Dimensioning of Signaling Capacity on a Cell Basis in GSM/GPRS

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***Abstract*- Accurate dimensioning of signaling capacity is decisive for the efficient operation of mobile telecommunication networks. In this paper, an automatic optimization algorithm for adaptation of permanent signaling resources in GSM/GPRS is proposed, which is based on statistical measurements of signaling and call traffic. Analysis of real network indicators demonstrates that overall revenue losses caused by blocking effects may be greatly minimized.**

I. INTRODUCTION

Dimensioning of voice channels is of utmost importance for cellular operators when aiming to maximize call revenue. Thus, a lot of effort has traditionally been dedicated to dimensioning traffic channels of all cells in the network, as on these channels the payload is carried. However, the emergence of new services, such as Multimedia Messaging Services (MMS), which rely heavily on signaling procedures, poses new challenges on the management of the associated signaling load.

Signaling capacity in GSM/GPRS networks largely depends on dimensioning the control channel capacity [1]. These channels, relating mainly to mobility management procedures (i.e. call delivery and location updates), have a great impact on network performance. First, the Paging Channel (PCH) is used for notification of incoming calls. The bi-directional Stand-alone Dedicated Control Channel (SDCCH) is subsequently used for purposes such as call set-up, mobile station attach/detach, location update and short message submission. Therefore, congestion avoidance on these channels proves to be extremely relevant for operators when aiming to minimize loss of traffic, i.e. loss of revenue.

Different approaches to overcome this problem have been covered in the literature. As a first step, reduction of the signaling load offered at the origin has been suggested in several references [2-5]. Both static (i.e. global or network dependent) and dynamic (individual or mobile dependent) strategies have been suggested. In parallel, several features are available in the network that deal reactively with particular congestion problems on the SDCCH channel, by relying on spare Traffic Channel (TCH) capacity in the cell. For example, in *Fast Associated Control Channel* (*FACCH) call setup* algorithm, the mobile station (MS) is assigned directly from the Common Control Channel (CCCH) to unused TCH Time Slots (TSL), normally reserved for call traffic channels, where the signaling procedure finally takes place. Thus, different kind of call set-ups, short messages and supplementary services (but not location updates) may be performed using FACCH. Likewise, in *Dynamic SDCCH allocation* algorithm, idle Traffic Channel (TCH) resources are temporarily configured for SDCCH use. Once the demand for SDCCH signaling is reduced, the TCH TSLs are configured back to their original use. Both reactive features offer benefit in cases where spare TCH capacity can be used dynamically for signaling purposes.

Unfortunately, experience shows that in most cases signaling and call traffic peaks tend to be rather correlated. In this situation, additional SDCCH capacity from spare TCH cannot be provided since call traffic load uses the available TCH TSLs. Likewise, other congestion relief strategies such as directed retry and load sharing [6] do not provide any improvement either, since users are prevented from even accessing the network. As a consequence, handover to surrounding neighboring cells is not possible. Therefore, a minimum share of cell capacity has to be permanently reserved for signaling purposes to minimize revenue loss.

Finally, the dimensioning process for this territory should account for the fact that the offered traffic in a cellular network tends to appear unevenly distributed in the spatial domain. Therefore, this territory should be configured on a cell-by-cell basis if full adaptation to spatial traffic patterns in the network is desired. However, this approach comes into conflict with the traditional optimization strategy where operators fix SDCCH territory on a network wide basis, due to the effort and expenses related to this cell specific signaling territory optimization.

In this paper, a fuzzy-logic based optimization algorithm for off-line adaptation of permanent signaling resources on a per-cell basis in GSM/GPRS networks is proposed. First, section II is focused on the description of the fuzzy adaptation algorithm. Subsequently, analysis of field measurements is presented in section III to confirm the validity of the approach in real networks. Finally, the main conclusions are summarized at the end of the paper.

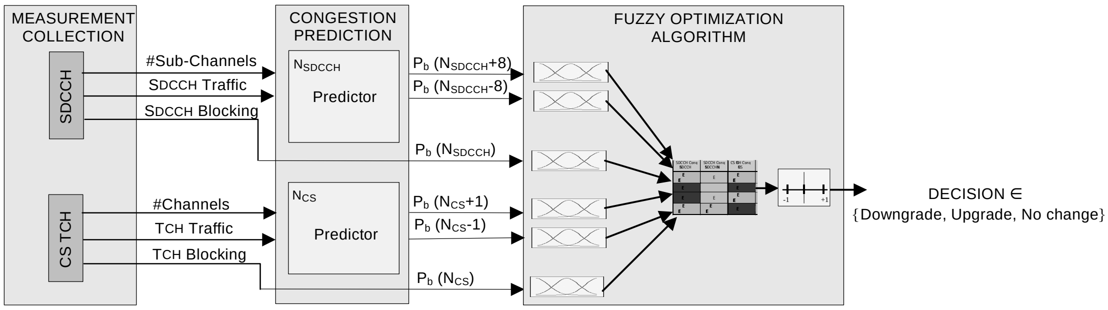

Figure 1. Structure of the process devised for SDCCH territory optimization.

II. Description of The Optimization Process

The structure of the optimization procedure suggested in this paper is outlined in Fig. 1. In essence, the system decides on a per-cell basis whether to reassign TSLs between TCH and SDCCH, based on measurements of traffic demand and allocated capacity resources for both traffic classes.

As depicted in Fig 1, relevant network traffic statistics and cell configuration are first gathered. Subsequently, the consequences derived from the reallocation of traffic resources between the different traffic classes are predicted. Finally, a fuzzy optimization algorithm determines the optimum TSL allocation. Due to the inherent granularity in the TSL assignment process (i.e. the number of TSL must be an integer number), the problem is reduced to a combinatorial optimization problem, where evaluation of the full limited set of options is performed. In this particular case, the number of re-assignable TSL has been limited to one, and therefore only three outcomes from the algorithm are possible: SDCCH territory reduction (i.e. downgrade), extension (i.e. upgrade) and preservation of the current state (i.e. no change).

In the following sections, analysis of the most suitable indicators for the congestion estimation is carried out. Then, the core of the reckoning process is covered with the description of the fuzzy system.

A. Main traffic indicators

The proposed adaptation process aims at minimizing the congestion problems in both the signaling and call traffic channels in each cell of the network. Therefore, the ability to detect if traffic resources reserved for a certain traffic class are under- or over-dimensioned is crucial for a proper performance of the algorithm.

Existing network statistics provide multiple indicators that may be used to evaluate the utilization of traffic resources. In particular, blocking rate has been selected to model the congestion effects derived from the reassignment of TSLs. Likewise, comparison between the number of available and maximum busy SDCCH sub-channels have been used to detect excess allocation of signaling resources.

Since parameter changes related to SDCCH territory require temporal disabling of the cell, fast reactive control approaches (i.e. hourly) are discarded. Therefore, periodic off-line execution of the optimization procedure is suitable, where weekly averaging of Busy Hour (BH) measurements has been considered. Regarding the selection of the BH period, it is worth noting that SDCCH-BH and TCH-BH may not be fully coincident in time. Fig. 2 depicts the overall carried traffic in a typical network for both traffic classes, represented on an hourly basis. From Fig. 2, it is evident that SDCCH and TCH traffic peaks are not fully aligned. Since the worst case for each traffic class is normally used for dimensioning purposes, different BH periods for measurement collection have been configured in the algorithm for both traffic components.

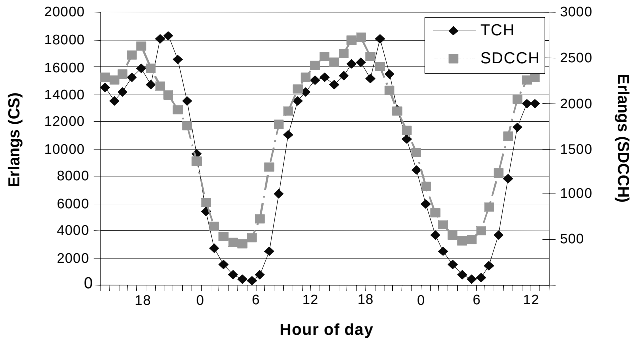

Figure 2. SDCCH and TCH traffic pattern in a typical network.

Once the network statistics are gathered, the subsequent congestion prediction module anticipates the effects caused by any potential territory modification. Under poissonian traffic assumption, Erlang-B formula can be used to estimate the blocking probability of both traffic classes based on their respective traffic intensity and territory settings. It is worth noting that the assignment of 1 TSL for signaling purposes will lead to 8 SDCCH (sub-) channels.

A further refinement could be entailed in the SDCCH blocking estimation to account for the different priority given by the operator to diverse messages carried over the signaling channel. Thus, consideration of higher priority traffic (e.g. mobile outgoing/terminating calls, call re-establishment, emergency calls, supplementary services, SMS) and neglect of lower priority traffic (e.g. IMSI attach/detach, location update) could be performed. On the following, only the aggregation of SDCCH traffic is considered for the sake of clarity.

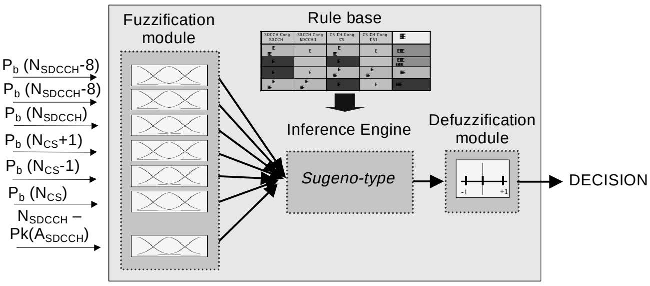

Figure 3. Structure of the fuzzy decision module.

B. *Fuzzy optimization algorithm*

Rule-based fuzzy techniques have been applied to design the decision method [7]. The main advantage of this approach lies in the flexibility to define the behavior of the optimization system by means of natural language instead of complicated numerical formulas.

The structure of the fuzzy decision module, within which the intelligence of the algorithm resides, is depicted in Fig. 3. Basically, the module consists of a fuzzification module, a rule base, an inference engine and a de-fuzzification module.

The initial fuzzification module evaluates the potential states of the network based on the calculated congestion predictions. This process entails the reckoning of membership probabilities to predefined sets, based on the membership functions depicted in Fig. 4. Blocking rate predictions $P_b(.)$ for SDCCH and TCH traffic are classified either as *Low(L)*, *Medium(M)* or *High(H)*, following subjective judgement by the user of the system. Thus, congestion problems caused by an inadequate territory setting are highlighted. Likewise, the number of unused SDCCH sub-channels, derived from the difference between the number of available (N_{SDCCH}) and peak used ($pk(A_{SDCCH})$) sub-channels, is classified either as *Low(L)* or *High(H)*. Thus, an indicator for over-dimensioning of SDCCH resources is also established.

The basic function of the rule base is to represent the control policy of an experienced operator in a structured way by means of *if <network state>, then <control output>* rules. Table I presents a set of rules suitable for the problem under study, by establishing the relationship between blocking conditions and control actions linguistically. For instance, the second rule in Table I reads:

"*If* $[P_b(N_{SDCCH})$ *is High]* & $[P_b(N_{CS})$ *is Low or Medium]* & $[P_b(N_{CS}\text{-}1)$ *is Low or Medium], then Decision is Upgrade*".

In short, SDCCH territory re-configuration is performed if large differences in congestion exist between the two traffic classes, and the new configuration does not cause high blocking in either traffic class. Furthermore, an additional rule provides a mechanism that performs a gradual decrease of the SDCCH resources when no congestion problems are detected or envisaged (rule 8). The rule set reflected in Table I is believed to be sufficient for carrying out all required control action for signaling dimensioning in GSM/GPRS.

From this knowledge base, the inference engine computes the overall value of the output variable based on the result from conditional firing of rules. A zero-order Sugeno-type inference engine with singleton output values {-1, 0, +1} has been selected due to its simple structure. Finally, the de-fuzzification module takes charge of the decision making.

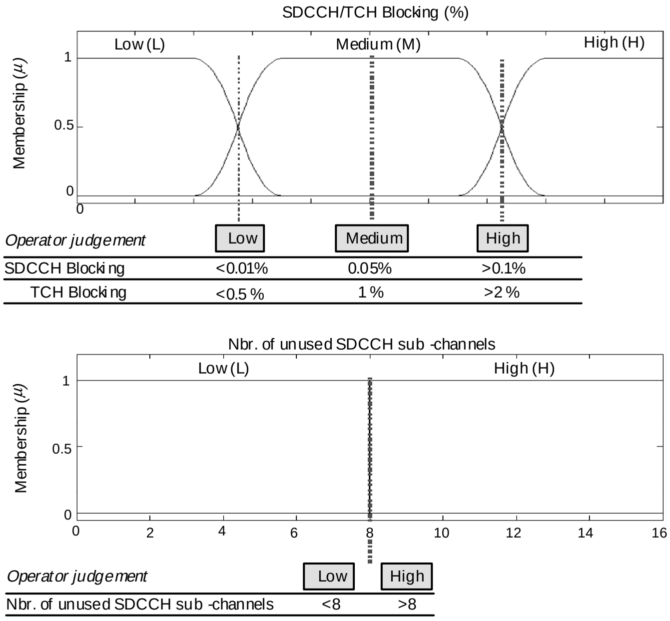

Figure 4. Fuzzy sets of input state variables.

TABLE I
RULE SET IN THE FUZZY DECISION SYSTEM

	Network State					*Output*
Rule	P_b (N_{SDCCH})	P_b $(N_{SDCCH}\text{-}8)$	P_b (N_{CS})	P_b $(N_{CS}\text{-}1)$	N_{SDCCH} - $pk(A_{SDCCH})$	*Decision*
1	*H*		*H*			NO CHANGE
2	*H*		*L* | *M*	*L* | *M*		UPGRADE
3	*H*		*L* | *M*	*H*		NO CHANGE
4	*L* | *M*	*L* | *M*	*H*			DOWNGRADE
5	*L* | *M*	*H*	*H*			NO CHANGE
6	*L* | *M*	*M* | *H*	*L* | *M*			NO CHANGE
7	*L* | *M*	*L*	*L* | *M*		*L*	NO CHANGE
8	*L* | *M*	*L*	*L* | *M*		*H*	DOWNGRADE

C. *Implementation details*

Some practical issues must be taken into account to help the deployment in a real network. Concretely, two different SDCCH allocation methods may be considered: sparse and compact. In sparse mode, the SDCCH territory is distributed among several transceivers (TRX) in the cell, which leads to a higher signaling reliability due to protection against TRX failure. In compact mode, TSL dedicated to signaling purposes are consecutively located on a TRX until its maximum capacity is reached. This allocation strategy leads to TSL

TABLE II

INTERNAL OPTIMIZATION PARAMETERS

Min. nbr. SDCCH TSL		1
Max. nbr. SDCCH TSL		6
$P_{b\ SDCCH}$	*Low*	0.01%
	Medium	0.02%
	High	0.05%
$P_{b\ TCH}$	*Low*	0.5%
	Medium	1%
	High	2%
Unused SDCCH sub-ch. threshold		8

clusters, which may be instrumental when combined with packet-switched data territory management strategies.

Likewise, traffic measurements gathered during weekends are neglected in the averaging of blocking indicators, so that the TSL number is dimensioned for high traffic loads experienced during week-days.

III. THE ALGORITHM IN A REAL NETWORK

In the following, an example of the application of the proposed algorithm in a real network is presented. The described algorithm was tested in a live environment to estimate the potential gain from an optimum ascription of TSL resources. Once the trial setup conditions are clarified, analysis of the proposal for new territory settings (i.e. open-loop behavior) from network statistics collected will show the benefits of the proposed optimization procedure.

A. *Trial setup*

The results displayed here cover a time interval of three consecutive weeks. The trial area consisted of 354 cells (1140 TRX) providing seamless coverage. The rule set in Table I summarizes the optimization strategy, whilst the internal parameter settings for the algorithm are shown in Table II.

It is worth pointing out that, like in any optimization process, the resulting performance gain is dependent on how distant the current system configuration is from the optimum.

B. *Open-loop analysis*

First, the main traffic performance indicators in the trial area are examined. Fig. 5 depicts the daily overall BH traffic and blocking rates for both traffic classes during the trial. From the figure, it is clear that the TCH and SDCCH traffic remained virtually unchanged during the trial. The following analysis will focus on the weekly averages from the third week unless stated otherwise.

Table III breaks down the initial state of the network in the week under consideration. In the table, cells have been sorted based on their weekly average overall SDCCH and TCH blocking rates in the corresponding BH period. It is evident that numerous cells exist (i.e. 14+45=59 cells) where signaling resources had been over-dimensioned at the expense of a medium or high call blocking rate (i.e. higher than 0.5%). This result was expected since existing manual optimization

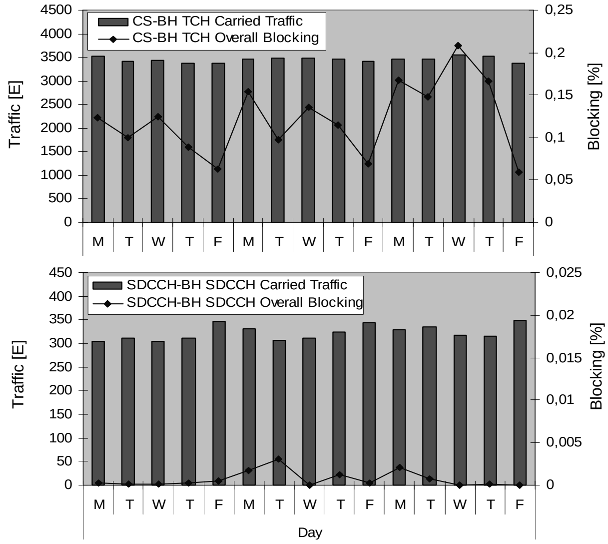

Figure 5. Daily overall BH traffic and blocking rate in the trial area.

TABLE III

CELL STATISTICS BEFORE OPTIMIZATION

$P_{b\ SDCCH}$ \ $P_{b\ TCH}$	P_b <0.5%	0.5%<P_b<2%	P_b ≥2%
P_b <0.01%	279	14	45
0.01%<P_b<0.05%	0	1	1
P_b ≥0.05%	3	2	9

TABLE IV

SDCCH TERRITORY DECISION STATISTICS

Decision	*Ocurrences*	*Share(%)*
DOWNGRADE	75	21.0
NO CHANGE	279	77.9
UPGRADE	4	1.1
TOTAL	358	100

procedures entailed only mechanisms to increase signaling resources but none to reduce them. Thus, operator policy finally resulted in the allocation of excessive SDCCH resources. This conclusion was reinforced by the outcome of the decision process of the optimization algorithm, which is summarized in Table IV. From this table, it can be concluded that most of the suggested changes (i.e. 75) entail a reduction of signaling resources. Likewise, only very few SDCCH territory upgrades (i.e. 4) were suggested for cells with unacceptable levels of SDCCH blocking.

The effects induced by the optimization procedure may easily be recognized over the changes in the distribution of weekly average cell blocking in the network. Fig. 6 represents the number of cells that exceed a certain level of blocking for SDCCH and TCH traffic, respectively. From the graph, it is inferred that most relevant effects are caused over SDCCH traffic. Despite the overall loss of signaling resources, improvement of SDCCH blocking performance is observed due to resolution of severe SDCCH congestion problems in isolated cells.

Meanwhile, TCH blocking also benefits from the ascription of additional resources (i.e. 75-4=71 TSLs). However, no extreme differences in the blocking distribution are predicted in spite of the large number of territory re-configurations. This result is motivated by the limited magnitude of added CS resources in relation to previous settings, which is a consequence of both the limits imposed on the optimization process (i.e. ±1 TS max.) and the large number of TRXs per cell in the concrete scenario of the trial (i.e. 3.22 TRX/cell).

Finally, the stability of the proposal given by the algorithm for the territory settings is studied. For that purpose, the algorithm was run on a weekly basis over the complete measurement set. Subsequently, the prediction module in the algorithm is used to estimate the performance gain attainable by the new territory settings. Separate prediction of blocking rates for individual traffic classes was carried out, based on their past average BH traffic demand and the revised resource configuration. Table V presents the estimated performance indicators before and after TSL re-configuration for each of the three weeks of the trial. For the sake of clarity, averages of the whole period are also provided.

The reduction of TSL devoted to signaling purposes is noticeable throughout the whole trial (i.e. 11% decrease in average number of SDCCH TSL). In addition, only small differences are discerned in the overall share of TSL between traffic classes, regardless of local variations in the traffic volume among the different time periods under consideration.

Despite the overall loss of signaling resources, improvement of overall SDCCH blocking performance is obtained (i.e. 58% decrease). Likewise, small effects in TCH blocking performance are observed, expected from the small increment in the number of TCH TSLs derived from re-allocation (i.e. 0.7% TSL increase leads to 3% decrease of blocked traffic).

From the results of the analysis here presented, it can be concluded that the optimum ascription of TSL carried out on a cell-by-cell basis by the algorithm can enhance the utilization of existing network resources, thus minimizing congestion effects in the network.

IV. CONCLUSION

Optimum configuration of traffic resources will be crucial to enhance the performance of complex mobile networks. Hence, an automatic optimization algorithm for off-line adaptation of permanent signaling resources has been proposed. Fuzzy-logic techniques have been employed to include the heuristics rules of an experienced operator.

Field measurement analysis highlights the limitations of existing manual optimization procedures related to the dimensioning of signaling resources. Therefore, an optimum ascription of TSL performed on a per-cell basis can minimize congestion problems in the network, without the need for additional hardware resources. In this particular case, a 58% decrement of weekly SDCCH blocking rate was obtained in spite of a 11% reduction of overall SDCCH resources.

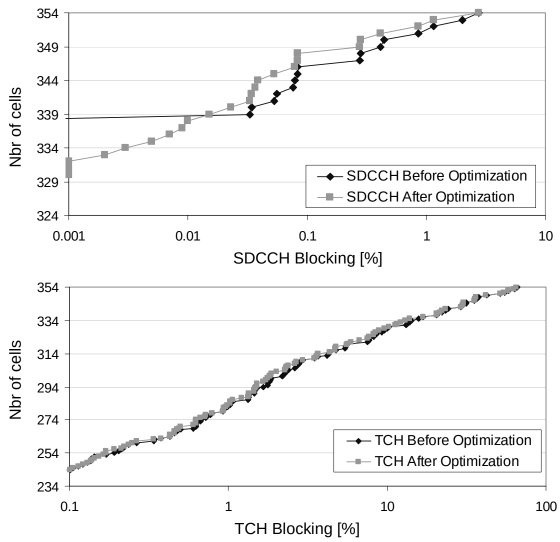

Figure 6. Blocking rate distributions before/after optimization.

TABLE V
ESTIMATES OF PERFORMANCE AFTER OPTIMIZATION

Week	*Selection*	*Total SDCCH TSL*	*Total TCH TSL*	*Overall SDCCH blocking [%]*	*Overall TCH blocking [%]*	*Overall SDCCH blocked traffic [E]*	*Overall TCH blocked traffic [E]*
1st	Measured	598	9466	0.015	9.90	0.046	339
	Optimized	517	9547	0.008	9.55	0.026	327
2st	Measured	598	9466	0.085	11.37	0.275	393
	Optimized	536	9528	0.020	11.04	0.066	382
3st	Measured	598	9466	0.034	14.25	0.114	495
	Optimized	542	9522	0.030	13.86	0.099	481
Avg	Measured	598	9466	0.045	11.84	0.145	409
	Optimized	532	9532	0.019	11.48	0.063	397
	Difference	-66 (-11%)	+66 (-0.7%)	-0.026 (-58%)	-0.36 (-3%)	-0.082 (-58%)	-12 (-3%)

As a result of the attained congestion relief, cell capacity expansion strategies, such as TRX addition or cell splitting, may be delayed in time. Thus, long-term capital investments are minimized. In addition, manual work devoted to signaling dimensioning is reduced, enhancing network operability and minimizing operational expenditures.

REFERENCES

[1] 3GPP TS 05.02 V8.10.0. "Multiplexing and multiple access on the radio path". August 2001.

[2] P.García, V.Casares, J.Mataix. "Reducing location update and paging costs in a PCS Network". *IEEE Trans. on Wireless Commun*,,vol.1,No.1, pp.200-209 Jan. 2002.

[3] A.Bar-Noy, I.Kessler, M.Sidi, "Mobile users: To update or not to update". *Proc. INFOCOM' 94*, Toronto, Canada, June, pp. 570-576.

[4] I.F.Akyildiz, J.S.M.Ho, Y.B.Lin. "Movement-based location update and selective paging for PCS networks". *IEEE/ACM Trans. Networking*, vol.4, pp.629-638, Aug. 1996.

[5] Y.B. Lin. "Reducing location update cost in a PCS". *IEEE/ACM Trans. Networking*, vol.5,pp.25-33,Feb1997.

[6] J. Karlsson and B. Eklund. "A cellular mobile telephone system with load sharing- An enhancement of directed retry". *IEEE Trans. Commun.*, Vol.37, no.5, pp.530-535, May 1989.

[7] E.Cox. "The fuzzy systems handbook". 2nd edition. Academic Press 1999.