

Balancing GoS in Cellular Networks using Static Channel Relaying Strategy with Adaptive Threshold

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Abstract— In cellular networks, the provided bandwidth is limited but the number of mobile subscribers (MS) keeps increasing everyday. Enhancing network capacity while maintaining the Grade of Service (GoS) is one of the most important issues. There are a numbers of solutions given to solve this problem, such as channel assignment, channel borrowing [1]-[2], channel sharing [3] and channel relaying [4]-[5]. Co-channel interference is the limitation of [1]-[3], and unbalanced GoS is the constraint of [5]. This paper presents an algorithm selecting the suitable threshold to adapt with certain traffic load. This adaptive threshold (AT) then can be used in Static Channel Relaying Strategy (SCRS) to reduce the call blocking probability of *hot cells* to the value equal to that in *cold cells*. The GoS of hot and cold cells now is balanced by SCRS-AT. This scheme can be applied to different network's sizes for best channel utilisation.

I. INTRODUCTION

Cellular telephone networks have grown rapidly during recent decades. The numbers of mobile users increase every single day while the cellular bandwidth is limited. Enhancing the network capacity while maintaining the Grade of Service (GoS), is one of most important issues in cellular systems. There is a number of solutions given to solve this problem, such as channel assignment, channel borrowing [1]-[2], channel sharing [3] and channel relaying [4]-[5].

The basic idea of [1] is using different schemes to assign the network resources efficiently. Depending on the traffic conditions, fixed or dynamic channel assignment (FCA or DCA) is performed to optimise the frequency reuse. Moreover, the available channels in certain cells can be borrowed by their neighbours to balance the traffic load in the network [1]-[3]. The borrowed channels can be used in a new cell if they do not interfere with the other operating channels around. This condition is the limitation of [1]-[3].

Channel relaying strategy (CRS) is a scheme that uses relay stations (RS) to relay channels between cells [4]-[5]. The free channels in a particular cell can be relayed and operated comfortably in other cells in the network without

interference. However, the number of RS used in [4] is high and the CRS can only relay the traffic from *hot* to *cold cells* only (the concept of hot and cold cells will be detailed later in the paper). These problems can be solved in [5] by locating the RSs in the vertices between three hexagonal cells (instead of the shared edge between two cells [4]). The analyses in [5] show that the number of RSs used in this scheme is much smaller than that in [4], and the traffic can be relayed from hot to cold cells, between hot cells and even from cold to hot cells. These improvements help CRS operating in a more flexible and efficient way.

In previous works, we proposed a method using CRS to release congestion in cellular networks [5]. The key idea of [5] is to reduce the call blocking probability in hot cells while maintain the GoS of cold cells. Firstly, the GoS of cold cells is set at 2%. Then, all free channels in cold cells are relayed to the hot cells within a certain hot region to relieve the call blocking probability [5]. However, the results in [5] show that the GoS of hot cells can still be larger than 2%. In other words, after applying this method, the GoS is not balanced within the network. This can be explained by the fact that cells are usually classified as hot or cold based on a fixed parameter called threshold, which is calculated using the number of reserved channels, i.e, the number of channels within a cell which are only used if the case becomes congested or for borrowing purposes from other cells. When this threshold value is fixed for all cells in the networks, the GoS is not balanced in the network after CRS is applied, partly because the actual number of channels available for borrowing in cold cells can be greater than the number of reserved channels, leading to a misuse of resources. In this paper, we show that if we allow this *threshold* to adapt to different traffic conditions in hot and cold cells, the GoS can be perfectly balanced throughout the network with a satisfactory call blocking probability on both cold and hot cells.

The rest of this paper is organised as follows. Section 2 discusses briefly about Channel Relaying Strategy (CRS). Our proposed Static Channel Relaying Strategy with Adaptive Threshold (SCRS-AT) is presented in section 3. Numerical results are given and discussed in section 4. Section 5 concludes the paper.

II. CHANNEL RELAYING STRATEGY

1. Classify hot and cold cells

At certain times, the concentration of users in a particular cell is greater than the nominated level, so the cell may be congested and it is called *hot cell*. Because it is hot, there are not enough traffic channels to satisfy any request from users, so the call blocking/dropping probability of that cell may be higher than an acceptable value (normally 2%). On the other hand, the traffic load in other cells in the network is smaller than that in the hot cell. There are available channels in these cells and they are called *cold cells*. The nominated level used to classify hot and cold cells is called *threshold*. The notion of threshold was first introduced in [2] as a fixed parameter with the typical values arbitrarily set to 0.2 or 0.25. In other words, if the threshold is set to 0.2, this means that only 80% of the total available channels within the cell are allocated to this cell only. The 20% remaining channels are available for borrowing purposes or for the cell itself if it becomes congested. In fact, the threshold is used as a parameter to determine whether the cell is hot or cold: if none of the channels within the “reserve” is used, the cell is cold, and vice versa.

Similar to [5], in this paper, the parameters degree of cell d_c and threshold t_c will be used to classify hot and cold cells. They are calculated as:

$$d_c = \frac{N_a}{N_c} \quad (1), \text{ and}$$

$$t_c = \frac{N_r}{N_c} \quad (2)$$

where N_a is the number of available channels in a cell and N_r the number of channels in the “reserve” (i.e reserved channels). N_c stands for the total number of channels normally assigned to a cell. In general, $0 \leq t_c \leq 1$ and the value of t_c indicates the channel reserve capability of a cell. The cell is hot when $d_c \leq t_c$, otherwise it is cold. Moreover, when $N_a=0$ ($d_c=0$ also), the cell will be heavily congested.

2. Channel relaying strategy

Channel Relaying Strategy (CRS) is the scheme that uses the Relay Stations (RSs) to relay channels between cells [4]-[5].

The RS is a wireless device that communicates with BTSs and Mobile Stations (MSs) via cellular and 2.4 GHZ ISM band respectively. Moreover, RSs should be located at the vertex between three hexagonal cells to minimise number of requirement RSs and provide better services in the networks. The service radius of RS is $r = R/2$, where R is the coverage radius of a cell (Fig.1) [5].

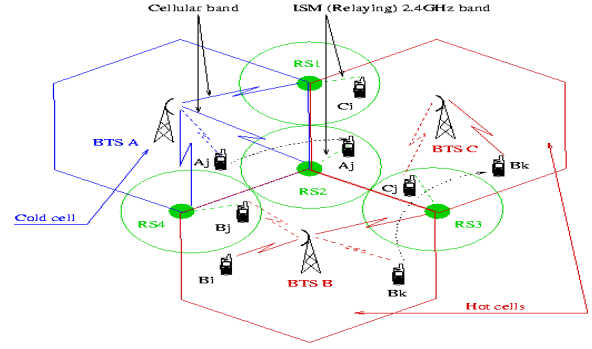


Figure 1: Basic network model for CRS

In Fig.1, suppose that BTS A is the neighbour cold cell of two hot cells B and C in three cells network model. The basic performances of CRS are presented via SCRS and HCRS as follows.

Static CRS: The process which provides a channel to the user moving inside the hot cell is called *SCRS*. In Fig.1, suppose that user B_j in cell B and user C_i in cell C generate new calls, and C_i is in the coverage of RS1 while B_j is out of coverage of both RS2 and RS4. In the case of C_i , the relaying route is set via connections from C_i to RS1 and from RS1 to BTS A. This type is called *direct SCRS*. In order to serve the user B_j , RS4 (and also RS2 if necessary) have to scan to find the user B_j in cell B, who is engaged in an on-going call and located within the coverage of one of the two RSs. The process of obtaining free channel for B_j is as follows. The relaying route will be set between B_j and BTS A via RS4 similar to that between user C_i and BTS A above. Now the channel released by B_j can be used by B_j . This is called *indirect SCRS*.

Handover CRS: This strategy refers to the relaying process whereby channel is relayed for an on-going call handed over between cells. In Fig.1, users A_j in cell A and B_k in cell B are engaged in on-going calls while they move to cell C. However, C is a hot cell so there are no free channels in this cell available to serve these calls, hence they would normally be dropped. The handover relaying will help to reduce the call dropping probability. The handover relaying process can be explained as follows. Because of the destination of MS A_j in cell C is in the coverage of RS2, so the relaying route is set: BTS A \rightarrow RS2 \rightarrow MS A_j (Fig.1). In this case, the channel used by MS A_j in cell A is relayed to the new destination in cell C via RS2 (*direct HCRS*). On the other hand, the MS B_k moves out of coverage of the RS2/RS3, so the mechanism assigning channel to B_k as a result from channel swapping between B_k and C_j using CRS (BTSC(B_k) \rightarrow RS3 \rightarrow C $_j$ // BTSC(C_j) \rightarrow B $_k$) (*indirect HCRS*).

In general, when the GoS is set at 2% and the threshold t_c is fixed, the number of free channels in cold cell A is also fixed (i.e 20% of the total number of channels N_c).

However, the degree of hot cells B and C are normally unstable and depend on the traffic conditions. Consequently, SCRS in [5] can help to release congestion in these cells by relaying all of free channels from cell A to cell B and C, but it cannot balance the GoS between them. By using SCRS-AT, this problem can be solved by quantifying the number of channels that should be made available for borrowing purposes, based on the global requirements of the network. The details of SCRS-AT are presented in next section.

III. BALANCING GOS IN CELLULAR NETWORKS BY USING STATIC CHANNEL RELAYING STRATEGY WITH ADAPTIVE THRESHOLD

1. Apply SCRS-AT to simple network model:

The simple network model is presented in Fig.1. Recall that BTS A is the neighbour cold cell of two hot cells B and C. The call blocking probability of these cells before applying SCRS-AT is calculated by Erlang B formula as:

$$P_{A,B,C} = \frac{\frac{T_{A,B,C}^N}{N!}}{\sum_{k=0}^N \frac{T_{A,B,C}^k}{k!}} \quad (3)$$

where $P_{A,B,C}$ and $T_{A,B,C}$ are the call blocking probability and traffic load in cell A, B, and C respectively. N is the nominated number of working channels in a cell and calculated by: $N = (1-t_c) * N_c$ (4).

Because it is cold cell, so $P_A < 2\%$; and B and C are hot cells, so $P_{B,C} \geq 2\%$. As mentioned in section 1, GoS of cold cell is set at 2%, so the number of free channels in cell A is:

$N_f = N - N_A$, where N_A is calculated from:

$$0.02 = \frac{\frac{T_A^{N_A}}{N_A!}}{\sum_{k=0}^{N_A} \frac{T_A^k}{k!}}, \quad (5)$$

For best channel utilisation, these N_f channels can be used to reduce as well as balance P_B and P_C using SCRS as

follow:
$$\begin{cases} \frac{T_B^{N+N_B} / (N+N_B)!}{\sum_{k=0}^{(N+N_B)} T_B^k / k!} = \frac{T_C^{N+N_C} / (N+N_C)!}{\sum_{k=0}^{(N+N_C)} T_C^k / k!}, & (6) \\ N_B + N_C = N_f \end{cases}$$

It is important to recall that in [5], since t_c was fixed then N_f was not determined according to the GOS constraint. In that case, it was just a fixed arbitrary value; In order to equalise P_A , P_B and P_C , the threshold t_c has to be such as the condition below is satisfied:

$$\begin{cases} 0.02 = \frac{T_B^{N+N_B} / (N+N_B)!}{\sum_{k=0}^{(N+N_B)} T_B^k / k!} = \frac{T_C^{N+N_C} / (N+N_C)!}{\sum_{k=0}^{(N+N_C)} T_C^k / k!}, & (7) \\ N_B + N_C = N_f \end{cases}$$

In practical networks, the traffic load is random value, so the equations (5) and (7) can be solved when t_c is controlled by the suitable algorithm to adapt with different traffic conditions. Hence, SCRS-AT is combination of SCRS and the algorithm to select the threshold. This algorithm will be detailed in next section.

2. Apply SCRS-AT to large network models:

Generally, SCRS is useful to relieve congestion in the hot cells, so SCRS-AT should be applied to certain hot regions. In this paper, the model of a hot region is described as a hexagonal ring, as in [2], [5].

The hot region is an area where there is a concentration of a fixed number of hot cells within the ring (Fig.2). To avoid the propagation of congestion, we place a condition on the hot region that there is at least one edge shared between contiguous hot cells in the region.

The size and location of the hot region is determined via its diameter d and its centre cell. The diameter d is the largest cell distance between any two cells in the hot area. The cell in the middle of the line connecting two most distant hot cells is called centre cell (or ring 0th). Ring n^{th} , where $n = d/2$, is the largest ring in the hot region. Hence, the hot region consists of $(n+1)$ rings, from ring 0 to ring n^{th} , so n also can be used to indicate the size of hot region.

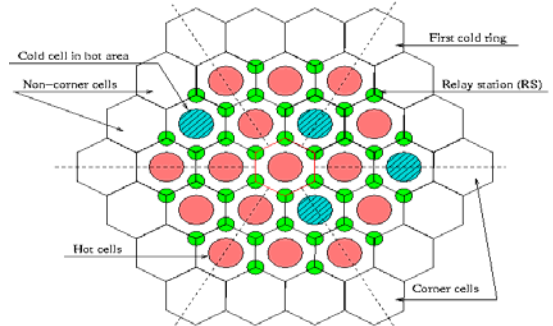


Figure 2: The hot region with $n = 2$ and $d_h = 0.75$.

In order to evaluate the “temperature” of a hot region, we define the parameter d_h ,

$$d_h = \frac{\text{the - number - of - hot - cells}}{\text{the - total - cells}} \quad (8)$$

and interpret it as the degree of the hot region.

The total number of cells in a local hot region is calculated by [2], [5]:

$$SUM_{cell} = 1 + \sum_{k=1}^n 6k = 1 + 3n(n+1) \quad (9)$$

By using the value of d_h above, we have:

The number of hot cells in the hot region is:

$$SUM_{hc} = d_h \cdot N_{cell} = d_h \cdot [1 + 3n(n+1)] \quad (10)$$

and the number of cold cells in the hot region is:

$$SUM_{cc} = (1 - d_h) \cdot N_{cell} = (1 - d_h)[1 + 3n(n+1)] \quad (11)$$

Recall that t_c is used to indicate the number of channels in the “reserve” of a cell. For example, when $t_c=0.25$ and $N_c=40$, there are 25% (10/40 channels) of channels available for borrowing purposes. Meanwhile, the number of working channels $N=30$, so the load threshold of a cell is $T_t=21.93$ Erlangs at $GoS=2\%$ (see (3)).

In this paper, the network model will be studied with $N_c=40$, $GoS=2\%$. Assume that the largest load $T_{Max}=40$ Erlangs when $N_c=40$ channels. Hence, the traffic load in hot and cold cells are respectively denoted by T_h and T_c can be generated as:

- $T_c = \{0 - T_t\}$
- $T_h = \{T_t - 40\}$

The mechanism of SCRS is to reduce the temperature of the local hot region by relaying all of available channels in cold cells to hot cells [5]. Suppose that average number of free channels in a cold cell is N_f (N_f is calculated similarly as in section 3.1 above), the average number of channels used to cool down a hot cell is:

$$N_{SCRS} = \frac{N_f \cdot SUM_{cc}}{SUM_{hc}} = \frac{(1 - d_h)N_f}{d_h} \quad (12)$$

After using SCRS, the GoS of a hot cell becomes:

$$GoS_{SCRS} = \frac{T_h^{N+N_{SCRS}}}{(N + N_{SCRS})!} \quad (13)$$

$$\sum_{k=0}^{N+N_{SCRS}} \frac{T_h^k}{k!}$$

With a certain value of t_c , the corresponding N , N_f and N_{SCRS} can be computed respectively via equations (2) and (12) above. To balance the GoS between hot and cold cells (at 2%), N_{SCRS} in (12) has to satisfy the condition:

$$GoS_{SCRS} = \frac{T_h^{N+N_{SCRS}}}{(N + N_{SCRS})!} = 0.02 \quad (14)$$

$$\sum_{k=0}^{N+N_{SCRS}} \frac{T_h^k}{k!}$$

The equations (2), (12), and (14) can be used to show the relationship between t_c , N , T_t , N_f , N_{SCRS} and d_h as follows (Fig.3).

t_c	N_t	T_t	N_f	N_{SCRS}	d_h
0.05	38	29.17	16	6	0.73
0.1	36	27.34	15	7	0.68
0.15	34	25.53	14	8	0.64
0.2	32	23.73	13	9	0.59
0.25	30	21.93	12	10	0.55
0.3	28	20.15	11	11	0.5

Figure 3: The relationship between t_c , N , T_t , N_f , N_{SCRS} and d_h

In practice, the standard values of d_h can be approximated to match with t_c as follow (Fig.4).

t_c	0.3	0.25	0.2	0.15	0.1	0.05
d_h	0.5	0.55	0.6	0.65	0.7	0.75

Figure 4: The proposed values of t_c , d_h to balance GoS at 2%

The algorithm controlling t_c to adapt with different traffic conditions using standard table in Fig.4 is presented below.

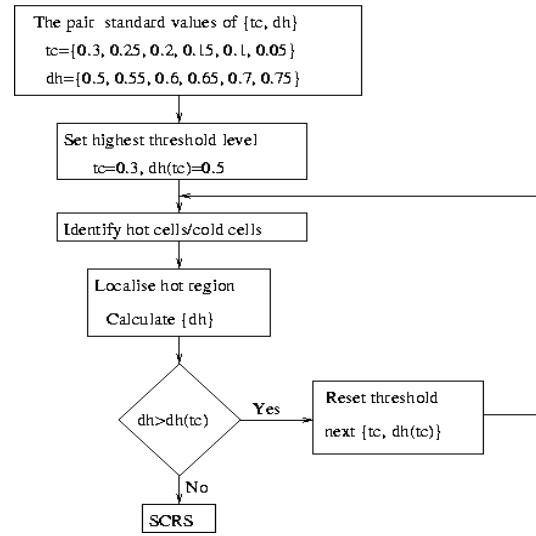


Figure 5: The selective threshold mechanism

IV. THE SIMULATION RESULTS AND DISCUSSION

The sizes of the hot region used in the simulations are with $n = 2, 5$, and 10 ; Therefore, the corresponding number of cells are 19, 91 and 331 respectively. Recall that $N_c=40$ and adaptive threshold t_c given in Fig.4. The results of SCRS-AT are shown in Fig.6-Fig.10 as follows.

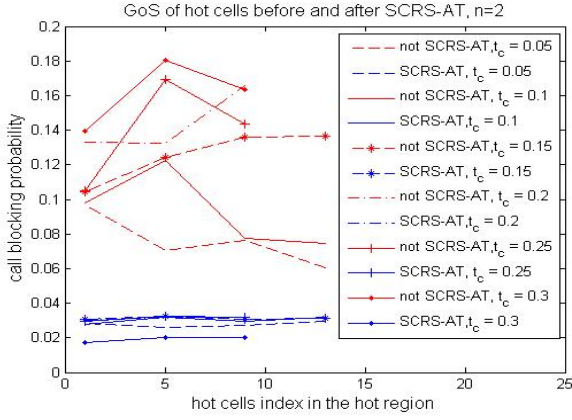


Figure 6: GoS of hot cells in 19 cells network using SCRS-AT.

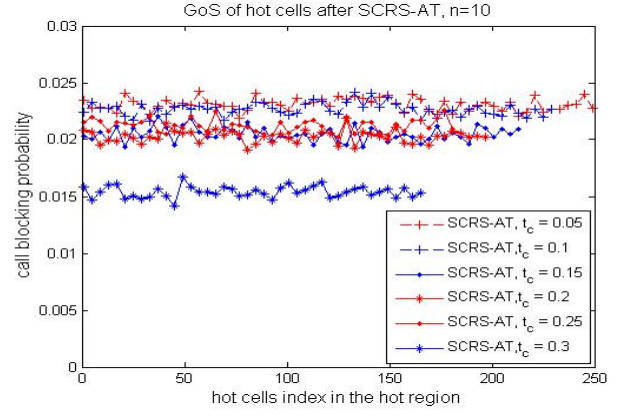


Figure 9: GoS of hot cells in large network after SCRS-AT applied

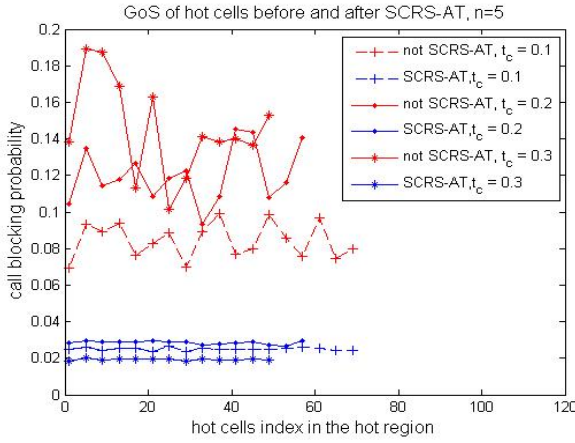


Figure 7: GoS of hot cells in 91 cells network using SCRS-AT.

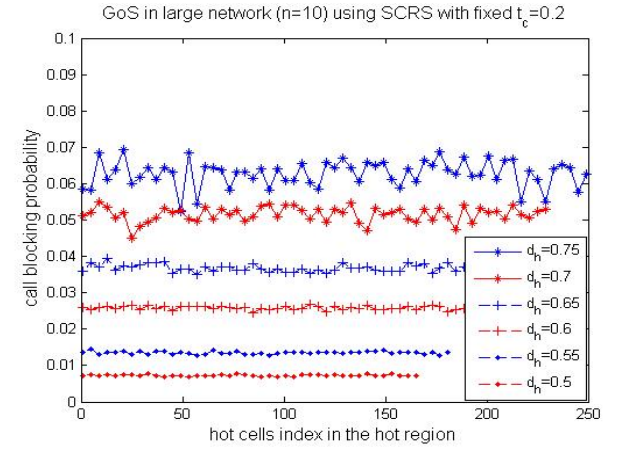


Figure 10: GoS of hot cells in large network using SCRS without AT

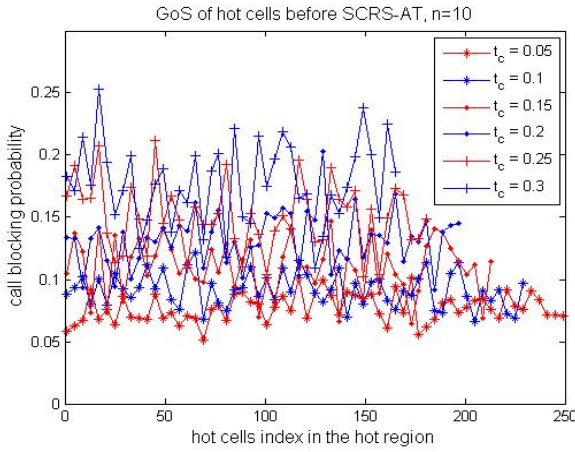


Figure 8: GoS of hot cells in large network before SCRS-AT applied.

The results in Fig.6-Fig.9 show that SCRS-AT can be applied to any size of hot region to reduce the call blocking probability of hot cells to approximately 2%. The percentage reduction of blocked calls attains a maximum of 23.5% ($t_c=0.3/d_h=0.5$) and a minimum of 5% ($t_c=0.05/d_h=0.75$) in a large network (331 cells) (Fig.8-Fig.9). The average percentage of reduction is 12%.

It also can be seen in Fig.10 that the call blocking probability of hot cells is *not balanced* if the *threshold is fixed*. When t_c is fixed at $t_c=0.2$, the minimum percentage of blocking is 0.6% and the maximum of its is 6% in the same network models in Fig.8 and Fig.9. This means that the threshold controlling algorithm not only helps releasing congestion in hot cells but also balancing GoS between hot and cold cells in the hot region.

V. CONCLUSION

Static Channel Relaying Strategy with Adaptive Threshold (SCRS-AT) is presented in this paper as an efficient scheme for balancing GoS and best utilising the network resources. The GoS of the network can be satisfied

in various load conditions, from light load ($t_c=0.3$, $d_h=0.5/T_{h-min}=20.15$ Erlangs) to heavy load ($t_c=0.05$, $d_h=0.75/T_{h-min}=29.17$ Erlangs). Moreover, the simulation results show that SCRS-AT is applicable to different sizes of hot region. It also can be developed to use in Next Generation Cellular Networks.

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