Model-based congestion analysis during outage and system reconfiguration in GPRS networks

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Abstract

This paper deals with congestion analysis of a simple GPRS network composed by two cells partially overlapping. In particular, we consider that one of the two 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 other one. For this purpose, we introduce a modelling technique to support a proper calibration of the parameters involved in a reconfiguration action, in order to successfully treat the congestion phenomenon. The effectiveness of a reconfiguration action is evaluated in terms of indicators that represent the Quality of Service (QoS) perceived by the users in the congested and adjacent cells.

1 Introduction

Any cellular network unavoidably has to face traffic congestion events during its operational life. A network is congested when the available resources are not sufficient to satisfy the experienced workload traffic. Congestion is usually caused by an increase of the traffic because of some extraordinary events (like emergency situations and sports events) or because some network resources become suddenly unavailable due to malfunctions. The occurrence of an outage is the typical event leading to a total or partial unavailability of the cell resources, leading to a complete block of the affected cell or in degraded operational behavior, respectively. Congestion treatment is hardly managed in cellular networks, especially in case of heterogeneous radio resources environment. This is the objective of the current ongoing project IST-2001-38229 CAUTION++ [1] which aims at providing an optimal management of the available radio resources in an heterogeneous environment, including GSM, GPRS, UMTS and WLAN network technologies. In CAUTION++, a number of Radio Resource Management Techniques (RMTs) for each of the four mentioned technologies are under development, to cope with congestion events affecting network segments and aiming at optimizing the resources utilization. Each RMT has its own conditions of applicability, expected beneficial effects and parameters to be set for the actuation.

To contribute to a better understanding of the issues involved in a proper setting of the internal parameters and in the actuation of a class of resource management technique, in this paper we fucus the attention on the congestion analysis of a simple GPRS network composed of two cells partially overlapping. In particular, we consider the occurrence of an outage in one of the two cells and we analyze the effectiveness of applying a class of RMTs involving both cells, in order to alleviate the congestion phenomenon. The evaluation is conducted in terms of indicators representative of the Quality of Service (QoS) perceived by the users in the congested and adjacent cells. This work has been performed in the context of the CAUTION++ project and provides a relevant contribution in the improvement of the CAUTION++ capability to properly calibrate the reaction to a specific alarm situation, and to optimize resource assignment. In particular, our proposed framework for a model-based analysis of the reconfiguration strategies can be usefully employed for two purposes. First, to perform the fine-tuning of parameters internal to reconfiguration strategies, that is to properly calibrate such parameters values so as to obtain the most performing system behavior from the actuation of the considered RMT. Second, to compare the effectiveness of alternative reconfiguration strategies, in order to choose the most rewarding one.

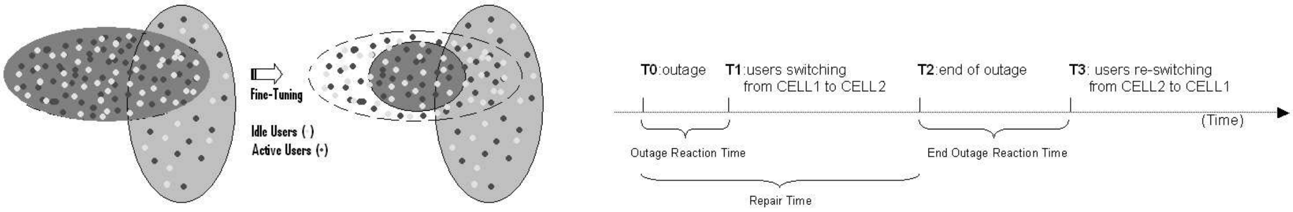
The rest of this paper is organized as follows. Section 2 describes the class of RMTs treated in this work. Section 3 introduces the measures used to evaluate the effectiveness of a reconfiguration action and describes a methodology to construct a GPRS network model that accounts for such reconfiguration. The results of the model-based analysis are presented in Section 4, while the conclusions are in Section 5.

2 A class of Radio Resource Management Techniques for GPRS

In the wireless environment we target, Resource Management System (RMS) is in place, which reacts to a congestion event by selecting and applying a radio Resource Management Technique (RMT) capable to adequately treat the traffic overload. The “tuned RMTs” are those techniques that include some internal parameters that need to be properly tuned. In order to construct an efficient fine-tuning model, it is firstly necessary to identify the parameters that have to be tuned in advance in order to get the best overall performance from the network. Despite the fact that these parameters are dependent on a specific context, for the analysis purpose, they are managed considering their macroscopic effects only. In fact, a too detailed model would require large computational resources, which is hardly feasible, with dubious benefits on the accuracy of the results.

Instead of concentrating on a specific RMT, the focus is on a general class of management techniques whose reconfiguration actions ultimately result in a cell resizing or, equivalently, in a switching of users from one cell to another. To better understand the effects of a congested cell resizing, consider the example of Figure 1(a).

There is an urban area covered by two cells partially overlapped. We suppose that, at certain instant of time, one of the



(a) (b)

Figure 1. (a) Effects of congested cell resizing and (b) the considered sequence of temporal events

two cells (the dark gray cell in the figure) is affected by a partial outage leading to a traffic congestion. The RMS reacts sometime after by applying a reconfiguration strategy whose effect is the reduction of the congested cell size. This will lead to a reduction of the attached users and, then, to a decongestion of the cell. On the other side, the traffic workload of the adjacent cell (the light gray cell in the figure) will increase, as more users are camped in this cell. Moreover, some users could be lost because they cannot be reselected in the adjacent cell (e.g. because of a non totally overlapping zone). A fine-tuning modelling approach can be used to find the optimal trade-off between the following parameters: i) users remaining in the cell; ii) users switched from the congested cell to the adjacent one; iii) users whose service requests will be lost.

3 Model development

In this paper, we analyze the behavior of two GPRS cells partially overlapping where **CELL1** is the cell that will be affected by the outage, and **CELL2** the other one. An **OVERALL** model includes both cells and it is able to evaluate the effectiveness of a reconfiguration along the following temporal events (see Figure 1(b)):

- At time T0, an outage occurs in CELL1, thus determining congestion some time after;
- At time T1, the RMS reacts to the outage and decides to switch X users from CELL1 to CELL2. The number of users X to be switched is the result of a fine-tuning procedure. The number of users really switched at the end of the reconfiguration action can be smaller than X, say Y$\leq$X. This happens when the switching procedure doesn't complete, for example because of the short duration of the system outage;
- At time T2, the outage ends;
- At time T3, the RMS reacts to the end of the outage and starts the re-switching procedure of Y users from CELL2 to CELL1.

The behavior of each cell is analyzed during the random access procedure, when users compete to get a free channel. In fact, during massive congestion events, the blocking on the PRACH (Packet Random Access Channel) may become a bottleneck of the system ([4]). In particular, we examine the case of a partial or total outage of CELL1 due to the unavailability of a subset of traffic channels (SPDCH - Slave Packet Data Channel). During the outage, users try to access the service and accumulate their requests in CELL1 because of the reduced availability of the data channels. The accumulated requests determine a higher probability of collisions on resources assignment, leading to a degradation of the QoS perceived by the users. RMS tries to alleviate this negative effect by applying a RMT soon after the outage is detected. The effect of the cell resizing strategy is the switching of users from CELL1 to CELL2. The objective of the study is to understand the effects of the users switching in CELL1 and CELL2, both individually and as an overall. To this purpose, appropriate QoS indicators are introduced in the following section.

3.1 Measures of Interest

The effectiveness of a reconfiguration action is here evaluated with respect to the improvement of the QoS perceived by the users, rather than of the network connection quality. The term QoS is used to indicate the degree of satisfaction of users in getting completed their requests. Before detailing such measures, it is necessary to clarify which are the considered user operational modes. A user may be: i) in the *idle* mode if he/she is not making any service request to the network system; ii) in the *active* mode if he/she is attempting to connect the network to get a service, and finally iii) in the *in-service* mode if he/she is connected and awaiting to get the service completed. On this basis, the following QoS parameters have been identified:

- **Point-wise Congestion function (PCf)**
  This is point-wise QoS measure showing the congestion perceived by the users at varying of time. In particular, we evaluate the service degradation during the outage manifestation, the congestion treatment and the outage recovery. The measure is calculated as the ***percentage*** *of the active users with respect to the total number of users in the cell.* If such percentage increases, it means that more users are competing to get a service or, equivalently, the congestion perceived from the users gets worse.

- **Total Congestion indicator (TCi)**
  In order to easily compare the effectiveness of a reconfiguration action, we define a Total Congestion indicator (TCi) whose value represents the ***percentage*** *of the average congestion perceived (*ACP*) by the users with respect to the maximum congestion perceivable (*MCP*) by the same users in the cell.* The ACP value is mathematically calculated as the integral of the Pointwise Congestion function (PCf) in the interval of time from the outage occurrence to the time the system reaches again its steady-state. The MCP value represents the congestion perceived by the users in the worst scenario that is the PCf is always equal to 100%). Thus, the MPC is 100% for the length of the considered interval of time. It derives that the Total Congestion indicator is: TCi=$(\text{ACP}/\text{MCP})\times 100$.

The necessity of evaluating both a point-wise and a total congestion indicator in the transient period spanning from the outage occurrence (T0) to the new system steady state (according to Figure 1(b)) is determined by the possibly different requirements imposed to the system in order to satisfy users needs. For example, requirements could be stated on not having point-wise performance values below a certain threshold, or on a specific Total Congestion indicator value. Indeed, these are key factors which have to be taken into account in the reconfiguration selection process.

We also evaluate the impact of varying the time necessary for the reconfiguration action to show its effects on the QoS metrics defined above; such evaluation is performed through a sensitivity analysis at varying the time that the RMS spends to decide and actuate a reaction on the network.

3.2 Modelling assumption

Our modelling is based on our previous work in [2] where a single GPRS cell has been analyzed. The assumptions on the random access procedure model (that we call the BASIC model) presented in the referred paper are the following:

1. The cell contains a constant number of users, whose contexts are permanently retained (no ”attach” and ”detach” procedures are considered);
2. All users in a cell belong to the same priority class, they are indistinguishable from the point of view of generated traffic;
3. User requests fit in one LLC frame and, from the user’s viewpoint, once a request has been made, he cannot abort it but has to wait until the service is provided;
4. The radio channel is considered faultless, meaning that no retransmissions are necessary at the LLC and RLC levels. To keep consistent, the coding scheme considered is the CS-1, characterized by a 1/2 code rate, payload of 184 bit per RLC block. This is the most robust coding scheme among the four accounted for by the standard;
5. One radio frequency is at maximum devoted to the GPRS traffic (8 time slots);
6. Only one MPDCH, for signaling and control information, is assumed, carrying 1, 2, or 4 PRACHs;
7. Each traffic channel is allocated to a single user at a time, who will retain it until the completion of his data transmission;
8. It is allowed to queue the request at BTS side through an Access Grant Reservation when all channels are occupied.

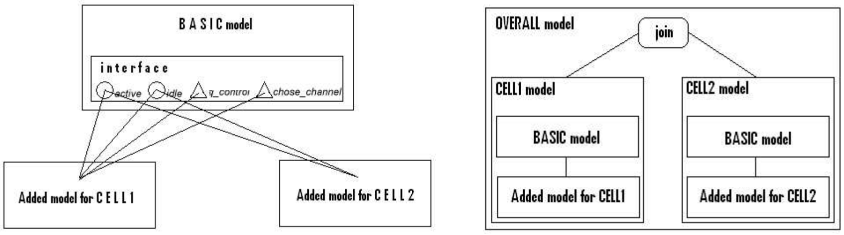
Here, we extend them to consider the users switching process between two GPRS cells in case of an outage. In detail, the modelling assumptions for CELL1 and CELL2 models are the following:

- An outage is experienced as a consequence of malfunctions of traffic channels in a GPRS cell. If not all the available traffic channels are damaged, the network is not completely blocked but works in a degraded manner. The repair time is assumed to follow a deterministic distribution;

- The users switching procedure doesn't affect the in-service users;
- The users lost during the switching procedure (e.g. because of non overlapping cells) are subtracted from CELL1 before the switching procedure starts (as a percentage of idle users and/or active users). The users lost (both in idle and active mode) are re-added as idle users to CELL1 at re-switching time;
- When the outage occurs, CELL1 and CELL2 are working in a steady-state condition.

3.3 From the BASIC model to the OVERALL model: an overview

All models presented in this paper are derived using Stochastic Activity Networks (SAN) [5] and solved using the simulator provided by the Möbius tool [6]. In this section, we outline the methodology that we use to construct the OVERALL model starting from the BASIC one. The model of the random access procedure that we use as BASIC model has been deeply described in previous works (see [2] and [3]) and it's briefly outlined in Section 3.3.1. With respect to the purposes of our analysis, we can consider the BASIC model as a black-box in which there are only few visible components (see Figure 2(a) which shows the interfaces among models).



(a) (b)

Figure 2. (a) CELL1 and CELL2 models construction and (b) Structure of the OVERALL model

The set of these visible objects (like places, gates or transitions) represents the interface between the BASIC model and the other models. We note that the interface is composed by two controlling elements (the *q_control* and *chose_channel* gates) and two places, *idle* and *active*. The place *idle* represents the users that are not requiring any service (the idle users in the idle mode), while the place *active* represents users trying to connect the network (those in the active mode). The CELL1 and CELL2 models are simply constructed by connecting the BASIC model to the "added model" for CELL1 and CELL2, respectively, as described in Section 3.3.2 and Section 3.3.3. Then, the OVERALL model is obtained joining the CELL1 and CELL2 models as described in Section 3.3.4 (see Figure 2(b)).

3.3.1 BASIC model for a GPRS cell

The model of the random access procedure (the BASIC model) is shown in Figure 3 and its description is here briefly outlined:

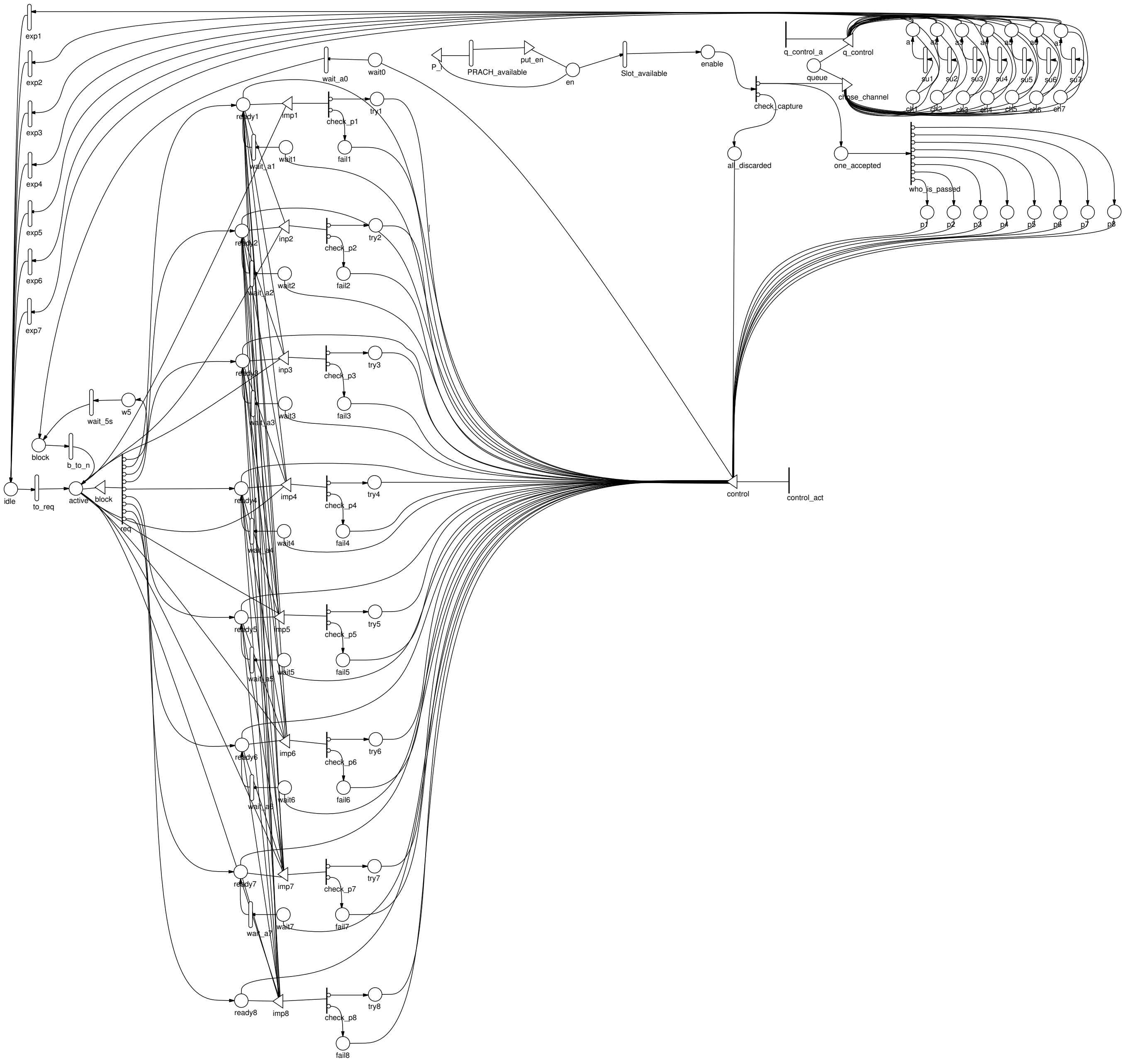


Figure 3. GPRS cell: the BASIC model

- Tokens in the place *idle* represent those users that have sent successfully their up-link data. After some time, accounted for by the timed transition *to_req*, a user issues a new request and a token is moved from *idle* to the place *active*.
- The block starting with the instantaneous activity *req* and ending with the input gate *control* represents the dynamics of the random access procedure. The transition *req* states the maximum number of attempts a user is allowed to make in sending an Access Burst. It has one case for each possibility; the associated probabilities have been derived on the basis of the parameters M, P, S, T and the timer. Tokens in places *ready1*, ..., *ready8* represent the number of users allowed

to make a maximum of 1, ..., 8 attempts, respectively. The instantaneous activities *check_p1*,..., *check_p8* model the persistence level. If the user passes the persistence level, he can send an Access Burst and moves into the place try_i, otherwise he moves into the correspondent place $fail_i$. Should a user consume all his assigned attempts to make his request, or should the time-out regulating the maximum allowed time for making a request (set to 5 sec) expire, the user is moved into the place *block*. A blocked user will do a new attempt after a time sampled from the timed activity *b_to_n*, having exponential rate and taking into account Automatic Retransmission Time (ART). The place *w5* and the activity *wait_5* take into account those users that haven't been assigned any attempt, because they will always fail the persistence level. According to the standard specification, they have to wait 5 seconds before moving in the place *block*.

- The instantaneous transition *check_capture* checks, stochastically, if there is a successful receipt of one Access Burst; if yes, a token is placed in *one_accepted*, unless the queue is full and there is no available traffic channel, in which case a token is put in *all_discarded*. The instantaneous transition *who_is_passed* fires when there is a token in *one_accepted* and it allows to choose which level the accepted Access Burst comes from, placing a token in one of the places *p1*, ..., *p8* (each Access Burst at each level has the same probability to be the accepted one). The input gate *control* and the activity *control_act* properly update the places recording the residual tries made available to the other concurrent requests (places *ready1*, ..., *ready8*, *try1*, ..., *try8*, *fail1*, ..., *fail8*, *wait_a0*, ..., *wait_a7* and *p1*, ..., *p8*).

- When there is a successful receipt of one Access Burst and there is a free channel (that is at least a free pair between *ch1*-*a1*,...., *ch7*-*a7*), the output gate *choose_channel* puts a token in one of the places *ch1*, ..., *ch7* otherwise it puts a token in the place *queue*. The timed activities *su1*, ..., *su8* simulate the set-up time of a radio link to send user data. The transitions *exp1*, ..., *exp7* follows a uniform distribution and represent the data sending time.

- The sub-net enclosing the timed activities *PRACH_available* and *slot_available*, and the places *en* and *enable*, models the multi frame on the MPDCH.

- A token in the place *queue* represents a pending request waiting for up-link channel reservation. The immediate transition *q_control_a* fires when a channel is released and there are pending requests in the queue. When transition *q_control_a* fires, the input gate *q_control* moves a token from *queue* to a place *chn* (*ch1*, *ch2*, ..., *ch7*), corresponding to the available channel.

3.3.2 Added model for CELL1 (cell affected by the outage)

Our purpose is to construct a GPRS cell model that accounts for partial outage of the traffic channels and enables users switching between CELL1 (the cell affected by outage) and CELL2 (the receiving cell) and users re-switching between CELL2 and CELL1. In Figure 4, we show the sub model that has been added to the basic GPRS cell model. The gray line separates the components belonging to the BASIC model interface (on the left) from those belonging to the added model (on the right).

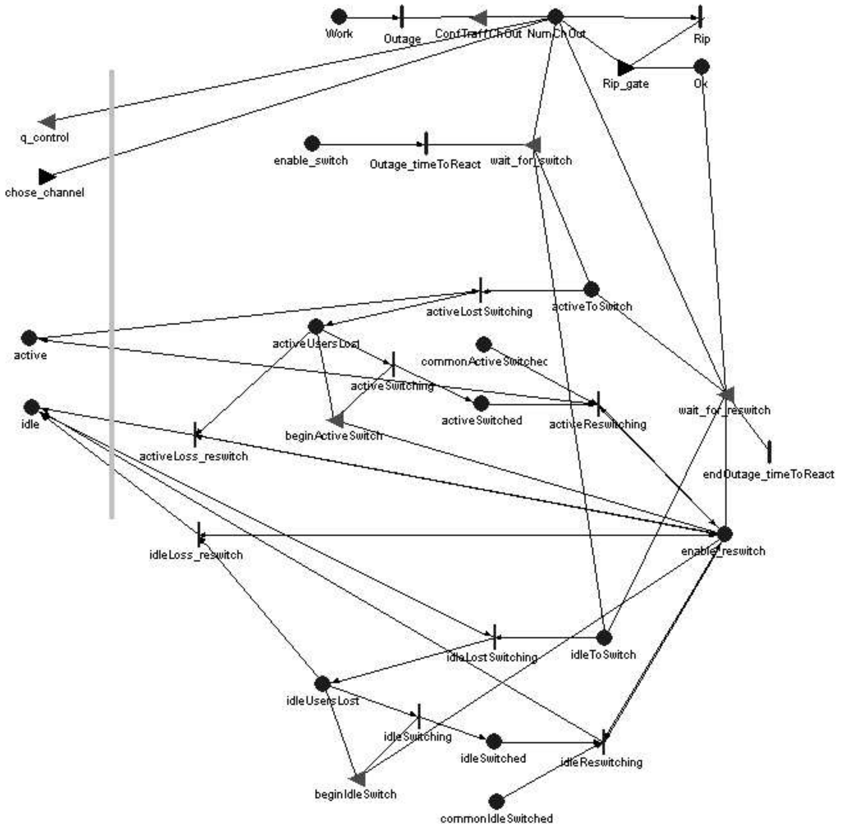


Figure 4. Outage and Users Switching sub model for CELL1 (the cell affected by outage)

- A token in place *Work* means that the system works properly. Tokens in place *NumChOut* represent the number of unavailable traffic channels. A token in place *Ok* means that the outage is ended or, equivalently, that the system has been repaired. The place *enable_switch* contains only one token and then the transition *Outage_timeToReact* is able to fire only one time. Tokens in place *activeToSwitch* and *idleToSwitch* represent, respectively, the number of active and idle users to switch from CELL1 to CELL2. Tokens in place *activeUsersLost* and *idleUsersLost* represent, respectively, the number of active and idle users that are lost during the switching procedure. Tokens in place *activeSwitched* and *idleSwitched* represent, respectively, the number of active and idle users really switched from CELL1 to CELL2. Tokens in place *commonActiveSwitched* and *commonIdleSwitched* represent, respectively, the number of active and idle users really re-switched from CELL2 to CELL1. A token in *enable_reswitch* enables *activeReswitching*, *idleReswitching*, *activeLoss_reswitch* and *idleLoss_reswitch* transitions.
- The marking of place *Work* and *enable_switch* is initially set to 1, while *idle* place contains *NumUsers* tokens.
- The deterministic transition *Outage* fires at 200 seconds (T0), that is the time required by the system to reach the

steady-state. The other deterministic transitions, with the corresponding firing time, are:

- *Outage_timeToReact* (firing in *outageReactionTime* sec.), that represents the time necessary for the system to react to the outage (it's equal to T1-T0);
- *Rip* (firing in *riptime* sec.), that represents the time necessary for the system to be repaired (it's equal to T2-T0);
- *endOutage_timeToReact* (firing in *outageEndReactionTime* sec.), that represents the time necessary for the system to react to the end of the outage (it's equal to T3-T2).

The input and output gates are defined as in Table 3 in the Appendix.

Here, we briefly describe the model behavior following the temporal events of Figure 1(b). Before time T0, the system is in steady-state. At time T0 the *Outage* transition fires and some tokens are put in place *NumChOut*, that represents the number of unavailable traffic channels. From this moment, the system is working in a degraded manner. At time T1, the gate *wait_for_switch* puts the established number of tokens (users) in place *activeToSwitch* (active users to switch) and *idleToSwitch* (idle users to switch) and then the switching procedure starts. Tokens (users) that remain in place *activeUsersLost* and *idleUsersLost* represent the number of active and idle users lost during the switching procedure, while tokens in place *activeSwitched* and *idleSwitched* represent the number of active and idle users really switched from CELL1 to CELL2. At time T2 the *Rip* transition fires and the outage ends. From this moment, CELL1 restarts to work properly. At time T3, the *endOutage_timeToReact* transition fires, the mark of the place *enable_reswitch* is set to 1 and the re-switching procedure starts. The transitions *activeLoss_reswitch* and *idleLoss_reswitch* are enabled and the users previously lost are reinserted in the *idle* place. The *activeReswitching* and *idleReswitching* transitions are enabled and then the users in places *commonActiveSwitched* and *commonIdleSwitched* (representing, respectively, the active and idle users to be re-switched from CELL2 to CELL1) are sent, respectively, to place *active* and *idle*. The re-switching procedure ends when the same number of users previously switched from CELL1 to CELL2 is then re-switched.

3.3.3 Added model for CELL2 (receiving cell)

Because of their role in the users switching process, the two cells have opposite behavior with respect to each other. Therefore, when in the model of CELL1 the number of users decreases because of users switching toward CELL1, in the model of CELL2 the number of users has to increase of the same quantity, and viceversa when users are re-switched. In Figure 5, we show the sub model that has been added to the basic GPRS cell model. The gray line separates the components belonging to the BASIC model interface (on the left) from those belonging to the added model (on the right).

- Tokens in place *activeSwitched* (or *myActiveSwitched*) and *idleSwitched* (or *myIdleSwitched*) represent, respectively, the number of active and idle users really switched from CELL1 to CELL2. The *enable_reswitch* place contains

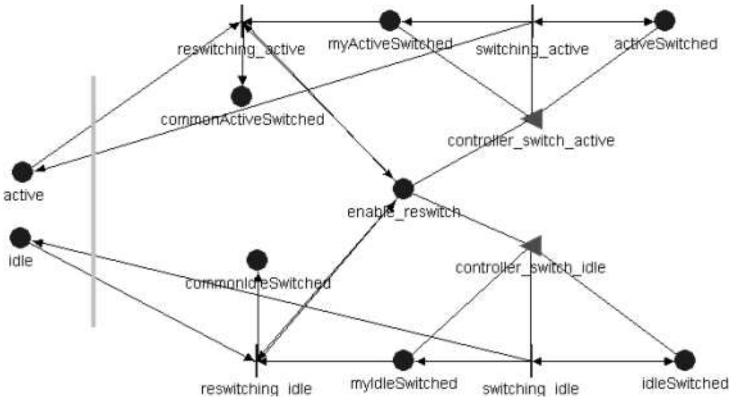


Figure 5. Users Switching sub model for CELL2 (the receiving cell)

one token if the re-switching procedure is enabled, zero otherwise. Tokens in places *commonActiveSwitched* and *commonIdleSwitched* represent, respectively, the active and idle users re-switched from CELL2 to CELL1.

- We set the marking of place *idle* to *NumUsersCELL2*, that is the initial number of users in idle mode camped in the cell.

The input gates are defined as in Table 4 in the Appendix.

Here, we briefly describe the model behavior following the temporal events of Figure 1(b). Before time T0, the system is in steady-state. At time T1, the switching procedure from CELL1 to CELL2 starts and then some tokens arrive in places *activeSwitched* and/or *idleSwitched*, that represent the number of active and/or idle users really switched from CELL1 to CELL2. Places *myActiveSwitched* and *myIdleSwitched* follow the respective variations. At time T3, the mark of the place *enable_reswitch* is set to 1 and the re-switching procedure starts. The users re-switched from CELL2 to CELL1 are available in place *commonActiveSwitched* and *commonIdleSwitched*. The re-switching procedure ends when places *myActiveSwitched* and *myIdleSwitched* are empty.

3.3.4 The Overall Model

Previously, we showed how to construct the models for CELL1 and CELL2 starting from the BASIC model, that represents the random access procedure of a generic GPRS cell. In this section, we specify how to construct the OVERALL model that includes the preceding two models.

The overall model (see Figure 2(b) and Figure 6) is composed by two cells: the outageCell (CELL1), that is the cell affected by the outage, and the receivingCell (CELL2), that is the cell that receives some users from the congested cell. These two models interact each other through some shared places defined in the *join* operation provided by the Möbius tool. In particular, the places shared between CELL1 and CELL2 models are the following:

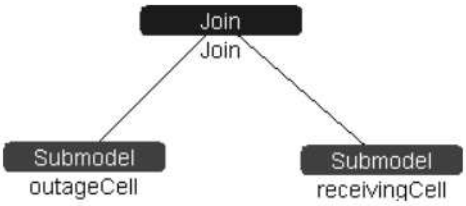


Figure 6. Overall Model: CELL1 + CELL2

- *activeSwitched*, representing the number of active users really switched from CELL1 to CELL2;
- *idleSwitched*, representing the number of idle users really switched from CELL1 to CELL2;
- *commonActiveSwitched*, representing the number of active users really re-switched from CELL2 to CELL1;
- *commonIdleSwitched*, representing the number of idle users really re-switched from CELL2 to CELL1;
- *enable_reswitch*, that enables the users re-switching procedure.

4 Model evaluation

As already pointed out, we conducted a transient analysis in the interval of time following the occurrence of an outage to the new system steady-state after the outage repair. The nature of the measures and the order of magnitude of the results we are looking for, made a simulation approach appropriate for studying the system. Therefore, the preceding models have been numerically solved using the simulator provided by the Möbius tool (see [6]).

We are interested in evaluating the congestion perceived by the users in CELL1, CELL2 and CELL1+CELL2 (the OVERALL model). The congestion perceived is the percentage of users in the active mode (that is those waiting to connect the network for a service request) at a certain point in time, with respect to the total number of users. For simplicity, we shall call

UsersInCELL1=(NumUsers - outageCell→activeSwitched→Mark() - outageCell→idleSwitched→Mark())
THE TOTAL NUMBER OF USERS IN CELL1 AT TIME T,

UsersInCELL2=(NumUsersCELL2 + receivingCell→myActiveSwitched→Mark() + receivingCell→myIdleSwitched→Mark())
THE TOTAL NUMBER OF USERS IN CELL2 AT TIME T,

UsersServedInCELL1=(outageCell→ch1→Mark() + outageCell→ch2→Mark() + outageCell→ch3→Mark() +
outageCell→ch4→Mark() + outageCell→ch5→Mark() + outageCell→ch6→Mark() + outageCell→ch7→Mark() +
outageCell→a1→Mark() + outageCell→a2→Mark() + outageCell→a3→Mark() + outageCell→a4→Mark() +
outageCell→a5→Mark() + outageCell→a6→Mark() + outageCell→a7→Mark())

Symbol	***Description***	***Default Value***
GPRS_Channel	Number of Slave Packet Data Channel for CELL1	3
GPRS_ChannelCELL2	Number of Slave Packet Data Channel for CELL2	3
NumUsers	Number of users in CELL1	150
NumUsersCELL2	Number of users in CELL2	150
Time_to_req	User inter-request time for CELL1, following an exponential distribution	60 sec. (average)
Time_to_reqCELL2	User inter-request time for CELL2, following an exponential distribution	60 sec. (average)

Table 1. CELL1 and CELL2 - Relevant parameters and their values

THE TOTAL NUMBER OF USERS THAT ARE ACTUALLY BEING SERVED IN CELL1 AT TIME T,

UsersServedInCELL2=(receivingCell→ch1→Mark() + receivingCell→ch2→Mark() + receivingCell→ch3→Mark() + receivingCell→ch4→Mark() + receivingCell→ch5→Mark() + receivingCell→ch6→Mark() + receivingCell→ch7→Mark()+ receivingCell→a1→Mark() + receivingCell→a2→Mark() + receivingCell→a3→Mark() + receivingCell→a4→Mark() + receivingCell→a5→Mark() + receivingCell→a6→Mark() + receivingCell→a7→Mark())

THE TOTAL NUMBER OF USERS THAT ARE ACTUALLY BEING SERVED IN CELL2 AT TIME T,

ActiveUsersInCELL1=(UsersInCELL1 - outageCell→idle→Mark() - UsersServedInCELL1)

THE TOTAL NUMBER OF ACTIVE USERS IN CELL1 AT TIME T, and

ActiveUsersInCELL2=(UsersInCELL2 - receivingCell→idle→Mark() - UsersServedInCELL2)

THE TOTAL NUMBER OF ACTIVE USERS IN CELL2 AT TIME T.

Therefore, we define the following reward functions:

- **RewardCELL1**= $\frac{\text{ActiveUsersInCELL1}}{\text{UsersInCELL1}} \times 100$,

  that is the percentage of active users in CELL1 with respect to the total number of users camped in CELL1 at time t;

- **RewardCELL2**= $\frac{\text{ActiveUsersInCELL2}}{\text{UsersInCELL2}} \times 100$,

  that is the percentage of active users in CELL2 with respect to total number of users camped in CELL2 at time t;

- **RewardOVERALL**= $\frac{\text{ActiveUsersInCELL1} + \text{ActiveUsersInCELL2}}{\text{UsersInCELL1} + \text{UsersInCELL2}} \times 100$,

  that is the percentage of active users in CELL1 and/or CELL2 with respect to sum of the total number of users camped in CELL1 and CELL2 at time t.

4.1 Settings for the Numerical Evaluation and Analyzed Scenarios

Tables 1 and 2 show the values we assigned to the main parameters of CELL1 and CELL2 and to those related to the outage and the reconfiguration procedure. Looking at them, it can be observed that we consider two cells with the same number of traffic channels and user population. The outage affects traffic channels (SPDCH) of CELL1, reducing their availability from 3 to 1 SPDCH. The question marks identify the parameters that are left variable in our analysis, in order to study their effects on the congestion perceived by users.

Symbol	***Description***	***Default Value***
numChOut	Number of Slave Packet Data Channel out of service	2
riptime	Outage duration, following a deterministic distribution	120 sec.
activeUsersToSwitch	**Number of active users to switch from CELL1 to CELL2**	**? variable:** 0, 40, 60, 80
activeUsersToLose	Number of active users lost during switching procedure	10% of *activeUsersToSwitch*
idleUsersToSwitch	**Number of idle users to switch from CELL1 to CELL2**	**? variable:** 0, 20, 40, 80
idleUsersToLose	Number of idle users lost during switching procedure	10% of *idleUsersToSwitch*
outageReactionTime	**Time that occurs between the outage and the users switching**	**? variable:** 10, 40, 70, 100 sec.
outageEndReactionTime	Time that occurs between the end of the outage and the users re-switching	15 sec.

Table 2. Outage and Switching procedure: parameters and values

These settings for CELL1 and CELL2 have been used to analyze three different scenarios, which have been set up in order to tune the following three parameter: *activeUsersToSwitch*, *idleUsersToSwitch* and *outageReactionTime*.

- SCENARIO 1: The *outageReactionTime* parameter value is set to 30 seconds and the analysis evaluates the effectiveness of a technique that switches only active users (*idleUsersToSwitch*=0). So, the parameter under tuning is *activeUsersToSwitch*.
- SCENARIO 2: The *outageReactionTime* parameter value is set to 30 seconds and the analysis evaluates the effectiveness of a technique that switches only idle users (*activeUsersToSwitch*=0). So, the parameter under tuning is *idleUsersToSwitch*.
- SCENARIO 3: The *activeUsersToSwitch* parameter value is set to 60 users, while the *idleUsersToSwitch* parameter value is set to 0. The focus in this scenario is to evaluate the impact of the time necessary to Resource Management System to take a decision on the RMT. So, the parameter under tuning is *outageReactionTime*. This performance indicator can be used to set a maximum value on the time that the RMS is allowed to spend to elaborate a reaction to the observed overload.

4.2 Numerical Evaluation

In this section, we show the results obtained from the simulation of the previously described three scenarios.

The optimality of a solution can be analyzed under different point of views, depending on what is the specific goal. In particular:

◇− If the goal is to guarantee that the performance doesn't decrease under a certain minimum level, then an optimal solution is that for which the Point-wise Congestion function always remains under a specific threshold level;

◇− If the goal is to guarantee that the system is able to provide a quick response to the overload effects, then the solution to be preferred is the one that first achieves the inversion of the congestion trend in the subscribers' observed QoS levels;

◇− If the goal is to obtain the most performing solution, then the best choice is the solution that minimizes the value of the Total Congestion indicator;

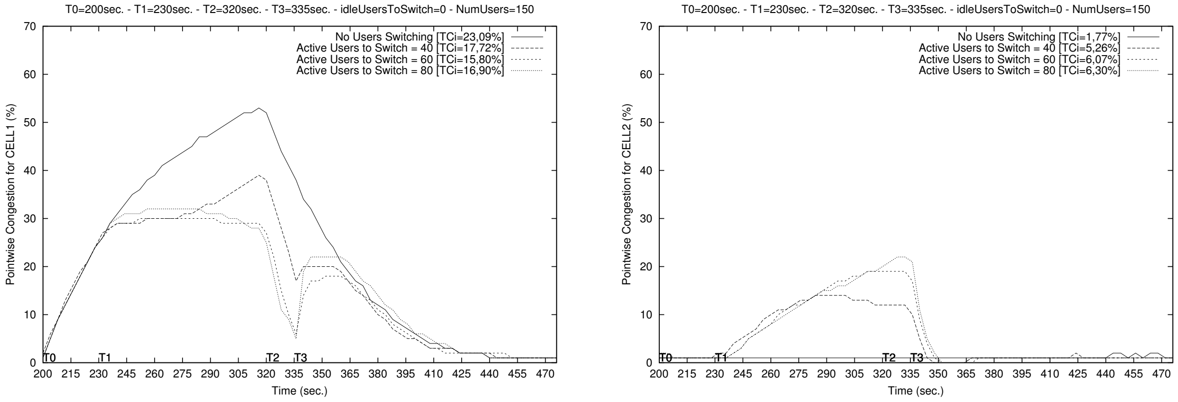
◇− If the goal is to obtain the most performing solution that doesn't decrease under a certain minimum level, it is necessary to combine the preceding evaluations.

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 470 sec. (the time the new steady-state is reached in both cells)

4.2.1 Evaluation in scenario 1: tuning of parameter 'activeUsersToSwitch'

Figures 7 and 8 show the simulation results in scenario 1.

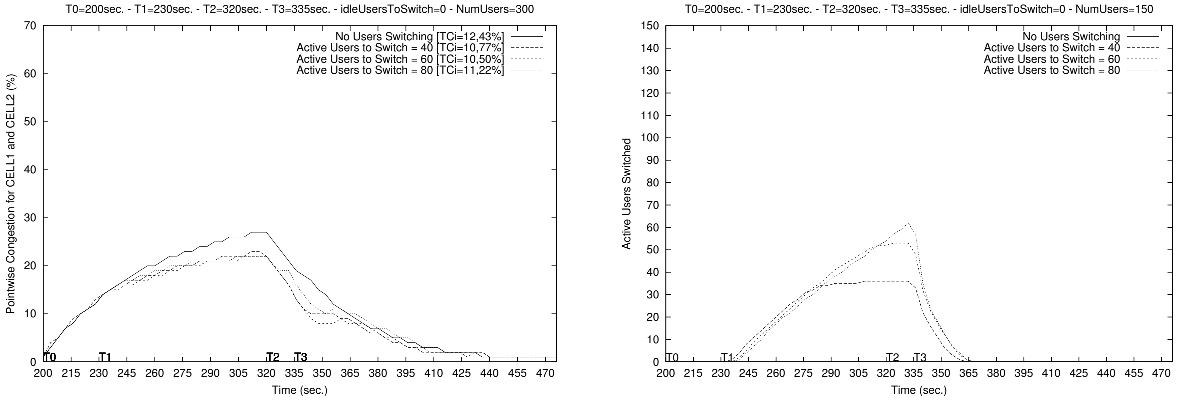
Figure 7(a) shows the congestion perceived by the users (the Point-wise Congestion function) in the cell affected by the outage at varying of the number of the active users to switch from CELL1 to CELL2. From the figure we note that, if we increase the *activeUsersToSwitch* parameter value, the TCi value initially decreases, but increases for *activeUsersToSwitch*=80. This happens, in general, when the switch involves a number of active users that exceeds the "saturation threshold level", that is the maximum number of active users that can be really switched before the system is repaired. The only effect induced by increasing the *activeUsersToSwitch* parameter value over this limit is the loss of other active users during traffic switching (saturation effect). Therefore, we conclude that we obtain the minimum value for TCi in CELL1 if the value of the *activeUsersToSwitch* parameter is the maximum number of users that the system can really switch before the re-switching procedure starts at time T3. It is also interesting to observe that the time to recover for this scenario is always quite good, as the perceived congestion is beneficially affected by the actuation of the technique in a very short amount of time.



(a) (b)

Figure 7. (a) Congestion Perceived in CELL1 and (b) Congestion Perceived in CELL2

Figure 7(b) shows the corresponding behavior of CELL2 (the receiving cell). Obviously, the TCi value increases when we increase the value of the *activeUsersToSwitch* parameter. We note that, after time T1, the congestion initially increases, but decreases immediately after. This happens when the receiving cell is not congested and, then, can absorb the added traffic.



(a) (b)

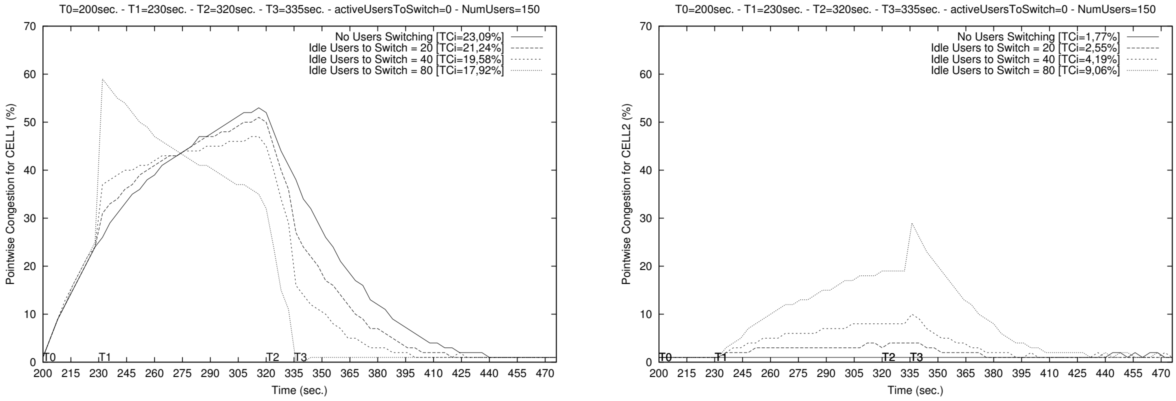
Figure 8. (a) Overall Congestion Perceived and (b) Active Users Switched from CELL1 to CELL2

Figure 8(a) shows the overall behavior of CELL1 and CELL2 at varying values of the *activeUsersToSwitch* parameter. We analyze the percentage of the congestion perceived from users in CELL1 and CELL2, with respect to the total number of users camped in the two cells (in this example 150+150=300 users). If the *activeUsersToSwitch* parameter value increases, we observe that the TCi value decreases until the saturation effect is reached. If the saturation threshold level is exceeded (see the plot with *activeUsersToSwitch*=80), the TCi value gets worse as the negative effect of CELL2 congestion is not compensated by the positive effect induced by the decongestion in CELL1. Therefore, we conclude that the best values for TCi in CELL1+CELL2 are obtained when the value of the *activeUsersToSwitch* parameter is equal to the saturation threshold level. Figure 8(b) shows the number of active users really switched from CELL1 to CELL2. 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 and re-switched at time T3. Moreover, analyzing the plot with *activeUsersToSwitch*=80, we note that the system is able to switch only 62 active users before time T3, and then this value represents the saturation threshold level for this scenario.

4.2.2 Evaluation in scenario 2: tuning of parameter 'idleUsersToSwitch'

Figures 9 and 10 show the simulation results in scenario 2.

Figure 9(a) shows the Point-wise Congestion function in the cell affected by the outage at varying of the number of idle users to switch. We note that when the *idleUsersToSwitch* parameter increases, the congestion perceived rapidly increases at time T1=230 sec. (switching time). Also, when the system is repaired at time T2=320 sec., the congestion perceived rapidly decreases. Figure 9(b) shows the corresponding behavior of CELL2 (the receiving cell): the congestion perceived in the receiving cell reaches the maximum value for T3=335 sec.



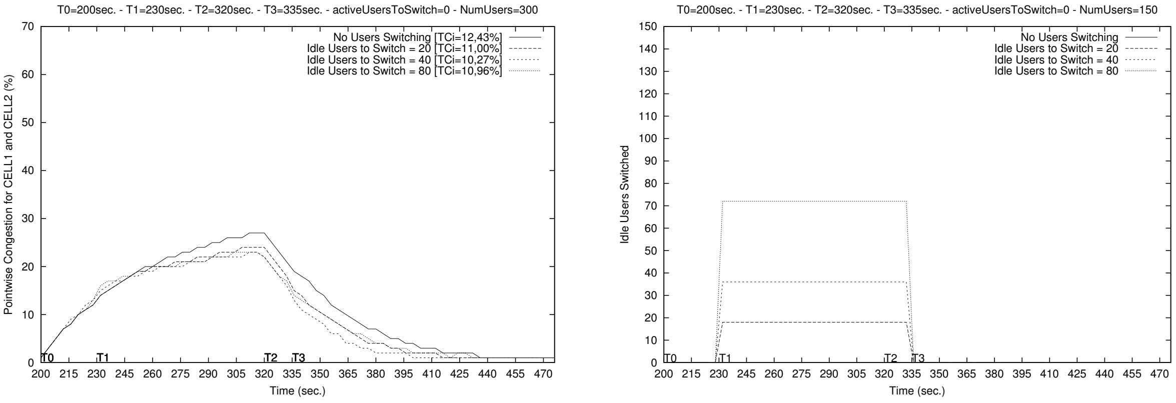
(a)

(b)

Figure 9. (a) Congestion Perceived in CELL1 and (b) Congestion Perceived in CELL2

We have to observe that the peaks of the PCf occurring at time T1 in Figure 9(a) and at time T3 in Figure 9(b) don't reflect a real increment of the congestion perceived inside the cell, as the number of "unsatisfied" users (the active users that are attempting to get a free data channel) doesn't change instantaneously. Actually, this effect is related to the PCf definition in Section 3.1. In fact, in this scenario only idle users are switched; therefore at time T1 for CELL1 and at time T3 for CELL2, the number of idle users camped in the cell instantaneously decreases, and then the percentage of active users that remain in the cell, with respect to the total, instantaneously increases. However, this phenomenon affects only the PCf calculus relative to a single cell (CELL1 or CELL2), as in the OVERALL model the total number of users doesn't change (it's always equal to 150+150=300 users).

Figure 10(a) shows the overall behavior of CELL1 and CELL2 at varying of the *idleUsersToSwitch* parameter. This is the percentage of the congestion perceived from CELL1 and CELL2, with respect to the total number of users camped in the two cells. We note that if we increase the *idleUsersToSwitch* parameter value, the TCi value doesn't always decrease. In particular, if *idleUsersToSwitch*=80 the positive effect on CELL1 congestion doesn't compensate the corresponding negative effect on CELL2 and then the total congestion gets worse.



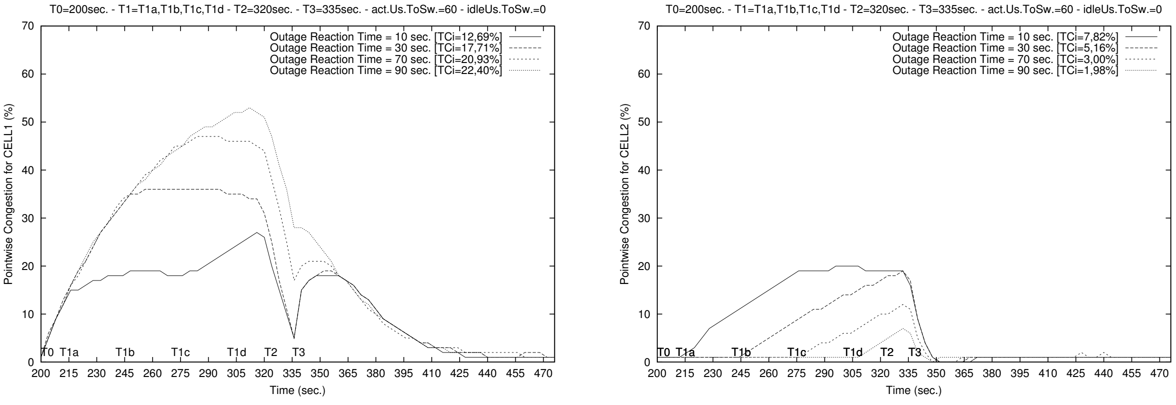
(a) (b)

Figure 10. (a) Overall Congestion Perceived and (b) Idle Users Switched from CELL1 to CELL2

Figure 10(b) shows the number of idle users switched from CELL1 to CELL2 at varying of time. We note that the switching and re-switching procedure is actually instantaneous. This means that there are enough idle users available to be switched at time T1 and T3.

4.2.3 Evaluation in scenario 3: tuning of parameter 'outageReactionTime'

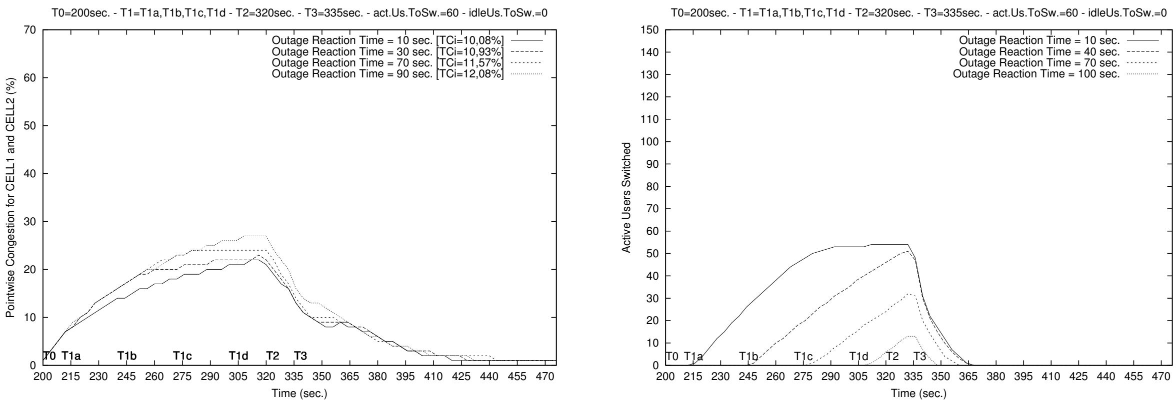
Figures 11 and 12 plot the simulation results in scenario 3. With reference to Figure 1(b), the time T1 is now variable assuming the values T1a, T1b, T1c, and T1d.



(a) (b)

Figure 11. (a) Congestion Perceived in CELL1 and (b) Congestion Perceived in CELL2

Figure 11(a) shows the congestion perceived from the cell affected by the outage at varying of the time needed to the system to react to the outage (*outageReactionTime* parameter). As expected, the congestion decreases when reducing the outage reaction time. Figure 11(b) shows the corresponding behavior of CELL2 (the receiving cell). If the outage reaction time increases, the congestion perceived increases as well.



(a) (b)

Figure 12. (a) Overall Congestion Perceived and (b) Active+Idle Users Switched from CELL1 to CELL2

Figure 12(a) shows the overall behavior of CELL1 and CELL2 at varying of the *outageReactionTime* parameter. This is the percentage of the congestion perceived from CELL1 and CELL2, with respect to the total number of users camped in the two cells (300 users for the considered setting). In particular, if we increase the parameter value the congestion perceived increases as well. The results shown in Figure 12(a) allow performing an interesting investigation on the amount of time that the system should be permitted to spend for its decision-making processes. Indeed, we can observe from the plots that if the reconfiguration is anticipated, the overall history of the perceived overload is positively affected. This allows defining a method to assign time constraints to the decision-making process. For example, if a maximum tolerable level of degradation is known a priori, by looking at the results shown in Figure 12(a) we can infer a value for the maximum *outageReactionTime*. Finally, Figure 12(b) shows the active users switched from CELL1 to CELL2 for a few values of the *outageReactionTime* parameter. As expected, the longer the time to start applying a reconfiguration technique and the lower the number of users actually switched, therefore implying a higher congestion in CELL1.

5 Conclusions and Future Works

This paper has presented a study to evaluate the effectiveness of resource management techniques, based on moving users among GPRS cells, to cope with congestion events caused by an outage occurrence. To this purpose, QoS related indicators representative of the congestion perceived by users during the outage duration and the reconfiguration management technique actuation have been identified and analyzed. The modeling methodology to capture the GPRS cells behavior and the operation of the reconfiguration strategy has been first outlined. Then, a sensitivity analysis based on simulation of the defined models in a transient period of time has been performed to tune parameters of the reconfiguration strategy in three relevant reconfiguration scenarios.

Although a simple GPRS configuration has been considered, made up of two cells only, nevertheless this study is very useful to better understand the underlying dynamics and the involved phenomena. As such, it significantly contributes to improve reconfiguration activities in cellular networks, as the CAUTION++ framework aims at. Of course, there are many directions that would deserve to be investigated, including the following ones: i) To differentiate the cells involved in the reconfiguration strategy in terms of user population and available resources; ii) To extend the analysis to deal with more than 2 GPRS cells; iii) To focus on other causes of congestion, namely the case of load picks because of critical events (e.g., accidents) or because of events aggregating a high user population (e.g., sports events etc..).

6 Acknowledgments

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A APPENDIX

In Table 3 and Table 4 we show, respectively, the definitions of the input/output gates used in CELL1 and CELL2 model. In particular, considering the *q_control* and *chose_channel* gates, we note that we induce the outage in CELL1 simply subtracting the number of traffic channels out of service (*NumChOut*) from the total number of available GPRS traffic channels (*GPRS_Channel*) for this cell.

Input Gate	q_control
Predicate	((ch1→Mark() + ch2→Mark() + ch3→Mark() + ch4→Mark() + ch5→Mark() + ch6→Mark() + ch7→Mark() + a1→Mark() + a2→Mark() + a3→Mark() + a4→Mark() + a5→Mark() + a6→Mark() + a7→Mark())<GPRS_Channel **- NumChOut**→**Mark()**)&&(queue→Mark()>0)

Function

```
queue→Mark()=queue→Mark()-1;
if ((ch1→Mark()+a1→Mark())==0) ch1→Mark()=1;
else if ((ch2→Mark()+a2→Mark())==0) ch2→Mark()=1;
  else if ((ch3→Mark()+a3→Mark())==0) ch3→Mark()=1;
    else if ((ch4→Mark()+a4→Mark())==0) ch4→Mark()=1;
      else if ((ch5→Mark()+a5→Mark())==0) ch5→Mark()=1;
        else if ((ch6→Mark()+a6→Mark())==0) ch6→Mark()=1;
```

Output Gate	chose_channel

Function

```
if ((ch1→Mark()+ch2→Mark()+ch3→Mark()+ch4→Mark()
  +ch5→Mark()+ch6→Mark()+ch7→Mark()+a1→Mark()
  +a2→Mark()+a3→Mark()+a4→Mark()+a5→Mark()
  +a6→Mark()+a7→Mark())<GPRS_Channel-NumChOut→Mark()) {
    if ((ch1→Mark()+a1→Mark())==0) ch1→Mark()=1;
    else if ((ch2→Mark()+a2→Mark())==0) ch2→Mark()=1;
    else if ((ch3→Mark()+a3→Mark())==0) ch3→Mark()=1;
    else if ((ch4→Mark()+a4→Mark())==0) ch4→Mark()=1;
    else if ((ch5→Mark()+a5→Mark())==0) ch5→Mark()=1;
    else if ((ch6→Mark()+a6→Mark())==0) ch6→Mark()=1;
    else ch7→Mark()=1; }
else queue→Mark()=queue→Mark()+1;
```

Input Gate	ConfTraffChOut
Predicate	1
Function	NumChOut→Mark()=GPRS_Channel_Out;

Input Gate	wait_for_reswitch
Predicate	(Ok→Mark()>0)
Function	activeToSwitch→Mark()=0; idleToSwitch→Mark()=0; enable_reswitch→Mark()=1;

Input Gate	wait_for_switch
Predicate	(NumChOut→Mark()>0)
Function	activeToSwitch→Mark()=activeUsersToSwitch; idleToSwitch→Mark()=idleUsersToSwitch; enable_switch→Mark()=0;

Output Gate	Rip_gate
Function	NumChOut→Mark()=0; Ok→Mark()=1;

Input Gate	beginActiveSwitch
Predicate	(activeUsersLost→Mark()>activeUsersToLose) && (enable_reswitch→Mark()==0)

Input Gate	beginIdleSwitch
Predicate	(idleUsersLost→Mark()>idleUsersToLose) && (enable_reswitch→Mark()==0)

Table 3. Relevant Input and Output Gate Configuration for CELL1

Input Gate	q_control
Predicate	((ch1→Mark() + ch2→Mark() + ch3→Mark() + ch4→Mark() + ch5→Mark() + ch6→Mark() + ch7→Mark() + a1→Mark() + a2→Mark() + a3→Mark() + a4→Mark() + a5→Mark() + a6→Mark() + a7→Mark())<GPRS_Channel)&&(queue→Mark()>0)

Function

```
queue→Mark()=queue→Mark()-1;
if ((ch1→Mark()+a1→Mark())==0) ch1→Mark()=1;
else if ((ch2→Mark()+a2→Mark())==0) ch2→Mark()=1;
  else if ((ch3→Mark()+a3→Mark())==0) ch3→Mark()=1;
    else if ((ch4→Mark()+a4→Mark())==0) ch4→Mark()=1;
      else if ((ch5→Mark()+a5→Mark())==0) ch5→Mark()=1;
        else if ((ch6→Mark()+a6→Mark())==0) ch6→Mark()=1;
```

Output Gate	chose_channel

Function

```
if ((ch1→Mark()+ch2→Mark()+ch3→Mark()+ch4→Mark()
  +ch5→Mark()+ch6→Mark()+ch7→Mark()+a1→Mark()
  +a2→Mark()+a3→Mark()+a4→Mark()+a5→Mark()
  +a6→Mark()+a7→Mark())<GPRS_Channel) {
    if ((ch1→Mark()+a1→Mark())==0) ch1→Mark()=1;
    else if ((ch2→Mark()+a2→Mark())==0) ch2→Mark()=1;
    else if ((ch3→Mark()+a3→Mark())==0) ch3→Mark()=1;
    else if ((ch4→Mark()+a4→Mark())==0) ch4→Mark()=1;
    else if ((ch5→Mark()+a5→Mark())==0) ch5→Mark()=1;
    else if ((ch6→Mark()+a6→Mark())==0) ch6→Mark()=1;
    else ch7→Mark()=1; }
else queue→Mark()=queue→Mark()+1;
```

Input Gate	controller_switch_active
Predicate	(activeSwitched→Mark()>myActiveSwitched→Mark()) && (enable_reswitch→Mark()==0)

Input Gate	controller_switch_idle
Predicate	(idleSwitched→Mark()>myIdleSwitched→Mark()) && (enable_reswitch→Mark()==0)

Table 4. Relevant Input and Output Gate Configuration for CELL2