Congestion analysis in a general GPRS network

Paolo Lollini[1], Felicita Di Giandomenico[2], Andrea Bondavalli[1], Stefano Porcarelli[2]

[1]University of Florence, Dip. Sistemi e Informatica, via Lombroso 67/A, I-50134, Italy
{lollini, a.bondavalli}@dsi.unifi.it
[2]Italian National Research Council, ISTI Dept., via Moruzzi 1, I-56134, Italy
{digiandomenico, s.porcarelli}@isti.cnr.it

Abstract

This paper deals with congestion analysis of a GPRS network composed of N cells partially overlapping. In particular, we consider that one of the cells is affected by an outage and we analyze the effectiveness of applying a class of congestion treatment techniques that ultimately results in a switching of users from the congested cell to the others. In order to efficiently solve this complex scenario, we introduce a resolution technique that overcomes the state space explosion problem by decomposing the overall model in a set of more simple and easier to solve models.

1 Introduction

Congestion events constitute a critical problem in networked systems, since they unavoidably affect such systems during their operational life. A network is congested when the available resources are not sufficient to satisfy the experienced workload traffic, and this can occur for many reasons, such as in case of extraordinary events determining an increase of traffic, or in case of unavailability of some network resources because of malfunctions (outage). Careful management techniques are necessary, to alleviate the consequences of such phenomena. The IST-2001-38229 CAUTION++ project aims at building a resource management system to efficiently cope with congestion events in heterogeneous wireless networks. Management techniques are usually equipped with internal parameters, whose values have to be properly assigned in accordance with the specific system characteristics. In order to support this "fine-tuning" activity, in CAUTION++ model-based analysis is promoted to analyze the behavior of the management techniques and to understand the impact of techniques and networks configuration parameters on properly identified Quality of Service indicators.

In this work, the attention is on the GPRS technology, which has been already analyzed in previous studies under more simplistic network configurations. In fact, extending previous work, the focus here is on the congestion analysis of a general GPRS network involving a number of cells partially overlapping.

The rest of this paper is organized as follows. Section 2 presents the system scenario under evaluation. Section 3 briefly introduces the resolution technique adopted to perform the QoS analysis. Section 4 provides an overview of the models defined to represent the GPRS and resource management techniques behavior. Then, in Section 5 the numerical results of the simulation studies are presented and discussed. Conclusions are finally drawn in Section 6.

2 The extended scenario

The main purpose of this paper is to perform congestion analysis of a GPRS network in a general scenario concerning a number of cells. This is the last step of a series of previous works carried out in this field of activity. A first work ([3]) dealt with the congestion analysis of a single GPRS cell during outage and outage recovery. A second work ([4]) extended the analysis to a network composed of two cells, accounting for the application of a class of Radio Resource Management Techniques for congestion treatment that ultimately results in a switching of users from the congested cell to the other one. Finally, in this paper we perform a further extension and refinement of the GPRS congestion evaluation by considering a very general scenario composed of one congested cell and several neighbor cells partially overlapping.

In more detail, let's suppose to have a network composed of N+1 cells partially overlapping, where one cell (CELL, the central one) is affected by an outage (see Figure 1). In order to successfully treat the congestion scenario, we suppose to apply a reconfiguration action that results in a resizing of the congested cell. From a macroscopic point of view, it is equivalent to consider a switching of users from the congested cell to all the others. This will lead to a reduction of the attached users and, then, to a decongestion of CELL. On the other side, the traffic of the adjacent cells (CELL-1, ..., CELL-N) will increase due to the increased number of attached users. Moreover, some users could be lost because they couldn't be camped in any of the adjacent cells (black-spot) or because of business model strategy. Once the congestion in CELL is overcome, a re-switching process is started, which moves users from CELL-1, ,, CELL-N back to CELL, thus restoring in this last its original population.

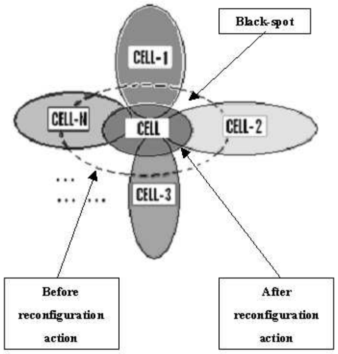

Figure 1. Extended GPRS network

A simple but fruitless resolution method is to build an overall model that has to be entirely solved in only one simulation. The main problem in solving the entire model is time complexity that rapidly increases if the number of receiving cells increases (state space explosion problem). A more efficient approach would consist in splitting the overall model in a number of simpler sub-models, to be solved separately. In this case, the main problem that we have to cope with is that not all users could be instantaneously switched from a cell to another. In fact, the switching process could act on those users who are in the *idle mode* (that is, they are not requiring any service) and/or on those users who are in the *active mode* (that is, they are trying to connect the network). Then, in case the population of idle and/or active users (in accordance with the switching policy adopted) is, at switching time, lower than the preset number of users to switch, the instantaneous switching cannot occur. Therefore, there is a temporal dependency between the congested cell and the receiving cells during user switching (from CELL to CELL-1, ..., CELL-N) and re-switching (from CELL-1, ..., CELL-N to CELL) procedures.

To properly cope with this temporal dependency, so as to maintain an homogeneous behavior between CELL and any of the other neighbor cells, assumptions are introduced on the way the users are switched and re-switched. In particular, we suppose that users are uniformly distributed inside each cell and that a pre-set number of users are switched from CELL to CELL-1, ..., CELL-N using the following rule (in pseudo-code):

```
while not all users have been switched from CELL to CELL-1, ..., CELL-N
{
for I=1..N { if not all users have been switched from CELL to CELL-I, then switch 1 user from CELL to CELL-I; } }
```

In the case of the users re-switching procedure, temporal dependency is easily coped with by considering two models in each simulation: one for the (previously) congested cell and one for the receiving one. Then, the receiving cell can re-switch the users only to the (previously) congested one.

3 Resolution technique

As we can see from Figure 2, we decompose the overall model in N independent sub models, each one composed of two cells: the first cell is always that affected by the outage (CELL), while the second is chosen from the other N receiving cells. Therefore, we solve N sub models separately. From the solution of each single model, we obtain two types of results:

- The QoS measures for each receiving cell, namely the percentage of unsatisfied users with respect to the total population;
- The distribution of the users switched from CELL to each receiving cell.

Then, the users switching distributions relative to each receiving cell are combined in order to obtain the users switching distribution from CELL to all other receiving cells. The final step is to solve the model for CELL using the previously obtained distribution, obtaining the QoS measure for CELL.

In more detail, the resolution technique is described by the following algorithm in pseudo-code:

```
i. for I=1..N {
a. We perform a congestion analysis of the system composed by two cells: the congested cell (CELL) and one receiving cell (CELL-I);
b. From this simulation we obtain two results for CELL-I: the congestion measures and the users switching distribution both for the idle and the active users. Those distributions are saved, respectively, in two arrays (idleSwitchedCell-I and activeSwitchedCell-I) of length R, where R is the number of points defining the switched users distribution. These two arrays, initialized only once to zero, are shared by all the N receiving cells, and allow combining the results of the N-step analysis;
}
ii. idleSwitchedTotal int[N]; (idle users switching distribution for CELL)
```

```
iii. activeSwitchedTotal int[N]; (active users switching distribution for CELL)
iv. for I=1..N {
      for j=1..R {
        c. idleSwitchedTotal[j] = idleSwitchedTotal[j]+ idleSwitchedCell-I[j];
        d. activeSwitchedTotal[j] = activeSwitchedTotal[j]+ activeSwitchedCell-I[j];
      }
    }
v. We perform a congestion analysis of a system composed of one cell, the congested one (CELL), in which we simulate the re-switching procedure using the arrays activeSwitchedTotal and idleSwitchedTotal. From this simulation we obtain the congestion measures for the congested cell (CELL).
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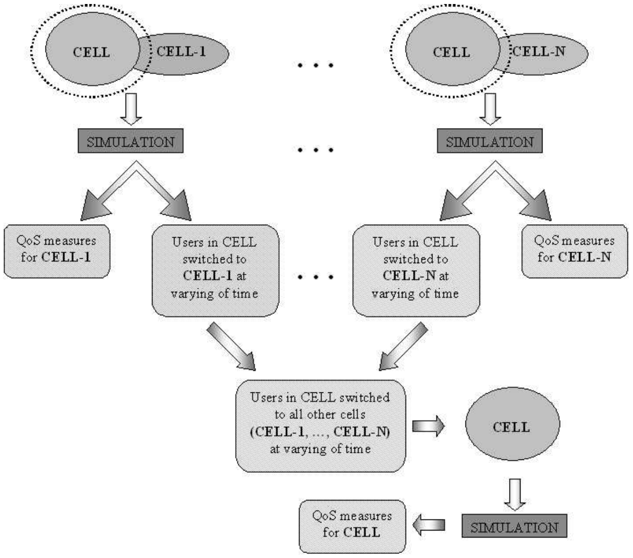


Figure 2. Resolution Technique

4 The network model: an overview

All models presented in this paper are derived using Stochastic Activity Networks (SAN) and solved using the simulator provided by the Möbius tool [5].

Figure 3 shows the abstract view of a general GPRS cell. The “generic GPRS cell model” was deeply described in previous works (see [1] and [2]) and it’s briefly outlined in [4]. The sub-model responsible for interacting with the other cells is the “users switching/reswitching sub-model”. It represents the interface between the congested cell and all the other cells and it is a critical part of the model. This sub-model determines the rule of the corresponding “generic GPRS cell model”. In particular, it has been specified in order to:

- simulate the behavior of the congested cell (CELL) during outage, cell resizing and outage recovery;

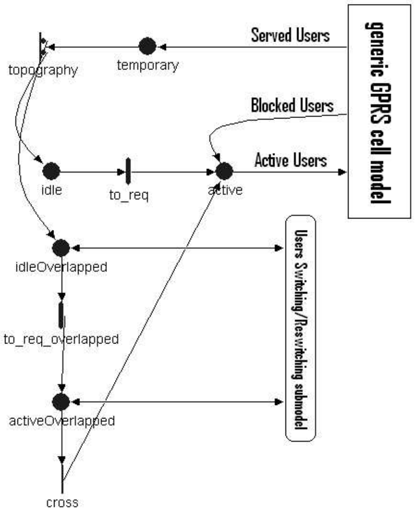


Figure 3. A generic GPRS cell with overlapping area

- simulate the behavior of a receiving cell (CELL-*I*) during the resizing of the congested cell;
- simulate the behavior of the congested cell (CELL) during outage, cell resizing and outage recovery using some external users switching distributions (see point *v.* of the pseudo-code algorithm in the previous section).

Models for the “generic GPRS cell model” and for the “users switching/reswitching sub-model” have been of course defined, since they are fundamental for the quantitative evaluation discussed in the next Section. However, for the sake of brevity, we omit a detailed presentation of such models and only provide basic indications of how the model in Figure 3 works.

When a user has been served, a token exits from the “generic GPRS cell model”. This generic user has to be mapped (using the *topography* activity) in the overlapping area of the cell (place *idleOverlapped*) or in the non overlapping one (place *idle*), in accordance with the topography of the network. The probability that a generic user is mapped in the overlapping area is dynamically calculated considering the original number of users in the overlapping area and the overlapping users that have been switched to the other cells. When an idle user requests a new service, he becomes active and enters in the “generic GPRS cell model” that simulates the random access procedure of a GPRS cell (see [1] and [2]). Finally, it is important to note that the users switching and re-switching procedure affects only the users in the overlapping area, both in idle and in active mode.

5 Model evaluation

We perform a transient analysis in the interval of time following the occurrence of an outage to the new system steady-state after the outage repair. All the models have been numerically solved using the simulator provided by the Möbius tool (see [5]).

We are interested in evaluating two measures:

- the point-wise congestion perceived by the users in each cell at varying of time (**PCf**), calculated as the ***percentage*** *of the active users with respect to the total number of users in the cell*;

- total congestion indicator (**TCi**), representing the average congestion perceived by the users.

For a more technical description, please refer to [4].

5.1 Settings for the Numerical Evaluation and Analyzed Scenario

Table 1 shows the values we assigned to the main parameters of each cell. We consider a network composed of one congested cell (CELL) in overlapping with other three cells (CELL1, CELL2 and CELL3), having the same number of traffic channels (three) but different user populations. Therefore, each cell has a different workload level at steady-state.

The fine-tuning is performed in terms of the number of active users to switch from CELL to each other cell. In particular, we consider three scenarios: i) the case where no cell resizing is performed; ii) the case where a cell resizing involving 50% of the users in the overlapping area is performed, and iii) the case where a cell resizing involving 100% of the users in the overlapping area is performed. Moreover, we suppose that 10% of the active users switched are lost during the reconfiguration action.

5.2 Numerical Evaluation

In this section, we show the results obtained from the simulations. In all the figures plotting the simulation results, the time interval on the x-axis starts at time 200 sec. (the outage occurrence time) and ends at time 556 sec. (the time the new steady-state is reached in all the cells). Moreover, the labels T0, T1, T2 and T3 on the x-axis have the following meanings: T0 is the time the outage occurs in CELL; T1 is the time the congestion management technique reacts and decides to switch X users from CELL, distributed as X1 users to CELL1, X2 users to CELL2 and X3 to CELL3; T2 is the time the outage ends; and T3 is the time the users re-switching from CELL1, CELL2 and CELL3 to the original cell (CELL) starts.

Figures 4(a), 4(b) and 5(a) show the congestion perceived by the users (the Point-wise Congestion function) in each receiving cell (that is CELL1, CELL2 and CELL3, respectively) at varying of the number of the active users to switch (0%, 50%, 100% of the number of users in the overlapping area). Obviously, the TCi value increases when we increase the value of the *activeUsersToSwitch* parameter. We note that, after time T1 (the switching time), the congestion initially increases, but decreases immediately after. This happens when the receiving cell is not congested and, then, can absorb the added traffic. Moreover, the traffic overload induced in the cell has more negative impact if the congestion level at steady-state increases.

Figure 5(b) shows the congestion perceived by the users in the cell affected by the outage at varying of the number of the active users to switch from the cell to all the other cells. From the figure we note that if we increase the total number of active users to switch from 75 to 150, the TCi value remains the same. This happens, in general, when the system tries to switch "too much" users and then the negative effects due, for example, to the augmented number of users lost is equivalent to the positive effects due to the augmented number of users switched.

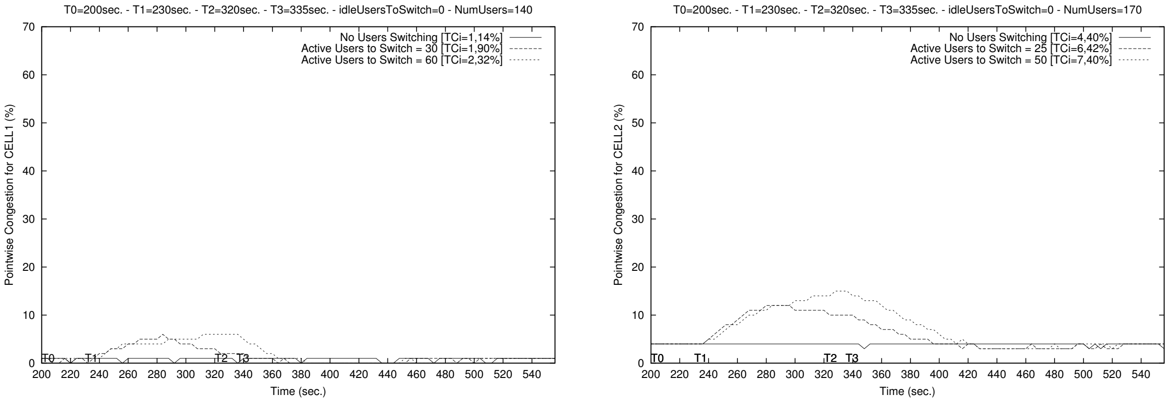
Figure 6(a) shows the behavior of the overall GPRS network composed of CELL, CELL1, CELL2 and CELL3 at varying values of the *activeUsersToSwitch* parameter. We analyze the percentage of the unsatisfied users in the network with respect to the total number of users camped in the four cells (in this example 180+140+170+200=690 users). We note that the 100% cell resizing curve is worse than the 50% one as the positive effects induced by the decongestion in CELL don't compensate the negative effects on CELL1, CELL2 and CELL3 (the receiving cells).
Lastly, Figure 6(b) shows the number of active users really switched from CELL to the other cells. We note that the switching and re-switching procedures are not instantaneous. This means that there are not enough active users immediately available to be switched at time T1 (the switching time) and re-switched at time T3 (the re-switching time).

6 Conclusions

In this paper, the congestion analysis of a general GPRS network configuration has been performed in terms of QoS indicators expressing a measure of the congestion perceived by users. This work constitutes an enhancement with respect to previous studies on GPRS congestion evaluation, since a general GPRS network consisting of a number of cells partially overlapping has been considered. When a congestion is experienced by one of these cells (in the study,

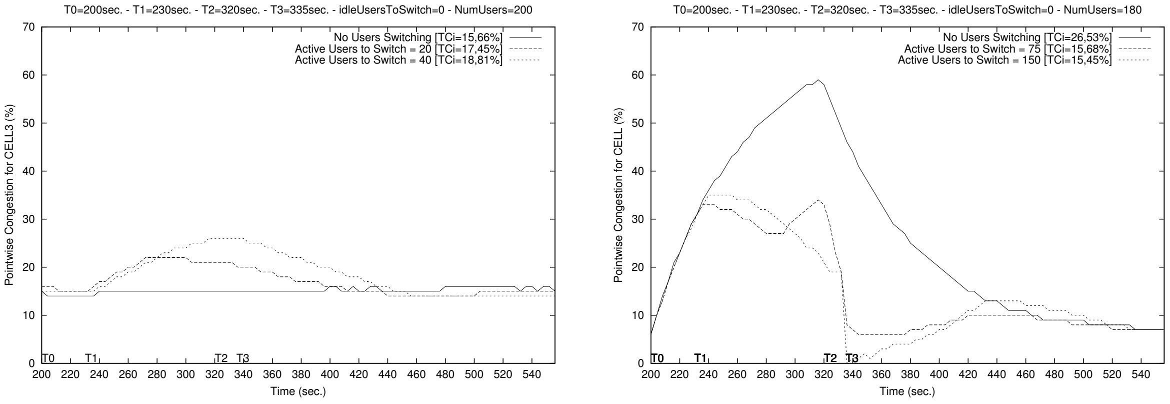
	Users	*Overlap.Users*	*Act.Users to Switch*	*Act.Users to Lose*
CELL	180	150	0, 75, 150	0, 8, 15
CELL1	140	60	0, 30, 60	0, 3, 6
CELL2	170	50	0, 25, 50	0, 3, 5
CELL3	200	40	0, 20, 40	0, 2, 4

Table 1. Analyzed scenario: cell topography and fine-tuning parameters



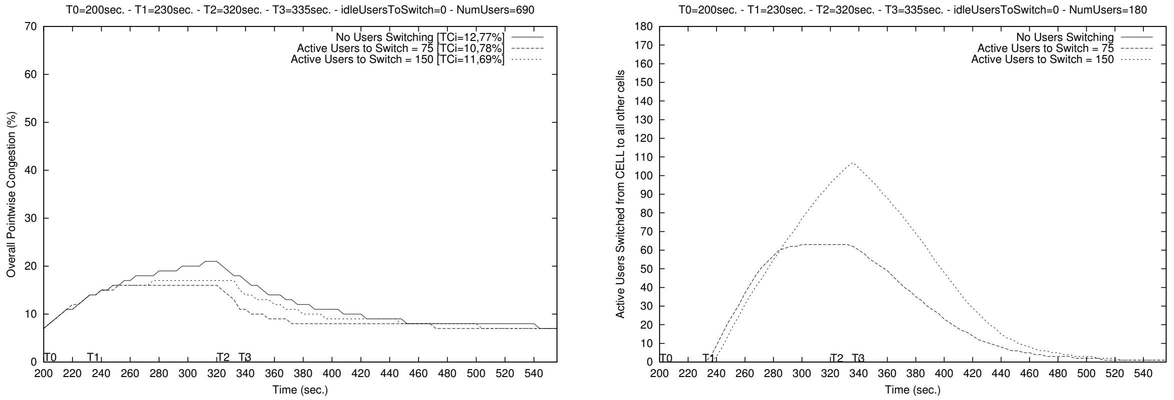
(a) (b)

Figure 4. (a) Congestion Perceived in CELL1 and (b) Congestion Perceived in CELL2



(a) (b)

Figure 5. (a) Congestion Perceived in CELL3 and (b) Congestion Perceived in CELL



(a) (b)

Figure 6. (a) Overall Congestion Perceived and (b) Active Users Switched from CELL to all other cells

the central one), a family of congestion management techniques is put in place, to operate a redistribution of a number of users in the congested cell to the neighbor cells, in accordance with the overlapping areas. Determining appropriate values for the users to switch, so as to determine an effective balance between congestion alleviation in the congested cell and congestion inducement in the receiving cells, is a critical aspect in such contexts. In order to carry on such fine-tuning activity, a modeling methodology has been outlined, appropriate to deal with the system complexity and the consequent state-space explosion problem. Models resolution through a simulation approach has been performed in order to provide numerical estimates. The obtained results, although dependent on the considered parameters setting, show behavior trends very useful to make an appropriate choice of the number of users to switch, which is the critical parameter for the congestion management technique.

7 Acknowledgments

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