources efficiently in case of bursty traffic. It will probably not increase the maximum throughput.

3.3 (E)GPRS simulator

The GPRS/EGPRS results are based on an ‘event-by-event’ driven simulator. One measurement cell is located at the centre of the simulation area. In the surrounding the co-channel cells are symmetrically distributed according to the cluster size parameter on a hexagonal grid. Mobiles are randomly sent over the area on straight tracks. The downlink radio resources in terms of time slots are randomly assigned to the mobiles actually located in the measurement cell (active mobiles).

The simulation is divided into a warm-up and a measurement phase. In a link budget calculation the *C/I* is derived for each active mobile. Therefore the transmission power, path loss, fading, shadowing, noise and co-channel interference is taken into account. Adjacent channel interference is neglected here. The LA protocol is responsible for the choice of the Coding Scheme (CS) or in EGPRS the Modulation and Coding Scheme (MCS). With the measured *C/I* and SNR values and the knowledge of the applied CS/MCS the effective throughput per user can be derived out of link level input tables. Frequency hopping and incremental redundancy (EGPRS only) are considered as well.

All active mobiles have the same priority if scheduling is necessary, independent of their actual location. No connection setup or termination phase is considered. The maximum achievable user bit rates per timeslot are 20 kbps for GPRS (CS-4) and 59.2 kbps for EGPRS (MCS-9). In GPRS/EGPRS spectral efficiency computation one timeslot in every second carrier is reserved for signalling purpose (PBCH), i.e. 7.5 timeslots per carrier are used for user traffic.

In contrast to UMTS where the radio resource (transmission power) is assigned, if possible, according to the defined service requirements, in GPRS/EGPRS the assigned resources (timeslots) are utilised best possible. The adaptation to the application has to be done by scheduling the time slot assignment.

4 Simulation Results

One of the difficulties that arise if 2G and 3G systems should be compared is the definition of suitable environments. Within the presented studies typical scenarios have been fixed for the competition of 2G/3G systems. With the help of simulations the most favourable deployment scenarios for the respective systems can be marked out.

It should be noted that the absolute figures presented here have to be treated carefully since they heavily depend on the parameter setting. Especially the radio propagation parameters, the fading channel and the orthogonality factor α (UMTS) have a great influence on system performance. Therefore it is recommended to focus more on relative figures and characteristics than on absolute values.

4.1 Scenarios and Network layout

Three environments were defined: Dense Urban (DU), Suburban (SU) and Rural (RU) with three deployment modes each. The environment takes into account the influence of the morphological structure and typical antenna heights on the path loss. The values for the path loss coefficients and the other parameters are summarised in Table 2. The deployment mode differentiates indoor, outdoor and in-car use with different grades of mobility. A fast fading is applied as recommended for each system. The Rayleigh fading channels Pedestrian A and Vehicular A have been chosen for the UMTS simulations according the ETSI recommendations. Additionally a log-normal distributed slow fading (zero mean value) takes into account shadowing effects. Its standard deviation is 12dB for indoor and 6dB for outdoor or in-car scenarios.

In the DU environment a building penetration loss of 21dB is considered, whereas in SU it is reduced to 15dB. The in-car scenarios include a penetration loss of 7dB, i.e. no external antenna is used which would give a gain of a few decibel. Furthermore the link budget includes 0dB receive antenna gain and a body loss of 3dB. For each deployment mode several cell sizes are investigated and tri-sectored cell configurations are presented here only as they are of main interest.

The simulation area is homogenously covered with one sort of identical cells. The resulting hexagonal cell footprint is used in the (E)GPRS simulations to attach the mobiles to the corresponding sector. In the UMTS simulations the Node B locations are distributed according to this footprint but the attachment of the mobiles is based on the measured link quality. Each sector is covered by an antenna with 60° or 65° main lobe width for UMTS and (E)GPRS, respectively. The antenna gain is 18dBi (UMTS) and 17dBi (GPRS).

4.2 Throughput vs. Distance

In GPRS/EGPRS the bit rate seen by the user strongly depends on the user location within the cell (no power control). Users in favourable positions get a higher throughput than the indicated mean bit rate, others get less, i.e. the average bit rate cannot be guaranteed. Figure 1 exemplary depicts a mean user throughput versus relative distance to the serving base station. For UMTS Figure 2 shows the measured user throughput for some Dense Urban scenarios depending on the normalised distance to the next Node B. For low system load (here 10UE per sector) it can be observed that the user performance is in fact quite independent from the user location. This is due to the effective operation of the UMTS transmit power control.

In high load scenarios the users located far away from the Node B observe a reduced performance. Due to the higher interference level the transmission power level increases for all links. The more demanding long distance links start to saturate earlier and the link performance

environment	**Dense Urban**			**Suburban**			**Rural**		
deployment	indoor 3km/h	outdoor 3km/h	in-car 50km/h	indoor 3km/h	outdoor 3km/h	in-car 50km/h	outdoor 3km/h	in-car 100km/h	in-car 250km/h
	DU3IN	DU3OUT	DU50CAR	SU3IN	SU3OUT	SU50CAR	RU3OUT	RU100CAR	RU250CAR
Antenna heights									
BTS/Node B	20m			30m			35m		
user terminal	1.5m			1.5m			1.5m		
topological model	flat terrain								
Okumura Hata	L = A+B log10(d/km)								
(E)GPRS (1800MHz)	A=135.6 dB		B=36.4 dB	A=126.2 dB		B=35.2 dB	A=111.3 dB		B=34.8 dB
UTRAN (2000MHz)	A=137.2 dB		B=36.4 dB	A=127.7 dB		B=35.2 dB	A=112.8 dB		B=34.8 dB
Rayleigh Fading									
GSM (TS 05.05)	Urban Area (TU)			Urban Area (TU)			Rural Area (RA)		
UTRAN (TR 30.03)	Pedestrian A			Pedestrian A			Vehicular A		

Table 2: Simulation scenarios and link budget parameters (see [7], [8])

decreases. Another effect is the saturation of the total Node B output power. This affects also the short distance links.

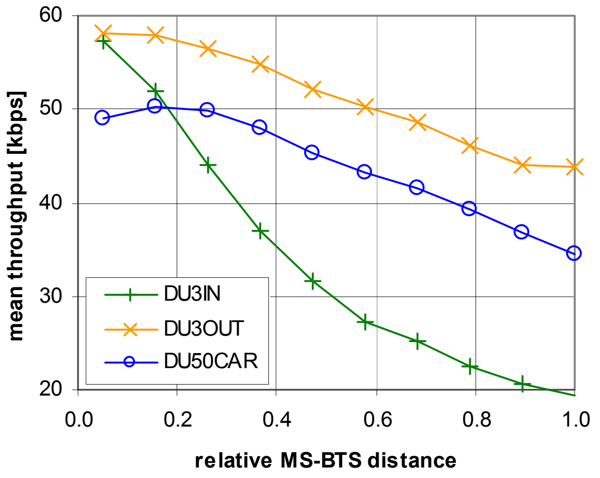

Figure 1: Distance depending throughput per timeslot (EGPRS 500 m cell radius)

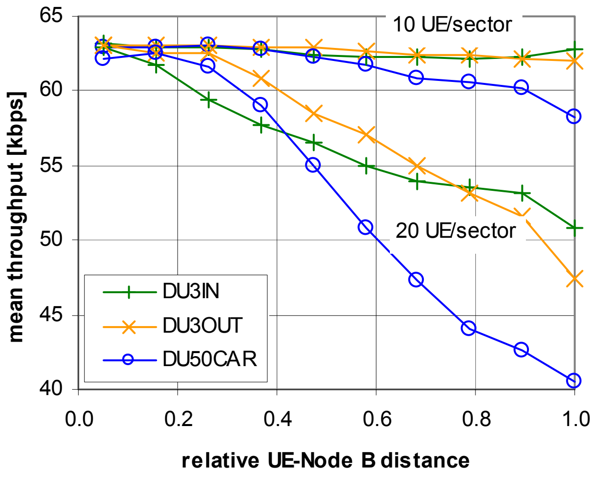

Figure 2: Throughput depending on the relative UE/Node B - distance (UMTS PS64, 500 m cells)

4.3 Spectral efficiency

Table 3 summarises the simulation results for the most interesting scenarios in terms of spectral efficiency. A graphical representation can be found in Figure 3. In the suburban scenario UMTS throughput decreases from the indoor to the outdoor deployment scenario in spite of the missing building penetration loss. This can be explained partly with the effect of interference attenuation but on the other hand the slow fading is set to have a higher deviation in indoor environment. The active set composition and the soft handover benefit from that.

			UMTS		GPRS 18		EGPRS 18	
		Cell radius [km]	Cell throughput [kbps]	Spectral efficiency [kbps/MHz]	Mean user throughput [kbps]	Spectral efficiency [kbps/MHz]	Mean user throughput [kbps]	Spectral efficiency [kbps/MHz]
DU	3IN	0.1	1112	222	15.7	48.9	41.3	129
		0.5	1100	220	13.9	43.5	30.0	93.8
		0.8	988	198	11.6	36.1	21.5	67.3
		1.6	--	--	7.1	22.2	10.9	34.1
	3OUT	0.5	1125	225	18.2	56.9	50.3	157
		1.6	1052	210	16.9	52.8	37.3	116
	50CAR	0.5	825	165	16.9	52.9	43.2	135
		0.8	796	159	16.2	50.7	37.9	119
		1.6	643	129	13.2	41.2	21.5	67.3
SU	3IN	0.8	1041	208	14.8	46.4	35.8	112
		1.6	1007	201	13.0	40.7	26.6	83.0
		3.6	388	78	8.3	26.0	14.5	45.2
	3OUT	0.8	997	199	18.0	56.3	49.2	154
	50CAR	0.8	731	146	16.7	52.3	43.2	135
		1.6	712	142	15.9	49.5	35.6	111
		3.6	438	88	11.9	37.3	18.0	56.2
RU	3OUT	3.6	657	131	18.0	75.2	46.3	193
	100CAR	2.4	724	145	15.6	65.2	39.3	164
		6.0	656	131	14.8	61.5	31.1	130

Table 3: Spectral efficiency results

To explain the UMTS performance decrease from Suburban to Rural scenarios the change of the Rayleigh fading channel from Pedestrian A to Vehicular A with reduced intra cell orthogonality has to be considered (more multipath effects, increased α).

5 Conclusions

The simulations show that the cell size in a UMTS system has to be set carefully, especially if a considerable downlink capacity should be provided. This is due to the fact that the transmission power is shared between all users. With the configuration and parameterisation assumed in this document typical cell radii for capacity dimensioning of the downlink with outdoor coverage are around 9.6 km in Rural, 3.5 km in Suburban, and 1.8 km in Dense Urban environment. If additional indoor coverage is requested the cell should not be larger than 2.1 km and

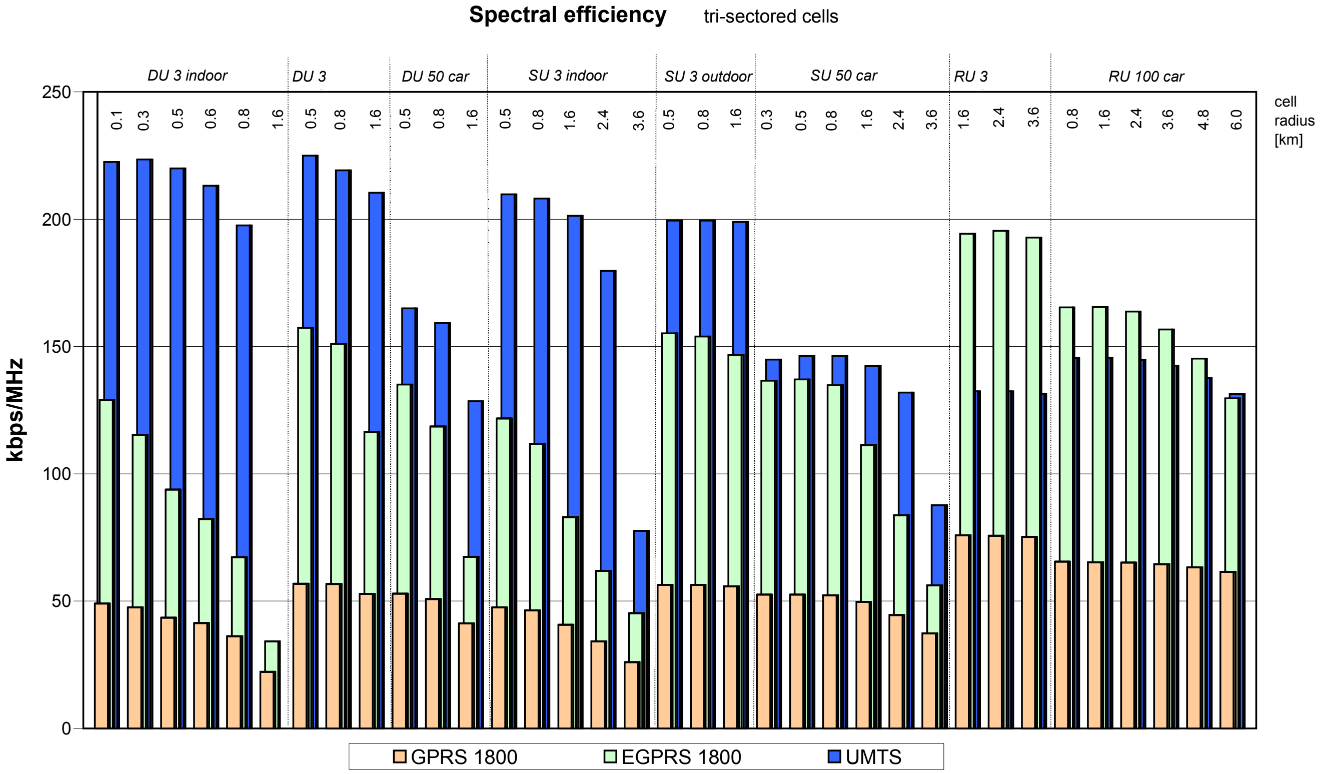

Figure 3: GPRS, EGPRS and UMTS spectral efficiency fort he considered scenarios

0.8 km in Suburban and Dense Urban environment, respectively. Uplink coverage is expected to limit the cell size even more stringent.

In tri-sectored scenarios with small cells UMTS utilises the spectrum considerably more efficient than EGPRS. Namely an increase up to 75% (indoor), 40% (outdoor) and 10% (in-car) were determined for Dense Urban and Suburban environments. However, in Rural environments and with larger cells EGPRS seems to be the technology with the better bandwidth efficiency.

In tri-sectored cells EGPRS performs typically 90-170% (factor 1.9-2.7) better than GPRS. Simulations at 900 MHz have shown quite the same relationship, but with decreased cell size dependency, i.e. the EGPRS advantage against GPRS can be utilised even with increased cell size levels compared to the 1800 MHz system.

Furthermore simulations with omni directional cell configurations have shown a considerable increase in spectral efficiency of 100-110% (i.e. a factor of 2-2.1) for EGPRS compared to GPRS with small and medium size cells. Whereas in large cells the advantage of EGPRS is less, because its efficiency stems from good channel conditions with high SNR.

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