

Performance Analysis of Quarter Rate Speech Channels

1. INTRODUCTION

In EDGE, the 8-PSK modulation was introduced to increase the gross bit rate from 22,8 kbit/s in GSM system to 68,4 kbit/s. For voice transmission, such gross bit rate can be used to increase the speech quality (Wideband AMR in full rate) or to increase the number of users per channel. In a quarter rate channel, the gross bit rate per user would be 17,1 kbit/s. This means that theoretically all the narrow band AMR speech codec modes (AMR12.2 to AMR 4.75) could be used for voice transmission. This document analyzes the performance of the quarter rate speech channels first from the link level viewpoint and then from the network viewpoint.

This document is the same as reference [1], except that results for macro cell no-LA case (Figures 9-10) and estimation of the mode switching rate have been added.

2. LINK LEVEL PERFORMANCE

2.1 Simulation assumptions

Three AMR speech codec modes have been simulated to evaluate the performance of the quarter rate channel : AMR 12.2, AMR 7.4 and AMR 4.75. Class 1a and 1b are defined as in the full rate speech codec modes [3]. Table 1 gives the channel coding used for the three speech channels. After the coding, each 20ms speech block is diagonally interleaved over 2 bursts as described below in the Figure 1.

Channel	Modulation	AMR Inband Data	CRC	Class 1a	Class 1b	Convolutional Code (K=5)	Puncturing
E-TCH/Q12.2	8PSK	6 bits	6	81 bits	163 bits	1/2	168 bits
E-TCH/Q7.4	8PSK	6 bits	6	61 bits	87 bits	1/3	138 bits
E-TCH/Q4.75	8PSK	6 bits	6	39 bits	56 bits	1/4	84 bits

Table 1. *Speech Channel Coding for Quarter Rate*

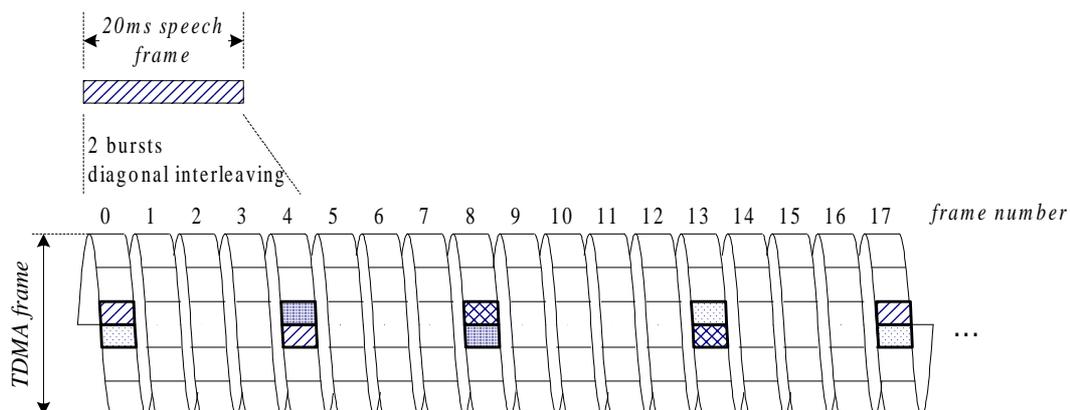


Figure 1. Quarter rate speech channel

2.2 Results

Link budget calculations are shown in Appendix 1. Table 2 sums up the link level results for interference limited case shown on the Figure 2 and Figure 3. The conclusion from these link level results is that the 7.4 and 4.75 kbit/s codecs are most feasible for the quarter rate channel. The 12.2 kbit/s codec requires a high C/I level because of its weak forward error correction in the quarter rate mode. These layer 1 simulation results show that in good channel conditions one channel could be shared by up to 4 speech users by using AMR 4.75 kbit/s, AMR 7.4 kbit/s and even AMR 12.2 kbit/s.

Table 2. Link level performance at 1 % FER for quarter rate speech channels on TU3 with ideal frequency hopping

Channel	Sensitivity (E_b/N_0)	Cochannel interference (C/I_{co})
E-TCH/Q 12.2	21.8 dB	28.5 dB
E-TCH/Q 7.4	14.7 dB	19.8 dB
E-TCH/Q 4.75	11.7 dB	16.7 dB

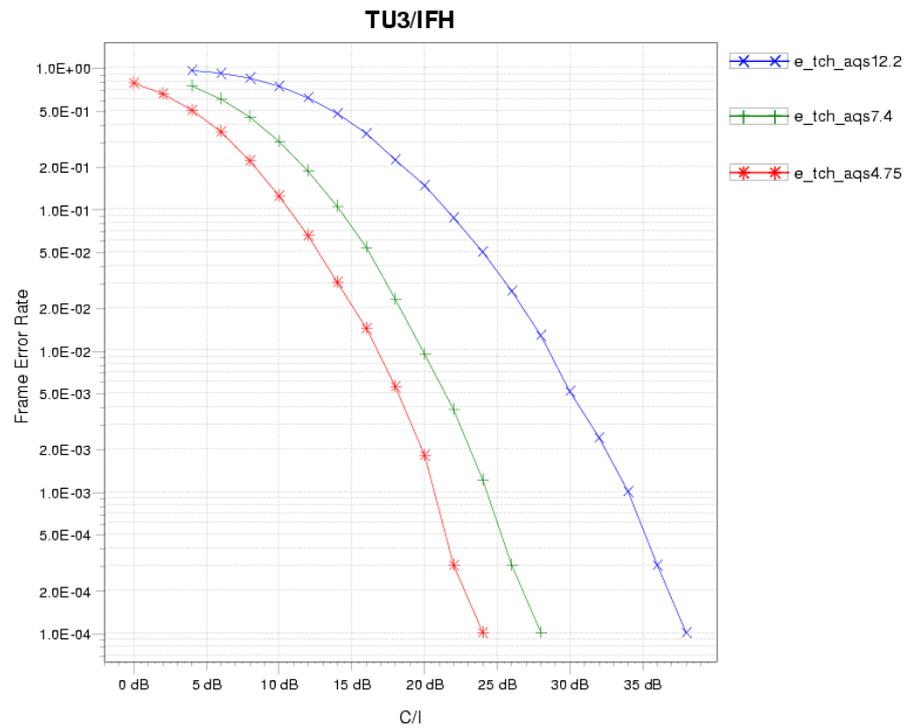


Figure 2. FER vs C/I_{CO} for quarter rate speech channels on TU3 with ideal frequency hopping

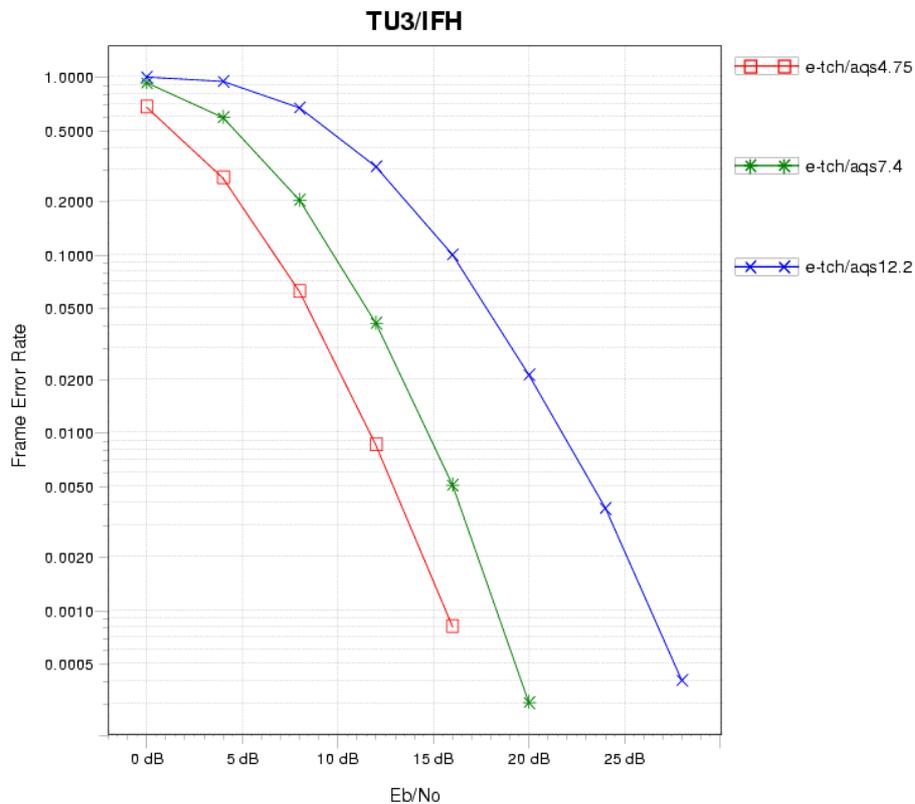


Figure 3. FER vs E_b/N_0 for quarter rate speech channels on TU3 with ideal frequency hopping

3. NETWORK PERFORMANCE

Both static and dynamic network simulations were run to evaluate the performance and applicability of Quarter Rate channels.

3.1 Static simulations

3.1.1 Modelling

The study is done with a static snap-shot simulator which calculates the signal to interference and noise distributions present in the system. Regular hexagonal geometry with three sectorized cells is used in the simulations. Co-channel interference is calculated from the 3 closest co-channel tiers. Adjacent channel interference is calculated from the same site and from the nearest tier. Table 3 summarizes the used simulation parameters. ACI suppression of -18 dB means that x dBm of adjacent channel interference before receiver filters is considered to be as harmful as (x-18) dBm of co-channel interference.

Parameter	Value	Comments
Transmission power	10 W	No power control
Carrier frequency	900 MHz	
Noise threshold	-108 dBm	
Attenuation slope	3.76	Propagation model according to [3]
Handover margin	3 dB	
Slow fading std.	6.0 dB	
Site separation	1.5 km, 3.0 km, 4.5 km, 6.0 km	
Load	50%	~ 2% blocking (full-rate channels, 1 TRX/sector)
Re-use factor	1/3, 3/9, 4/12, 5/15	All sites with three sectors

Table 3. Static simulation parameters

Figure 4 below shows the CIR distribution over one site in the network.

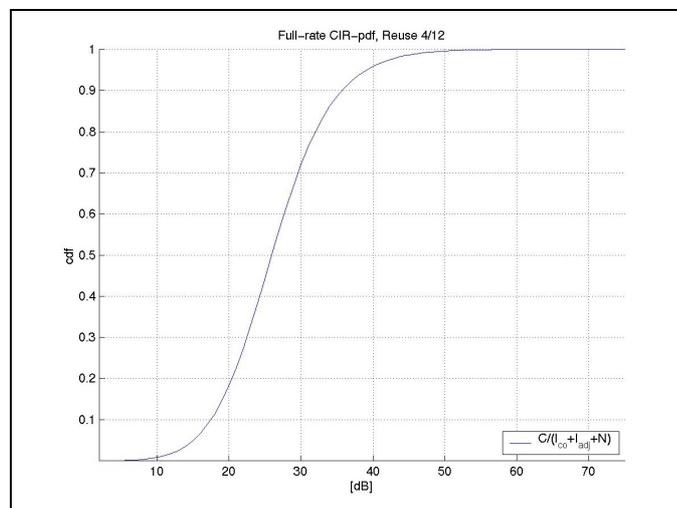


Figure 4. Interference and noise pdf for the site in the network (4/12, 4.5 km site separation)

All channel models use fixed 7.4 speech codec. Channel mode adaptation is assumed to be ideal CIR-based. Availability areas for each channel mode (ETCH-QS, ETCH-HS, ETCH-FS) are evaluated from link level results.

The actual simulation procedure is as follows:

1. Create snapshot assuming full-rate mobiles
2. Calculate interferences
3. Assign links to FR-HR-QR modes using CIR-based decision (thresholds from link level results, using 1% FER criteria)
4. Collect availability statistics for each mode

Several thousands of snapshots were taken. As a result, the network area can be divided into Full Rate, Half Rate and Quarter Rate availability (location probability) areas. It is assumed that the 50% and 25% average channel activity of HR and QR channels are compensated by 2-fold and 4-fold number of users on the corresponding area. Since the network load is calibrated according to 2% FR blocking, it can be assumed that there is basically no blocking in the HR and QR areas (due to trunking gain).

Final relative (compared to Full Rate only) capacity estimate can then simply be calculated with the following formula

$$C = 1 * RelativeArea_{FullRate} + 2 * RelativeArea_{HalfRate} + 4 * RelativeArea_{QuarterRate}$$

As mentioned before, the network operates under 2% blocking and with average call Frame Error Rate under 1%.

3.1.2 Capacity results

Figure 5 shows the availability area of the 3 channel modes.

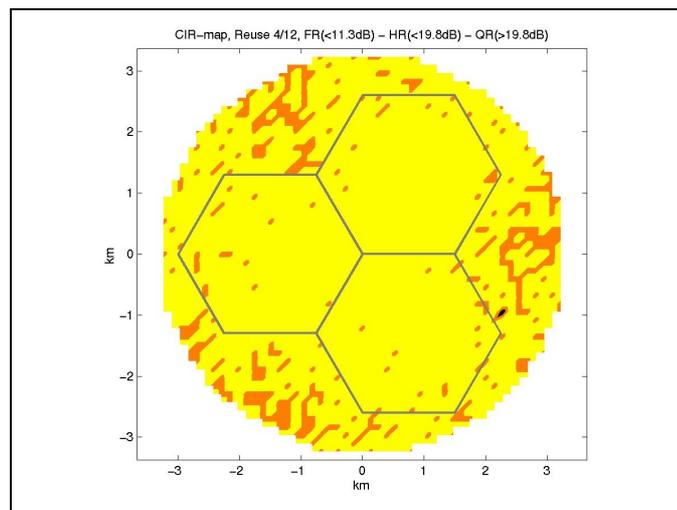


Figure 5. Simulated downlink availability area for ETCH-FS (black), ETCH-HS (orange) and ETCH-QS (yellow) reuse 4/12, 4.5 km cell separation

Table 4. Availability of different channel modes

7.4 kbps	CIR threshold	Relative area
Full rate	< 11.3 dB	0.4 %
Half rate	11.3 dB - 19.8 dB	17.5 %
Quarter rate	> 19.8 dB	82.1 %

Table 4 shows the simulation results for the relative availability areas (location probability) of different modes.

From the C/(I+N) distribution and speech codec mode thresholds, a simple upper bound (assumes perfect codec mode selection) for capacity gain values for FR+HR and FR+HR+QR modes compared to FR only mode can be calculated.

HR capacity gain per cell in case of 4/12 re-use:

$$C = 0.4 \% \times 1 + 17.5 \% \times 2 + 82.1 \% \times 2 = 199.6 \%$$

⇒ Almost twofold capacity per cell with respect to full rate.

QR capacity gain in case of 4/12 re-use:

$$C = 0.4 \% \times 1 + 17.5 \% \times 2 + 82.1 \% \times 4 = 363.8 \%$$

⇒ 3.6-fold capacity per cell with respect to full rate.

⇒ Introduction of quarter rate channels gives 82 % capacity gain per cell with respect to half rate.

In similar manner, upper boundary for capacity gains between FR+HR and FR+HR+QR modes for various cell sizes and re-use factors can be calculated. These are documented in the Table 5 below.

Table 5. Upper bound for relative capacity gain by introduction of QR mode

Cell radius →	1.5 km	3 km	4.5 km	6 km
reuse 1/3	12.5%	20.0%	23.8%	24.7%
reuse 3/9	44.8%	67.1%	70.6%	62.4%
reuse 4/12	61.4%	81.5%	82.3%	71.9%
reuse 5/15	68.3%	85.6%	84.6%	73.9%

The relative gain at larger reuse factors is bigger, but one has to factor in also the higher absolute spectrum efficiency at smaller cluster sizes in order to compare the absolute gain between different cluster sizes.

3.2 Dynamic simulations

3.2.1 Modelling

In dynamic simulations the mobiles were moving with speed of 3 km/h. Realistic radio resource algorithms were used – only important idealization was the applied CIR-based Channel Mode Adaptation (FR↔HR↔QR) algorithm which used accurate burst level interference measurements. The *maximum* CMA frequency was limited to 1 Hz for one call. No frequency hopping was used. "Bad quality" call criteria was fulfilled if average FER was more than 1% (both downlink and uplink were taken into account). Power control was not used in micro cell, macro cell simulations used realistic RxLev-RxQual –based power control. In general, the assumptions follow the recommendations of reference [4].

All simulations were run using TDMA frame resolution and link-system level mapping described in [5]. All calls used fixed AMR 7.4 codec mode.

Manhattan (micro cell) scenario

Micro cell (Manhattan grid) environment shown in Figure 6 below.

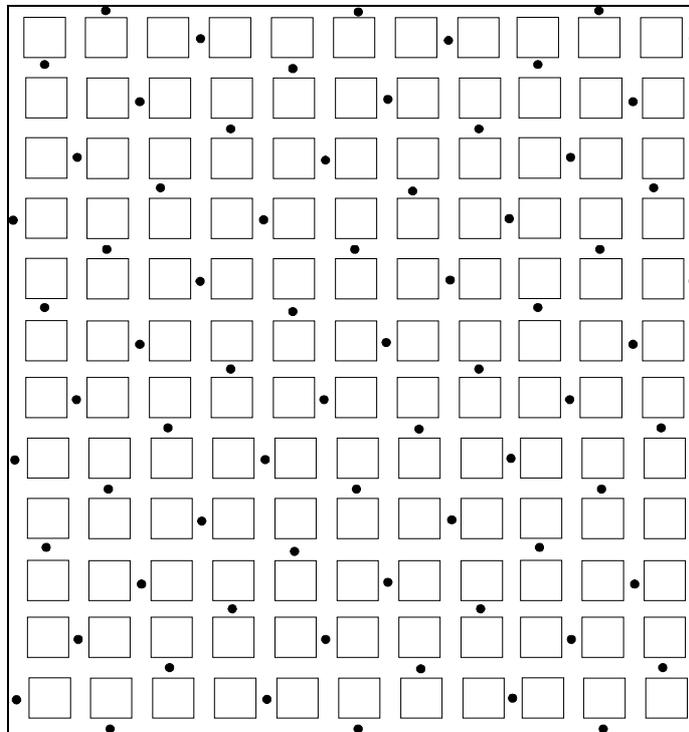


Figure 6. Micro cell deployment scheme. Complete description of the layout, propagation and mobility models etc. can be found in [3].

Main parameters of the micro cell scenario are given below:

- 72 cells with omnidirectional antennas of 15 meters height along the street canyons
- Street width 30 meters, 6,5 km² total area
- 132 pieces of 200x200 m building blocks
- A UMTS vehicular mobility model (mean speed 3 km/h, normally distributed with std of 0.3 km/h)
- Reuse factor about 6
- No frequency hopping
- 2 TRX per cell

Macro cell scenario

Macro cell scenario is the standard regular hexagonal scenario with 4/12 reuse, and 3 TRXs per cell. There were totally 75 cells in the whole network with cell radius of 500 m.

3.2.2 Results

Manhattan (micro cell) scenario

Figure 7 shows the capacity versus Network QoS (percentage of Satisfied Users). These simulations show that when introducing the possibility to switch to Quarter Rate mode, the

additional capacity gain from HR mode can be increased even further: ranging from 17 % (90% QoS level) to 25% (80%) QoS level.

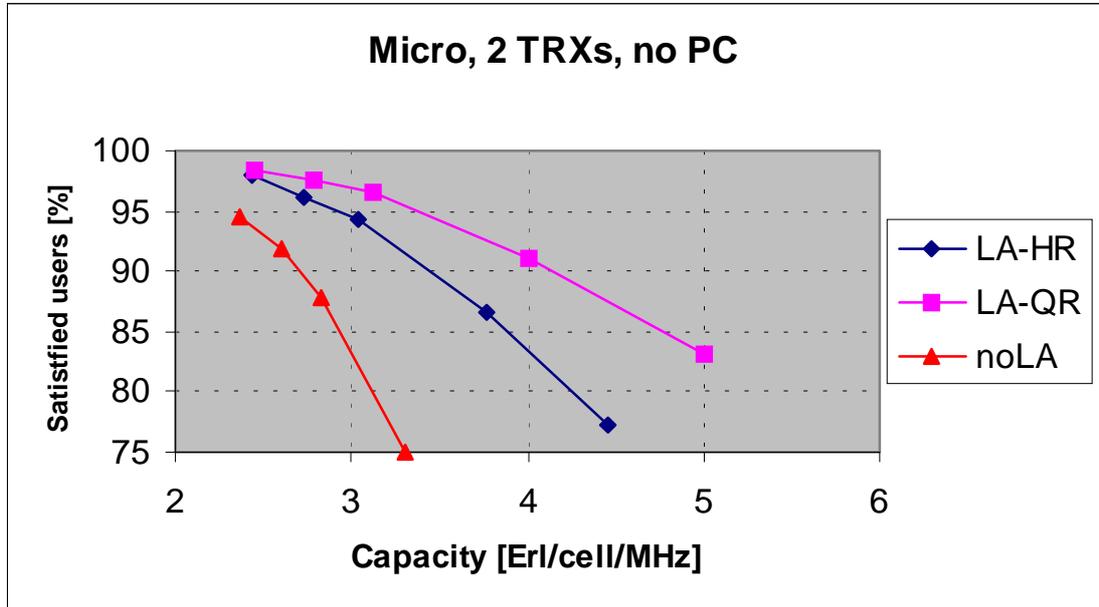


Figure 7. Capacity versus Network QoS of FR (no-LA), FR+HR (LA-HR) and FR+HR+QR (LA-QR) modes in a micro cell network.

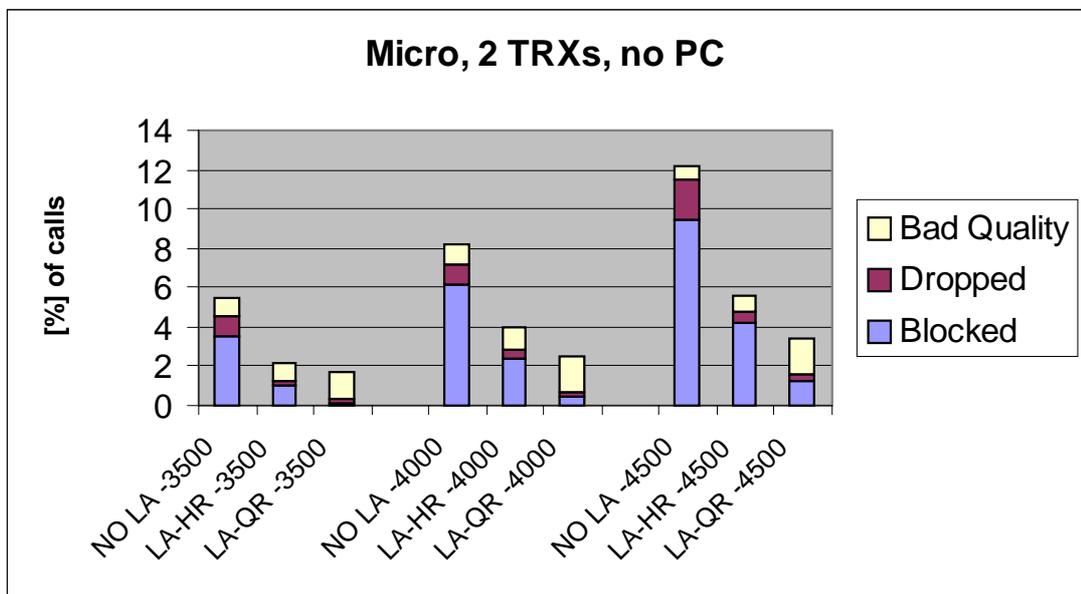


Figure 8. Details of bad call ratios of FR (no-LA), FR+HR (LA-HR) and FR+HR+QR (LA-QR) modes in a micro cell network.

Figure 8 show some additional info about blocking, dropping, and bad quality ratios for different modes (numbers in x-axis correspond to number of users in the network).

Macro cell

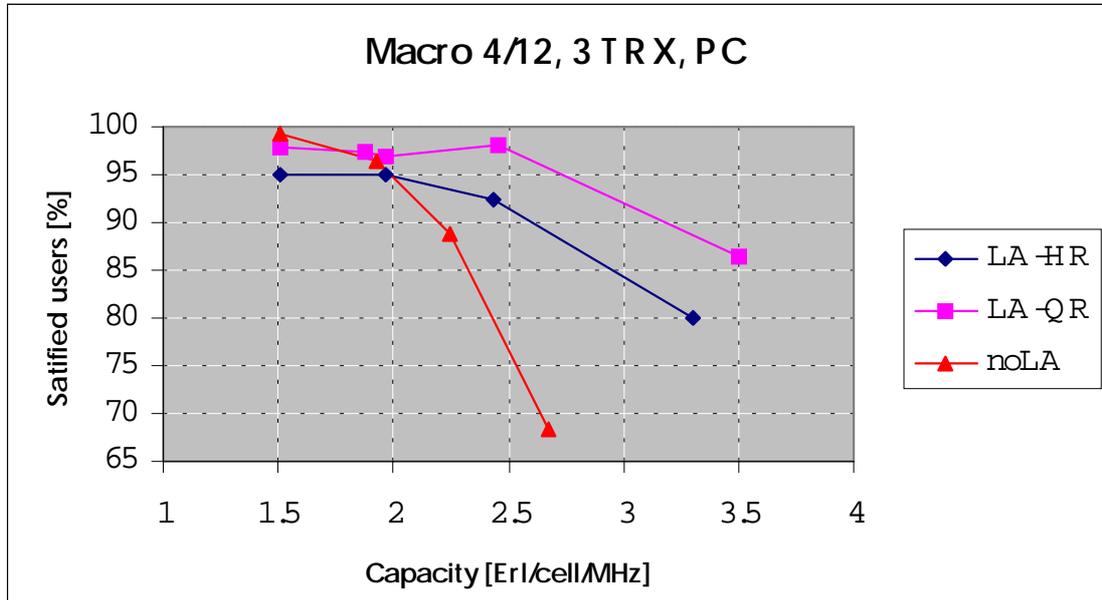


Figure 9. Capacity versus Network QoS of FR (no-LA), FR+HR (LA-HR) and FR+HR+QR (LA-QR) modes in macro cell network.

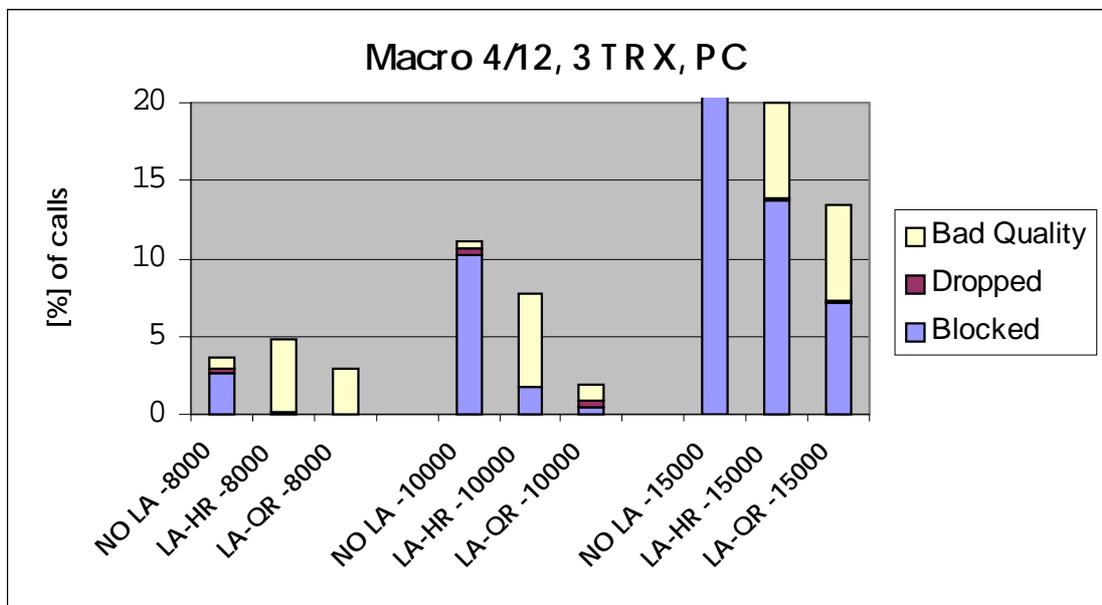


Figure 10. Details of bad call ratios of FR (no-LA), FR+HR (LA-HR) and FR+HR+QR (LA-QR) modes in macro cell network.

Figure 9 shows an estimate for QR gain, ranging from **40%** (95% network QoS level) to **28%** (90% level) capacity gain.

3.2.3 Estimation on the signalling load generated by Channel Mode Adaptation

The used algorithm restricts the frequency of Channel Mode Adaptation (rate switching FR-HR-QR, using intra-cell handovers) commands to be 1 Hz at maximum. Note that 6 dB hysteresis was also used in the algorithm. Consequently, the actual average handover rate was much lower in the simulation results presented:

Average rate switching frequency (when all modes available):

- In micro cell: **0.04 HOs/second/call** (≈ once every 25 seconds)
- In macro cell: **0.05 HOs/second/call** (≈ once every 20 seconds)

These values are about 10% higher compared to the case where only half- and full-rate mode was used.

The values are very moderate and the effect on speech quality is negligible. Simulations show also that restricting the adaptation frequency does not affect much to the capacity gain, which is also reported e.g. in reference [6].

4. CONCLUSION

Link level simulations show that QR channels are feasible in good channel conditions. For example, the average CIR requirement of 20.8 dB (@1%FER) for ETCH-QS7.4 bearer is a realistic value even in a macro cellular network with rather loose reuse. This is shown also with network level simulations.

Static network simulations with the given parameters, e.g., in a macro cell 4/12 network with 4.5 km site separation shows 82% additional capacity gain with the introduction of Quarter Rate channels.

Realistic dynamic network level simulations in micro cell network show **17-25% gain** for QR mode with sub-optimal algorithms and without power control. Macro cell simulations show **28% - 40%** gain when using power control.

Simulations showed small increase (about 10%) in channel mode adaptation commands when Quarter Rate was used. Since the absolute level of the signalling rate was still very low (4-5 mode changes/minute/call), this is not a problem.

Dynamic capacity gains reach to about half the gains reported in static simulations, which can be regarded as upper bound gains. From the figures it can be seen that QR does not only reduce blocking but it can (in some cases) also actually improve the quality for other users with its DTX effect. The QR technology seems to offer quite significant potential capacity gains.

5. REFERENCES

- [1] 3PP TSG GERAN AdHoc #1 (7th –11th August, Helsinki, Finland). Tdoc 2g00-76: "Performance analysis of quarter rate speech channels". Source: Nokia.
- [2] Digital cellular telecommunications system (Phase 2+), Channel coding (GSM 05.03

version 8.1.0 Release 1999).

- [3] Selection procedures for the choice of radio transmission technologies of the UMTS. ETSI Technical Report 101 112 V3.2.0 (1998-04).
- [4] ETSI SMG2 Meeting #36. Tdoc 2-00-1096 "GERAN Simulation Parameters Draft". (Source SMG2EDGE #13).
- [5] J. Wigard, T.T Nielsen, P.H. Michaelsen, P. Mogensen: BER and FER Prediction of Control and Traffic Channels for a GSM Type of Interface. Proc. VTC'98, pp.1588-1592.
- [6] O. Corbun, M. Almgren, K. Svanbro: "Capacity and Speech Quality aspects using Adaptive Multi-Rate (AMR)". Proc. PIMRC'98, pp. 1535-1539.

APPENDIX A

Link budget calculation below shows a comparison between 8PSK quarter rate and GMSK full rate speech service range for 95 % and 99 % location probability. Please note that the given values do not represent any actual product or recommended deployment.

		GMSK Full rate		8PSK Quarter rate	
		Uplink	Downlink	Uplink	Downlink
RX RF-input sensitivity	dBm	-108.0	-102.0	-108.0	-102.0
Codec rate	kBit/s	13.0	13.0	7.4	7.4
Eb/No in TU50 with IFH @ BLER=10%	dB	6.0	6.0	10.0	10.0
Es/No in TU50 with IFH @ BLER=10%	dB	6.0	6.0	14.8	14.8
Required signal power (sensitivity)	dBm	-108	-102	-93	-87
Addit. fast fading marg. (voice+VSD) /interference margin	dB	2.00	2.00	2.00	2.00
Cable loss + connector	dB	2.00	0.00	2.00	0.00
Body loss/x-coupling	dB	3.00	3.00	3.00	3.00
Rx antenna gain	dBi	15.00	2.00	15.00	2.00
UL+DL Diversity gain	dB	3.50	0.00	3.50	0.00
Isotropic power	dBm	-119.50	-99.00	-104.73	-84.23
TX RF output peak power (GMSK)	W	2.00	10.00	2.00	10.00
(mean power over RF cycle)	dBm	33.00	40.00	33.00	40.00
Backoff for 8-PSK	dB	0.00	0.00	4.00	2.00
Isolator + combiner + filter	dB	0.00	3.00	0.00	3.00
Cable loss + connector	dB	0.00	2.00	0.00	2.00
TX-antenna gain	dBi	2.00	15.00	2.00	15.00
Isotropic Path Loss Uplink / Downlink		154.50	149.00	135.73	132.23
Isotropic path loss (worst link)	dB	149.00		132.23	
<i>Range analysis</i>					
Environment	Macro				
Propagation Model	OH				
Location Probability over Cell Area	L%	99%		99%	
Range	km	2.61		0.89	
Location Probability over Cell Area	L%	95%		95%	
Range	km	3.66		1.24	