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Optimization of Half-Rate Codec Assignment in GERAN

M. Toril, R. Ferrer, S. Pedraza, V. Wille, J.J. Escobar

Abstract: Half-Rate (HR) channel coding can be used to deal with temporary traffic peaks in Global System for Mobile Communications (GSM)/Enhanced Data Rates for Global Evolution (EDGE) Radio Access Networks. Since operators have to pay for the use of HR codecs, the number of transceivers on which HR can be used is normally limited. An algorithm that optimizes the assignment of a limited number of HR codecs in a network is presented. The final solution obtained with the greedy algorithm proposed has proved to be optimal. Subsequent application of the algorithm in a real environment shows significant performance benefits in terms of network congestion reduction in comparison to the current approach used by network operators.

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Abbreviations

HR	Half-Rate
GSM	Global System for Mobile Communications
EDGE	Enhanced Data Rates for Global Evolution
GERAN	GSM/EDGE Radio Access Network
TRX	Transceiver
KP	Knapsack Problem
TSL	Time Slot
LP	Linear Programming
ILP	Integer Linear Programming
FR	Full Rate
BH	Busy Hour

Introduction

GSM/EDGE Radio Access Networks (GERAN) faces the challenge of providing capacity for existing and new services with a limited amount of spectrum. Several solutions have been proposed to improve network capacity in a cost-effective manner. During the planning stage, frequency reuse tightening is targeted through the use of features such as frequency hopping, discontinuous transmission, power control and adaptive multi-rate coding [1,2]. In subsequent network operation, intelligent traffic management algorithms ensure optimum load balancing among cells of different size, layer and frequency band [3]. As a last resort, congestion relief mechanisms such as Directed Retry [4] and Half-Rate coding [5] can be used to minimize call blocking in the system.

GSM specifications describe two kinds of traffic channels: full-rate (FR) and half-rate (HR) [6-8]. When a traffic channel is in HR mode, one timeslot, which normally serves one connection in FR mode, may be shared by two connections, thus doubling the number of connections that can be handled by a transceiver (TRX). In the context of circuit switched traffic, the HR feature allows operators to accommodate up to twice the number of users with the same hardware resources but at the expense of a slight call-quality reduction. Although it might seem that permanent application of HR coding might provide an overall capacity enhancement, this is not actually the case. The underlying reason is the higher C/I requirement for HR users compared to FR users when offering equal voice quality, which is translated into a lower frequency load permitted in the frequency hopping layers of the network [2]. Hence, HR mode does only provide a capacity benefit from its dynamic allocation as a blocking relief strategy during peak traffic periods.

The codec assignment problem

Outline of problem

In current networks, HR codecs are allocated on a per-TRX basis. Since operators have to pay for the use of these codecs, the number of TRXs on which HR can be used is normally limited. The codec allocation process is performed statically (i.e. dynamic share of a codec is not possible). Even though this process can be completed remotely, there might be a need to re-start the cell (or even site) to activate the changes. Since this action temporarily prevents traffic from being carried, this re-allocation process is a night activity, what makes dynamic codec allocation unfeasible. Thus, optimum assignment of a limited pool of HR codecs is key to reduce network congestion.

Traditionally, both the initial prediction of the required number of codecs and its subsequent assignment to suitable TRXs during network planning stages have been carried out manually. This approach proves tedious, time-consuming and does not guarantee optimum results. Furthermore, subsequent variations of traffic spatial distribution in the network over the course of time necessitate periodic assignment revision if optimum performance is targeted. It can thus be concluded that an automatic method is crucial to obtain maximum performance benefit from the use of HR codecs.

Mathematical formulation

The problem of codec ascription can be considered as a special case of the combinatorial optimization problem known as the 0/1 Knapsack Problem (KP), which has been extensively covered in the literature (for a survey, see [9,10]). The conventional KP originally gets its name from the common situation where a hitch-hiker has to select among various objects to fill up his knapsack, maximizing the profit. The 0/1 prefix emphasizes that a fraction or multiple instances of an object are not selectable.

In the case considered here, the KP is defined by a finite set $T = \{t_1, t_2, ..., t_n\}$ of TRXs that are potential candidates for codec ascription. Each TRX t_i has a positive integer penalty w_i (in terms of codecs seized) and profit p_i (in terms of blocked traffic relieved) derived from the assignment of a codec. Let C be the number of codecs in the pool owned by the network operator. Then, the problem calls for selecting the set of TRXs with a maximum profit among those sets that do not exceed the pool capacity.

The integer linear programming (ILP) model of the problem can be formulated as the search of a vector X of binary (decision) variables x_i (i=1, …, n) with the meaning

$$x_i = \begin{cases} 1 & \text{,if TRX is selected} \\ 0 & \text{,otherwise} \end{cases} \tag{1}$$

that maximizes the objective function P (profit)

$$P = \sum_{i=1}^{n} p_i x_i \qquad (2)$$

subject to the constraint

$$\sum_{i=1}^{n} w_i x_i \le C \qquad (3)$$

In the particular case analyzed, the benefit from the assignment of a codec to a certain TRX is not fixed, but depends on the existence of other TRX in the same cell. Hence, profit values p_i are dependent on the decision variables x_i, converting P into a non-linear objective function. Thus, the problem can be classified as a 0/1 non-linear KP.

Finally, the search of an optimal solution may be simplified taking into account that the assignment of a codec have a constant penalty, regardless of the TRX being considered, i.e. the reduction in the number of codecs in the pool by one unit (w_i =1). Thus, the constraint expressed in eq. (3) converts into

$$\sum_{i=1}^{n} x_i \le C \qquad (4)$$

The optimization process

Optimization technique

A large number of algorithms have been proposed in the literature for exact and approximate solutions to the KP problem [11-13]. Among them, the greedy algorithm, the branch and bound algorithm and the dynamic programming algorithm are most popular. For the problem under study, the classical greedy algorithm used to solve the continuous relaxation of the 0/1 KP problem [13-15] has been chosen because of its simplicity.

In essence, a greedy algorithm finds a solution to a small part of a problem and extends it to the final solution, assuming that a local optimal solution is part of the global optimal solution. In the context of selection problems, the greediness property refers to the fact that, once a candidate has been included in the final selection list, its appropriateness is never evaluated again.

The main advantage of greedy algorithms is that they are easy to understand and easy to implement. However, unlike other algorithms, there is no guarantee that the optimal global solution is obtained. Nonetheless, when optimum is obtained, they are usually the most efficient option available. Thus, time complexity of greedy algorithm compares favorably with that of other approaches (i.e. greedy algorithm has polynomial time complexity O(n) in contrast to exponential $O(n2^n)$ and pseudo-polynomial O(nW) time complexities of branch and bound and dynamic programming algorithms, respectively). Hence, whenever optimality of greedy algorithms is proved, no gain will be achieved by using more complicated algorithms.

Optimization algorithm

The optimization criterion in the codec-assignment problem is to maximize the overall traffic congestion relief with a given number of HR codecs. To achieve this goal, the following procedure is applied:

1) *Sort of TRXs in the network based on their HR capabilities on a cell basis:* For that purpose, TRXs are first grouped by the cell to which they belong. TRXs in a cell are ranked by the number of HR capable time slots (TSLs), since some TSLs on a TRX might be devoted to signaling or packet data purposes and hence can not be used to carry voice traffic. This figure of merit may differ from TRX to TRX, due to the uneven distribution of non HR capable TSLs in the TRXs of a cell. Obviously, TRXs with more HR capable TSLs will be preferred within a cell, as they would provide higher congestion relief if a HR codec was used.

2) *Estimation of profit from codec assignment to TRXs* (p_i): The benefit from every codec ascription is defined as the increase of carried traffic during the busy hour (BH) due to the extension of traffic resources in the cell considered. Thus, the profit values p_i can be calculated from the difference between carried traffic with and without codec assignment as

$$p_i = \Delta A_c = A_c{'} - A_c \tag{5}$$

where $A_c \equiv$ BH carried traffic in Erlangs, and (') will denote values after codec assignment henceforth. The difference in carried traffic derives from the reduction of blocking probability due to temporary lack of free traffic resources as stated in (6),

$$p_i = A_c' - A_c = A_b - A_b' = A * B_k(A) - A' * B_{k'}(A') \tag{6}$$

where $A_b \equiv$ BH blocked traffic in Erlangs, $A \equiv$ BH offered traffic in Erlangs, and $B_k(A) \equiv$ BH call blocking probability with k traffic channels and offered traffic A. Under poissonian traffic assumption, the blocking probability is equal to the congestion rate (i.e. fraction of time that congestion takes place) [16]. Thus, the profit can be derived from the offered traffic and congestion rate values as stated in (9),

$$B_k(A) = E_k(A) \tag{7}$$

$$B_{k'}(A) = E_{k'}(A) \tag{8}$$

$$p_i = A * B_k(A) - A' * B_{k'}(A') = A * E_k(A) - A' * E_{k'}(A') \tag{9}$$

where $E_k(A) \equiv$ BH congestion rate with k traffic channels and offered traffic A. Since the offered traffic is likely to remain constant in the network, the new offered traffic can be estimated from past measurements of carried traffic and congestion rate as in (10). Thus, eq. (9) can be simplified into eq. (11).

$$A' = A = A_c + A_b = A_c \left(1 + \frac{1}{1 - E_k(A)}\right) = \frac{A_c}{1 - E_k(A)} \tag{10}$$

$$p_i = A * E_k(A) - A' * E_{k'}(A') = A * (E_k(A) - E_{k'}(A)) = \frac{A_c}{1 - E_k(A)} (E_k(A) - E_{k'}(A)) \tag{11}$$

From (11), it is evident that the profit values can be anticipated from the carried traffic and congestion rate with and without codec assignment. Among all these variables, the congestion rate after codec assignment $E_{k'}(A)$ is the only term which cannot be taken from past network measurements and must be still predicted. The congestion rate with the new number of channels k'

is estimated from the same indicator with the old number of channels k through the recursive version of the Erlang-B formula denoted in (12) [17].

$$E_i(A) = \frac{A * E_{i-1}(A)}{i + A * E_{i-1}(A)}, \quad E_0(A) = 1, \quad i = k+1, k+2, ..., k' \tag{12}$$

The potential benefit from incremental codec ascription is then estimated through (11). It is worth emphasizing the incremental character of the calculation process, to account for the loss of efficiency of additional codecs in a cell, once a configuration that assures full congestion relief is achieved. Likewise, it is worth noting that correct load thresholds for the dynamic triggering of FR to HR channel conversion are presumed, i.e. FR to HR conversion is always initiated before TRX congestion is reached.

3) *Sort of TRXs in terms of their expected profit (p_i) on a network basis*: From the classical greedy approach, TRXs are sorted based on their expected profit-to-penalty ratio as

$$\frac{p_j}{w_j} \geq \frac{p_{j+1}}{w_{j+1}} \quad (j = 1,..,n-1) \tag{10}$$

which, in this case, can be simplified to

$$p_j \geq p_{j+1} \quad (j = 1,..,n-1) \tag{11}$$

since all TRXs share the same penalty from codec ascription.

4) *Selection of optimum configuration for a given number of codecs C*: The best configuration in terms of expected traffic relief for a certain number of codecs C will be defined by the C first TRXs in the ordered list. The potential overall carried traffic gain P can be calculated as the sum of profits of the selected TRXs as

$$P = \sum_{i=1}^{C} p_j \tag{12}$$

5) *Optimization of the number of codecs C*: By representing the potential overall traffic gain from a number of codecs other than C, the tradeoff between the benefit and cost of each new codec in the pool (i.e. profit and cost of the size of the knapsack itself) can be evaluated.

Proof of optimality

The solution achieved by the devised greedy algorithm can be intuitively proved optimal from the fact that, among the unselected TRXs, there is no individual better than the ones in the selection list and no codec is left unassigned. More formally, the optimality of the solution can be proved by mathematical induction as follows. Let c be the index of codec in the pool as progressively assigned by the optimization algorithm.

1) *The solution proposed by the algorithm proves optimal for $c=1$*: The initial ranking of TRXs in each cell based on the number of HR-capable channels restricts the candidate set to the best individual in each cell. The subsequent selection of the best candidate among all cells in the network assures the optimality of the solution for $c=1$.
2) *Assuming that the solution proposed by the algorithm is optimal for $c=i$, the solution also proves optimal for $c=i+1$:* Starting from an optimum configuration of the previous i codecs, the incremental (i.e. not absolute) gain of the best remaining candidate of each cell in terms of HR-capable channels is evaluated. Thus, the subsequent identification of the highest potential gain among cells in the network leads to the optimal solution with $i+1$ codecs.

Field trial results

The above-described methodology was applied to a live GSM network in order to test the effectiveness of the algorithm in a real environment. For the sake of clarity, the preliminary conditions are first described and trial results are subsequently discussed.

Trial Set-Up

The optimization algorithm was used to deal with the automatic assignment of a pool of HR codecs in a live network. The trial area consisted of 2915 cells (1266 sites, 7176 TRXs) providing seamless coverage. In the past, the pool under consideration comprised 22 codecs, which had been assigned following a manual procedure. In this manual approach, the assignment process was carried out through inspection of call blocking figures collected on a cell basis, without any prediction of the benefit obtained.

Coincident with the launch of the trial, the pool was extended from 22 to 33 codecs conditional on operator demand. Consequently, the aim of the trial was two-folded: on the one hand, to test the capability of the algorithm to correct past imperfect manual assignments, while checking the validity of the manual approach; on the other hand, to prove the benefit of relieving the operator from tedious calculations for the assignment and forecast of the gain of new codecs. It is worth remarking the independence of both objectives, since even though no improvement was observed with the algorithm (which is not actually the case, as will be shown later), the benefits from an automatic approach would perfectly justify its application.

The optimization algorithm was run twice per week (i.e. Wednesday and Friday, based on congestion data from the immediately preceding Monday-Tuesday and Wednesday-Thursday, respectively). Estimated traffic gains were reckoned on a TRX-by-TRX basis and a new configuration of codecs was subsequently downloaded to the network during the trial.

Trial Results

The overall tele-traffic performance indicators from the manual and automatic assignment processes are presented in Table 1. For the sake of clarity, the three most significant periods (referred as manual 22, automatic 33/1st iteration and automatic 33/2nd iteration) have been selected. As expected, the optimum configuration of an extended pool of codecs leads to a significant congestion relief, which is evident from the reduction of congestion rate by 50% (i.e. 0.56% to 0.28%) in spite of an increase of the offered traffic in the trial area (i.e. 4788Erl to 5004Erl) after the first automatic assignment. Similar results are obtained in subsequent iterations of the automatic process. It is worth noting that fluctuations in offered traffic during the trial were originated from changes of user demand, which are not under control of the operator.

Further analysis will focus on establishing the benefits from the application of the proposed method (labeled automated) over the one used previously (labeled manual). If a fair comparison between both approaches is to be established, it is important to isolate the gain of automatic redistribution of codecs from that of codec addition. For this purpose, the spatial traffic distribution in the network was first derived from real measurements during the period of manual assignment. Subsequently, the total lack of codec (i.e. situation where no HR codecs were assigned) was defined as the reference case against which the other cases could be fairly compared. Thus, estimations of blocked traffic with no codec (later referred as $A_{b\ 0}$) were calculated in a cell level. Finally, traffic gains from incremental codec ascription in both manual and automatic method were compared via congestion indicators.

Figure 1 depicts the traffic gain estimations after incremental assignment of codecs to individual TRXs in the trial area, ranked by magnitude as performed by the greedy algorithm. Figure 2 depicts the corresponding estimations of cumulative traffic gain from codec assignment. This cumulative curve explicitly shows the maximum overall traffic gain that might be attained from a certain number of codecs in the pool. The traffic gain of manually assigning 22 codecs is estimated at 36.1 Erl (dashed horizontal line). In the case that the same number of codecs were optimally allocated by the algorithm, the predicted overall traffic capacity gain would be 43 Erl (dotted line), which equates to an optimization gain of 19%, i.e. (43 – 36.1)/36.1. Thus, it is proved that the blocking performance achieved by the automatic process clearly surpasses that obtained with the manual approach.

Likewise, the cumulative curve in Figure 2 shows that pool extensions beyond the bespoken 33 licenses would produce negligible improvements in the network. Thus, the size of the extended pool selected by the operator is proved valid.

Table 2 summarizes the evaluation of several configurations based on estimations, where gains from automatic ascription and codec addition have been clearly isolated. As observed in Table 2, the optimized assignment of 22 codecs is expected to reduce BH congestion rate by 27%, i.e. (0.56-0.41)/0.56. All these results put into evidence the advantages of the outlined methodology over the manual codec assignment process.

For clarifying purposes, Table 3 breaks down the main calculations carried out in the first automatic iteration for the ten worst cells in terms of congested traffic before optimization. The second and third columns show the carried traffic and congestion rate gathered from network measurements, while the fourth column depicts the estimations of blocked traffic with no codec (i.e. the ranking criteria in the table). The next columns show the predicted benefits from incremental codec ascription in a cell level, where the shaded area highlights those TRXs finally granted with a codec due to their higher traffic gains. The last columns present the number of codecs and the expected blocked traffic per cell. As a complement of the information given in the table, it is worth noting that all 33 codecs in the pool were held by only 23 of the 2915 cells in the network.

Finally, the stability of the solution across time is analyzed, based on the outcome of consecutive iterations of the algorithm in the network. A priori, it can be assumed that, in spite of variations in overall traffic demand, spatial traffic distribution remains nearly unaltered. Hence, the ranking of TRXs in the network in terms of congestion relief from HR codec allocation might prove valid for subsequent periods. In the first optimization step, where the main benefit of the optimization process was envisaged, the number of new allocations was 19 (11 new codecs + 8 reallocations of existing codecs). In contrast, only 6 reallocations took place in the second optimization step. Despite the fact that a small number of residual reallocations still remained in subsequent optimization steps, insignificant performance benefits were observed. This effect is rooted in the tendency for TRXs whose gain differences are small (i.e. TRXs on the right-hand side of Figure 1) to be reordered.

In spite of these results, some small discrepancies between blocking predictions and measurements were detected from the comparison of Tables 1 and 2. Comprehensive analysis was carried out to check the significance of the predictions, which proved that prediction errors were caused by subtle changes in the spatial traffic distribution. Whenever further error reduction is desired, thus reducing the number of unnecessary codec reassignments, larger averaging windows for traffic measurements are recommended (e.g. a whole week instead of the two days used).

Conclusions

An automatic algorithm to deal with the problem of HR codec assignment in GERAN has been suggested. Its subsequent application over a real network has proved its capability to maximize network capacity by means of the optimum ascription of codecs, surpassing the performance of current manual approaches while relieving the operator from complex analysis tasks. In the presented case study, it is estimated that, compared to a manual approach, the outlined method increases the traffic capacity gain obtained from the same number of HR codecs by 19%, whilst reducing the BH congestion rate by 27%. The achievable gains will vary depending on network traffic conditions and the quality of the original HR codec assignment.

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Matías Toril received an M.S. degree in telecommunication engineering in 1995 from the University of Málaga, Spain. Since 1997, he is on the staff of the Communications Engineering Department, where he is currently working toward a Ph.D. degree. From 2000 to 2003, he simultaneously joined the Nokia Networks Competence Team in Málaga. His research interests include optimization of mobile radio access networks and radio resource management.

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Following under graduate studies in Germany and an internship at Bell Communications Research, USA, **Volker Wille** carried out postgraduate studies in UK leading to a PhD degree. In Nokia, he currently is responsible for development of features that enable self-regulation of cellular networks.

Juan J. Escobar obtained his M.S. in telecommunication engineering from the University of Málaga. He joined the Nokia Networks Competence Team in Málaga in 2001, where he worked in control and optimization algorithms for telecommunication cellular networks. In 2003 he joined TarTec, where he leads the development of a common framework for network performance optimization.

Figure captions:

Figure 1. Estimated incremental traffic gain from automatic half-rate codec assignment in a transceiver level.

Figure 2. Estimated cumulative traffic gain from automatic half-rate codec assignment in a transceiver level.

Figure 1

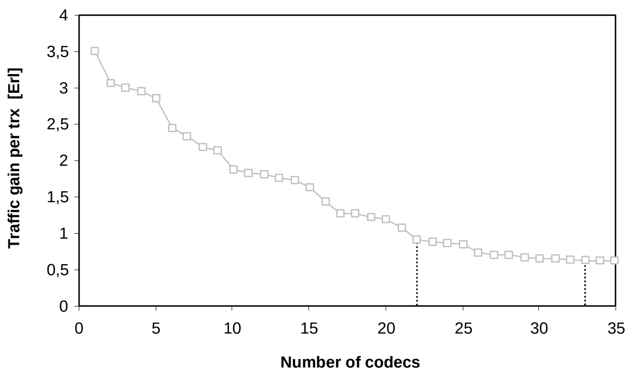


Figure 2

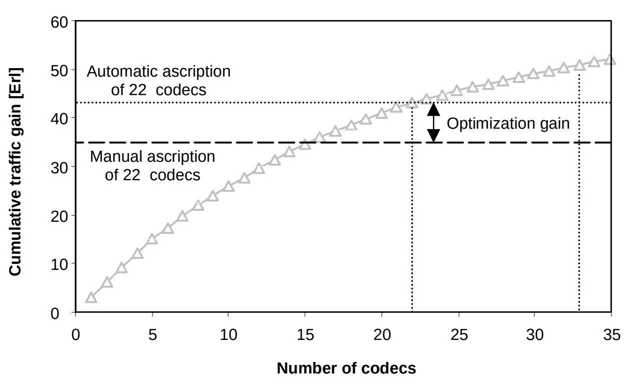


Table captions:

Table 1. Overall performance indicators before/after optimized half-rate codec ascription.

Table 2. Comparison between manual and automatic ascription of half-rate codecs.

Table 3. Main calculations performed by the algorithm for ten cells in the network.

Table 1

Case	Manual 22	Automated 33 (1^{st} iteration)	Automated 33 (2^{nd} iteration)
Nbr of HR codecs	22	33	33
Days of week	Mon-Tue	Wed-Thu	Wed-Thu
BH offered traffic [Erl]	4788.7	5004.2	4876.9
BH carried traffic [Erl]	4762.2	4990.0	4867.0
BH blocked traffic [Erl]	26.7	14.2	9.9
BH congestion rate [%]	0.56	0.28	0.20

Table 2

Case	Reference	Manual 22	Automated 22	Automated 33
Nbr of HR codecs	0	22	22	33
BH offered traffic [Erl]		4788.7		
BH carried traffic [Erl]	4725.9	4762.0	4768.9	4776.7
BH blocked traffic [Erl]	62.8	26.7	19.8	12.0
BH congestion rate [%]	1.31	0.56	0.41	0.25
BH traffic gain [Erl]	0	36.1	43.0	50.8

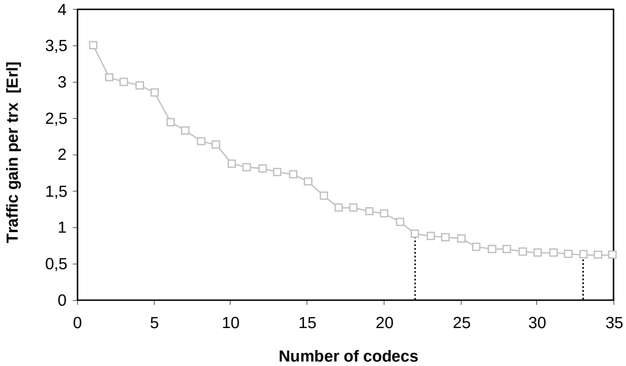
Extracted from network statistics

Table 3

Cell	A_c [Erl]	$E_n(A)$ [%]	$A_{b\,0}$ [Erl]	TRX traffic gain [Erl] 1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}	6^{th}	Nbr. of codecs	A_b' [Erl]
1	20,5	13,1	9,4	3,5	2,8	1,7	0,8	-	-	4	0,6
2	19,9	5,0	9,2	3,0	2,3	1,8	1,1	-	-	4	1,0
3	18,7	4,5	5,5	3,0	1,6	0,7	0,2	-	-	3	0,2
4	13,3	12,9	4,9	2,9	1,4	0,4	-	-	-	2	0,6
5	17,3	1,9	3,9	2,4	1,2	0,3	0,0	-	-	2	0,3
6	19,0	13,4	2,9	1,8	0,8	0,2	0,0	0,0	0,0	2	0,3
7	10,2	7,2	2,7	1,9	0,6	0,1	-	-	-	2	0,2
8	11,4	19,2	2,7	2,2	0,5	0,1	-	-	-	1	0,5
9	11,6	18,1	2,6	2,1	0,4	0,0	-	-	-	1	0,5
10	15,5	0,04	2,3	1,7	0,5	0,1	0,0	-	-	1	0,6

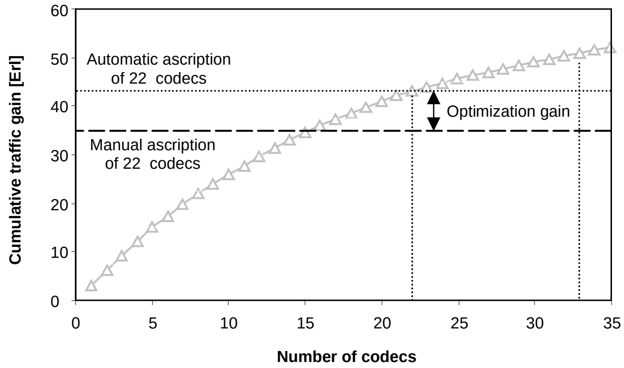
Transceivers granted with a codec

line figure



Traffic gain per trx [Erl]
4
3,5
3
2,5
2
1,5
1
0,5
0
0
5
10
15
20
25
30
35
Number of codecs

line figure



Cumulative traffic gain [Erl]
Number of codecs
Automatic ascription
of 22 codecs
Manual ascription
of 22 codecs
Optimization gain
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35

* Response to reviewer's comments

Reviewer #1: Page 3 - Last paragraph - The authors state that "Although it might seem that... actually the case". This has not been proven in the text until this point of the manuscript and so it should either be referenced or given an indication where this will be proved in the paper.

The corresponding reference has been included in the “Introduction” section.

Page 5 - It is stated that the greedy algorithm does not give a "guarantee that the optimal global solution is obtained". Then why was it used? Just because it is simpler? How does the complexity of this algorithm compares with the others mentioned in the text? What would be the gain of using these algorithms?

The main reason for its selection was its simplicity as an attempt to increase the confidence of the network operator on the optimisation process, which could risk its revenues. Nonetheless, it is proved in the text that, in this problem, it gives the optimum solution. Moreover, the greedy algorithm compares favourably in terms of complexity (i.e. polynomial time complexity O(n) of greedy algorithm in contrast to exponential $O(n2^n)$ and pseudo-polynomial O(nW) time complexities of branch and bound and dynamic programming algorithms, respectively). Thus, no gain would be achieved by other algorithms in this problem.

This fact has been explicitly stated and complexity orders have been added to prove this statement in the “Optimization technique” section.

Page 6 - You state that "TRXs with more...codec was used". Why? In any TRX if we have 1 HR TSL and we use it, isn't the relief approximately equal in equal congestion situations?

It is true that 1 HR TSL gives the same relief in any TRX, but it is the number of HR capable TSLs what gives the difference from TRX to TRX (note that when a codec is assigned to a TRX, all the TSLs in that TRX benefit from the assignment). Thus, after HR codec assignment to a TRX, the maximum number of connections in that TRX (which depends on the number of HR-capable TSLs) is doubled. Thus, when a codec in a cell is to be assigned to one of several TRXs with different number of HR capable TRXs, the one with a higher number of HR capable TSLs will end up with the highest traffic relief.

To reinforce the explanation, a sentence has been added in the “Optimization algorithm” section.

Page 10 - From what is reported in the paper the algorithm was tested with two sets of data. These sets were obtained over only two days (Monday-Tuesday and Wednesday-Thursday) or were they averaged over several weeks data?

Only two days were used to gather network statistics for each step in the optimisation process, due to the time (and workload) constraints given by the network operator for the field trial. The shorter the averaging period, the more agile the optimisation process. Regardless these operator constraints, it is suggested by the authors in the conclusions that a longer averaging period (i.e. a whole week instead of two days) would be preferable, to enhance the robustness of the method.

The words “immediately preceding” are now present in the “Trial setup” section to reinforce that no averaging of several weeks is present.

Based on the congestion data, is the assignment done in a static way (i.e. constant for a set of data)? Would it be possible to use a dynamic channel assignment?

The assignment is static. Even though this process can be completed remotely (i.e. no need for a site visit), there might be a need to re-start the cell (or even site) to activate the changes. Since this action temporarily prevents traffic from being carried, this re-allocation process would probably be an evening/night activity, what makes dynamic codec allocation unfeasible.

These comments have been added in the preliminary outline of the codec assignment problem.

Why is the comparison in Table 1 done for different traffic loads?

Changes in offered traffic are caused by fluctuations of user demand (which are not under control of the operator). As observed in the trial, in common networks, traffic in the middle of labour week (i.e. wednesday, thursday) is usually higher than in other days (i.e. monday, tuesday, friday). Nonetheless, spatial traffic distribution remains nearly unaltered. Hence, ranking of TRXs in the network in terms of benefits from HR codec allocation is still valid for periods with different overall offered traffic (although overall congestion relief obviously depend on actual traffic demand figures).

The corresponding sentences have been added to clarify it so in the explanation of Table 1 in the “Trial results” section.

What is the significance of the results? Are they based on only one run of the algorithm (e.g. In table 2 for 33 codecs we get an higher congestion rate with less offered traffic than in table 1)? The authors should clarify these points and if only one set of data was used, the paper should be revised to increase the significance of the results before an eventual resubmission.

In the previous version of the manuscript, it was reported that the algorithm was tested with two sets of data (i.e. predictions for the codec re-allocation process were performed twice). From this data, stability of the predictions could be analysed. However, only the performance obtained from one re-configuration of the network was presented (i.e. named automatic 33), apart from the results achieved by the previous manual configuration (i.e. named manual 22). Consequently, as remarked by the reviewer, the significance of the results might be considered not enough.

To increase the significance of the results, the performance statistics of a second download of automatic license allocation has been included. Thus, three data sets are now presented, showing the performance of two codec automatic re-allocations (referred as automatic 33-1st iteration and automatic 33-2nd iteration) and the previous manual allocation (referred as manual 22).

The addition of the third period was not straight-forward. In this last period, three cells, where HR codec allocation was not possible because of equipment constraints, were removed from the area covered in the trial. Hence, to keep the trial area consistent for the three periods, these three cells have been discarded in the analysis of previous periods. Thus, results throughout the trial have been recalculated and tables 1, 2, 3 and figures 1 and 2 have been updated. Although exact figures differ from the previous version of the manuscript, main trends remain unaltered.

From the data analysis, it is observed that the algorithm is again able to successfully reduce the blocking in the network, even though traffic gain is decreased. Likewise, discrepancies between blocking predictions and measurements, which were detected by the reviewer from the comparison of Tables 1 and 2, are now reduced. Nonetheless, comprehensive analysis has been carried out to check the significance of the predictions. Analysis has proved that remaining prediction errors are caused by subtle changes in spatial traffic distribution (i.e. even though overall offered traffic increases, less traffic is observed in some congested cells). These errors would be definitely smoothed by means of a longer measurement averaging. The corresponding comments have been added in the last paragraph of the “Trial results” section.

Reviewer #2: The paper considers assignment of a limited number of half-rate codecs in EDGE networks that is important to reduce the related codec costs and to alleviate congestion. The problem is of Knapsack 0/1 type for which the author inspects greedy-algorithm and discusses some practical field experiment to verify his assumptions. As such, the submitted paper shows a well-done engineering work whose practical results are on-line with the theoretical analysis.