DEPENDABILITY MEASURE OF A GPRS SERVICE FOR TELE-CONTROL APPLICATIONS

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ABSTRACT

Management of high natural and technological large incidents on national territory may require tele-medical or some other kind of tele-control assistance, based on communication networks, even public and mobile. In such applications, Tele Control Systems (TCS), based on communication networks, are used in prototypal fashion, for diagnosis, monitoring, therapy, control and protection of victims of a catastrophic event. The paper focuses on a PMN that supports both Global System Mobile (GSM) and General Packet Radio Service (GPRS) connections, for voice and data transmissions between Remote Mobile Nodes and Tele Control Center. Dependability measures of the PMN have been performed by building and executing stochastic models. Particularly, it is presented a GPRS model, based on the Stochastic Activity Networks formalism, to compute PMN dependability measures, as well as some numerical results, in the framework of validation by modelling of the related TCS. Two different layers of modelling have been implemented. At the first layer, separate sub models were built to compute the pure unavailability and the pure performance for voice and data packet services. At the second layer of modelling, two composed models were built by joining the availability sub model and the performance sub-models.

1.0. INTRODUCTION

High risks, recently appeared, such as large areas contamination from chemical pollution due to reactor faults, but also catastrophic events, such as earthquake, disruptive volcanic eruption in high density inhabited zones (such as the Vesuvian area) or flooding, may require emergency teams, able to perform even medical assistance in hard situations.

Even though the emergency personnel is qualified to do simple medical intervention and is provided of portable medical devices, there could be situations in which tele-medical assistance is needed immediately on site or during the transport to equipped sanitary structures.

When the territory is large, the number of victims that need aid is high, the fast transport ways (motorways, bridges, railways) are interrupted, there is unavailability of helicopters for rescue, but radio based communication lines (such as mobile networks) are still functioning, then emergency teams, relying on cross-country instrumented remote and mobile vehicles connected to a Tele Control Systems (TCS), may in real time:

- give informations on serious victims (diagnostic analysis, telemetry of vital parameters),
- receive tele-medical indications on actions to take or medicine to give.

As a further issue, such emergency teams may use their mobile communication terminal also to accomplish tele-control actions and civil protection tasks, such as:

- give news on the situation (damages to infrastructures/services, number of deceased/injured people),
- receive orders on things to do, places to go, etc.

The modern communication networks, on which our society increasingly depends, are usually born for not critical aims, but actually they are used, more and more, for emergency tele-control or tele–medical purposes (usually with dedicated networks).

In similar applications, Tele Control Systems (TCS), based on communication networks, are proposed in prototypal fashion, for diagnosis, monitoring, therapy, control and protection of victims of a catastrophic event.

TCS typically consists of one or more Tele Control Centres (TCC), interconnected to Remote Mobile Nodes to be controlled, by a wireless communication network, usually a public one (PMN: Public Mobile Network).

When a PMN is the heart of the system, then the TCS is more vulnerable due to many factors, such as complexity, mobility of nodes, response time and public access to the network. The paper focuses on a PMN that supports both Global System Mobile (GSM) and General Packet Radio Service (GPRS) connections, for voice and data transmissions between Remote Mobile Nodes and TCC.

Stochastic methods and tools for safety and quality of service evaluation of a TCS based on a PMN have been developed. Performance measures of the denial of service for GSM and GPRS connections of PMN, such as the Total Service Blocking Probability (TSB), have been computed to better understand the effects of the degradation of the performance and of the availability of the PMN on the Tele Control System main functions.

Dependability measures of the PMN have been performed by building and executing stochastic models. In fact, field experimentation on actual systems is not suitable for dependability measures, since just a limited number of field test could be run on actual TCSs, while complete tests would require long observation times (with loss of availability and money) and irreproducible scenarios (i.e.: simulations of the occurrence of incidents and emergencies).

Then the TCS has been validated according two main lines:

- building and executing stochastic models even hierarchically composed, to compute performability and dependability measures with the aim of understanding the effects of performance and availability degradation of the PMN on the TCS main functions;

- building and executing a functional model based on model checking, which looks at the interaction between the dimensioning of the PMN and the TCS main functions, with the aim of evaluating the safety properties of the TCS, such as the unreachability of the TCS states which could bring to dangerous scenarios.

Particularly, it is presented a GPRS model, based on the Stochastic Activity Network (SAN) formalism, to compute PMN dependability measures, as well as some numerical results, in the framework of validation by modelling of the related TCS. Stochastic Activity Network formalism offers analytical solutions, either time dependent or steady state solutions. The analytical solution suffers of the well known state space explosion problem. That is partially recoverable by resorting to the composition of models and to the simulative solution, both supported by SAN. To compute dependability measures on larger wireless telecommunication networks (such as for GPRS service at urban, regional or national level) ad hoc network simulators, on which adverse events (such as random failures and congestion events) are injected, may be needed.

Two different layers of modelling have been implemented. At the first layer, separate sub models were built to compute the pure unavailability and the pure performance for voice and data packet services. At the second layer of modelling, two composed models were built by joining the availability sub model and the performance sub-models.

The dependability measures of the PMN data services are based on a GPRS connection among remote instrumented terminals and TCC, combining service degradation/recovery due to PMN components failure and repair activities (availability measures) and data packet transmission requests (performance measures).

The work will be organized as follows:

- a description of the Tele Control System basic elements, focusing on GSM and GPRS connections;
- the dependability evaluation, in terms of assumptions, modelling formalism, models (availability/performance sub-models and composed model);
- some numerical results.

2.0. TELE CONTROL SYSTEM BASIC ELEMENTS

Tele Control Systems (TCS), based on communication networks, are proposed in prototypal fashion, for diagnosis, monitoring, therapy, control and protection of victims of a catastrophic event. TCS implements actions by transferring voice, commands and data between remote instrumented terminals and TCC, by means of a Public Mobile Network. TCC must be able to exchange information with more than one remote instrumented terminal at the same time in *bi-directional* way. Particularly, informative messages flow from remote instrumented terminals to TCC, in uplink path, and commands/messages flow from TCC to the single remote instrumented terminal or to a set of remote instrumented terminals, in downlink path.

Each terminal belonging to monitored area (after the occurrence of a registration procedure), sets up a GPRS connection towards the TCC. GPRS connection uses TCP transport protocol, which guarantees the correctness of received data by means of integrity checks in the receiver, and foresees a retransmission mechanism for bad-received packets. Each terminal is characterized by a TCP address (IP address + TCP port) which enables a point to point communication with the TCC, that is provided of an analogous address too.

Bidirectional voice calls, by GSM connection, are forecasted between terminals and TCC, in case GPRS data transfer is not enough to manage emergencies.

2.1. GSM and GPRS connections

GSM is a circuit-switched connection, with reserved bandwidth [2]. At air interface, a complete traffic channel is allocated to a single Mobile Station (MS), for the entire call duration. A cell is formed by the radio area coverage of a Base Transceiver Station (BTS). One or more BTS are controlled by one Base Station Controller (BSC). The BTS and the BSC form the Base Station Subsystem (BSS), figure 1. A BSS is viewed as a router, connecting the wireless cellular network to the wired part of the network. The combined traffic of MS in their respective cells is routed through a switch, the Mobile Switching Centre.

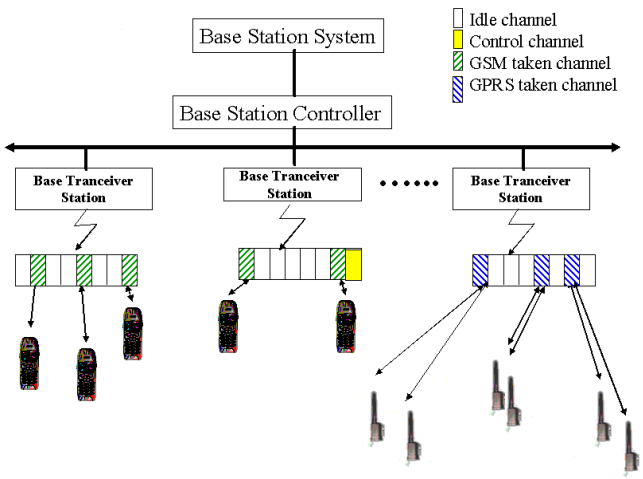


Figure 1. Base Station System

GSM uses a mixed multiple access technique to the radio resources (FDMA/TDMA, Frequency Division Multiple Access/Time Division Multiple Access). Within each BSS, one or more carrier frequencies are activated (FDMA), and over each carrier a TDMA frame is defined. TDMA allows the use of the same carrier to serve multiple MS. In GSM connection, the frame is constituted by eight timeslots and so the same radio frequency can serve up to eight MS. Typically one channel (time slot) is reserved for signalling and control. A MS can roam from a cell to a neighbouring cell, during active voice calls. Such a MS, that has established a voice call, and roams from a cell to another, must execute a handoff procedure, transferring the call from the channel in the old cell to a channel in the new cell entered by the MS.

GPRS is a packet switched connection with shared, unreserved bandwidth [2]. A radio channel will only be allocated when needed and will be released immediately, after the transmission of packets. With this principle more than one MS can share one physical channel (statistical multiplexing), figure 1. In order to integrate GPRS services into the existing GSM architecture, a new class of network nodes, called GPRS support nodes are used.

GPRS exploits the same radio resources used by GSM. To cross the wireless link data packets are fragmented in radio blocks, that are transmitted in 4 slots in identical position within consecutive GSM frames over the same carrier frequency [2], [3].

Depending on the length of the data packets, the number of radio blocks necessary for the transfer may vary. MS execute packet sessions, which are alternating sequences of packet calls and reading times. One time slot constitutes a channel of GPRS traffic, called Packet Data Traffic Channel (PDTCH). On each PDCH, different data packets can be allocated in the same TDMA frame or in different TDMA frames. When a user needs to transmit, it has to send a channel request to the network through a Random Access Procedure, which may cause collisions among requests of different users. In this case a retransmission is tried. The number of maximum retransmissions is one of the GPRS access control parameters. Typically, one of the channels, randomly selected out of the available channels, is dedicated to GSM and GPRS signalling and control.

3.0. PMN DEPENDABILITY MODELS

To obtain manageable models of our PMN, the following assumptions have been made (figure 1):

- a single Base Station System (BSS) has been focused, constituted by one Base Station Controller (BSC) and multiple Base Transceiver Stations (BTS);
- data exploits the same physical channels used by voice;
- channel allocation policy is priority of voice on data;
- handoff procedure has been accounted for voice connection, neglecting the possibility of handoff procedure for data connection;
- one Control Channel (CCH) is dedicated to GSM and GPRS signalling and control. CCH is randomly assigned to a BTS;
- GPRS implements a point to point connection;
- each remote instrumented terminal embeds a Mobile Station, which allows the contemporarily use of GSM and GPRS connections.

According to the above assumptions, GPRS services can be denied, due to the following contributes: a) the BSS, as a whole, becomes unavailable or b) the BSS is available and all its channels are full or c) the BSS is not completely available and all the channels in it, which are available, are also full.

The fact that the BSS and its channels are unavailable, depends upon BSS failure/repair activities. Particularly, BSS failure and repair activities are related to BSS physical components: MS, BTS and BSC, (figure 1). BSS components are assumed to fail and be repaired, with their own and independent rates. Actually, the reliability figures of MS are significantly better than those of the other network components, then we assume MS as fault free. Each BTS can hosts eight traffic channels or, randomly, could hosts the Control Channel (CCH) plus seven traffic channels.

To sum up, BSS Total Unavailability (TU) can be represented as the logical *OR* among the unavailability of the BSC (Base Station Controller), the unavailability of the CCH (Control Channel) (which depends upon the failure of the BTS which randomly can host it) and, finally, the unavailability of all the BTS.

When a BTS, which does not host the CCH, fails its physical channels became unavailable and the BSS operates in degraded conditions. If the failure of all the BTS occurs, the consequence is still BSS Total Unavailability.

To compute dependability measures for data packet connections, a stochastic model has been built, hierarchically composed, based on the above assumption and relying on the Stochastic Activity Network formalism. At a lower layer of modelling, a) availability model computes the denial of data service due to failure and repair activities of BSS components, and b) performance model compute the probability of data packets loss being all available channels full. Then, at a higher layer of modelling, composed model computes dependability measures for data packets accounting both availability and performances (figure 4).

3.1. Stochastic Activity Networks

Stochastic Activity Networks (SAN) is a modelling formalism which extends Petri Nets [4]. The basic elements of SAN are places, activities, input gates and output gates. Places in SAN have the same role and meaning of places of Petri Nets. They contain an arbitrary number of tokens. Activities are equivalent to transitions in Petri Nets. They can take a certain amount of time to be completed (timed activities) or no time (instantaneous activities). Each activity may have one or more input arcs, coming from its input places (which precede the activity) and one or more output arcs going to its output places (which follow the activity). In absence of input and output gates, the presence of at least one token in each input place makes it able to fire. After firing one token is placed in each output place. Input gates and output gates, typical constructs of SAN, can modify such a rule, making the SAN formalism more rich to represent actual situations. Particularly, they consist in predicates and functions, written in C language, which contain the rules of firing of the activities and how to distribute the tokens after the activities have fired.

As in Petri Nets, a marking depicts a state of the net, which is characterised by an assignment of tokens to all the places of the net. With respect to a given initial marking, the reachability set is defined as the set of all markings that are reachable through any possible firing sequences of activities, starting from the initial marking.

Other than the input and output gates, which allow to specifically control the net execution, SAN offers two more relevant high-level constructs for building hierarchical models: REP and JOIN. Particularly, such constructs allow to build composed models based on simpler sub-models, which can be developed independently, then replied, joined with others sub-models and executed.

SAN model specification and execution is supported by Möbius tool, developed by University of Illinois. The tool allows to specify graphical models, to define performance measures through reward variables, to compute measures by choosing a specific solver to generate solutions.

3.2. Availability sub model

To compute TU, we have built the availability sub model (figure 2), which represents failure/repair activities of the Base Station Controller and all the controlled Base Transceiver Stations. A failed BTS hosts the Control Channel (CCH) with probability c, or complementary host the CCH, with probability $1 - c$. If the failed BTS hosts the CCH, the BTS failure implies the failure of the Control Channel, and in turn, the

failure of the whole PMN. If the BTS, doesn't host the CCH, the BTS failure just implies the loss of the physical channels supported by it (eight channels/timeslots).

The marking of place *BTS_UP* represents the number of Base Transceiver Stations which are not failed. The firing of the activity *BTS_Fail* represents the failure of the BTS component. If the failed BTS hosts the CCH, it makes the whole BSS down (output gate *TU_CCH*, shown in table 1). If the failed BTS doesn't host the CCH, the channels which are currently up are decremented by the number of channels associated to the failed BTS (output gate *BTS_loss*). The marking of the place *BTS_DOWN* represents the number of failed BTS; one token in the place *CCH_DOWN* represents the CCH failure. The firing of the activities *BTS_Repair* and *CCH_Repair* represents the repair activities of the related BTS component.

One token in place *BCS_UP* represents that the BCS is not failed. One token in place *BCS_DOWN,* consequent to the firing of the activity *BCS_Fail,* represents the BCS failure. On BCS failure, the whole BSS goes down and all the channels are lost (output gate *TU_BCS*). The marking of the place *working_channels* represents the number of available and idle channels. The marking of the place *channels_in_service* represents the number of available and connected channels. After repair activities (*CCH_repair, BCS_repair, BTS_repair*) the channels are again up and ready to be taken in service (output gates *BTS_ON, BCS_ON, CCH_ON*). The firing time of activities is assumed to follow a negative exponential distribution.

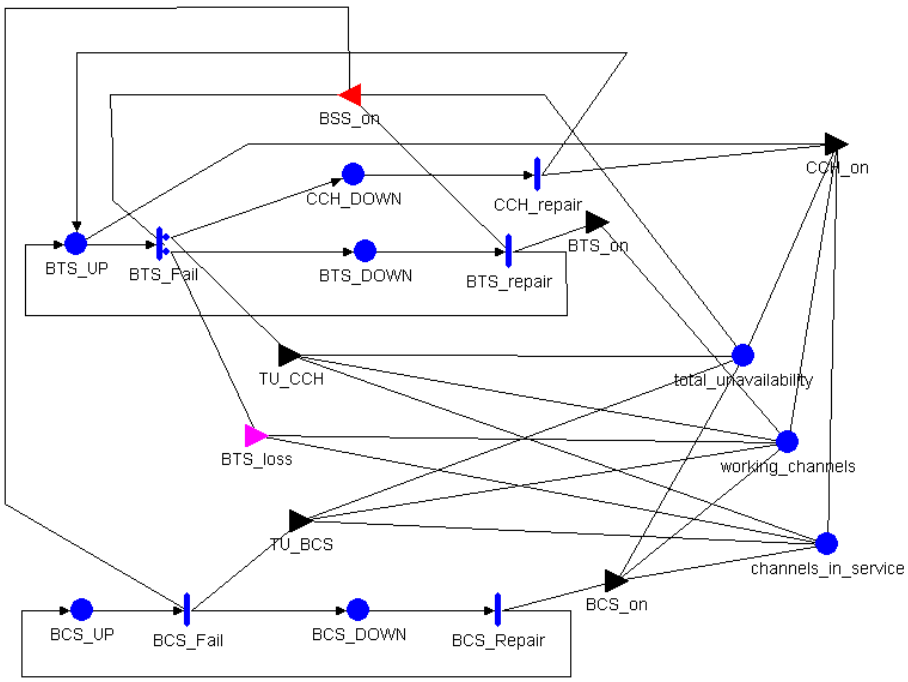


Figure 2. Availability sub model

Table 1: Definition of the output gate TU_CCH

Output Gate Attributes: TU_CCH	
Field Name	**Field Value**

Function	`total_unavailability->Mark()=1;`
	`working_channels->Mark()=0;`
	`channels_in_service->Mark()=0;`

3.3. GPRS performance sub model

GPRS performance sub model computes the pure performance aspects of the GPRS service, which contends physical channels to the GSM service. Voice calls are set up as long as at least one channel is available in the PMN, while data packets can be transmitted only over the channels which are not used for voice service. A remote terminal, which needs to communicate with Tele Control Centre or vice versa, tries to open a packet session. If the current number of open data packet sessions is less than the maximum number of data packet sessions which can remain simultaneously active, then a new data packet session can be opened. Into an active data packet session, the incoming data packets are queued in a buffer, as a sequence of radio blocks. Once in the buffer, the radio blocks can be transmitted with the proper GPRS transmission rate. The transfer of radio blocks over the radio link can be either successful, thus allowing the removal of the radio block from the buffer, or results in a failure; in the last case, the radio block is retransmitted.

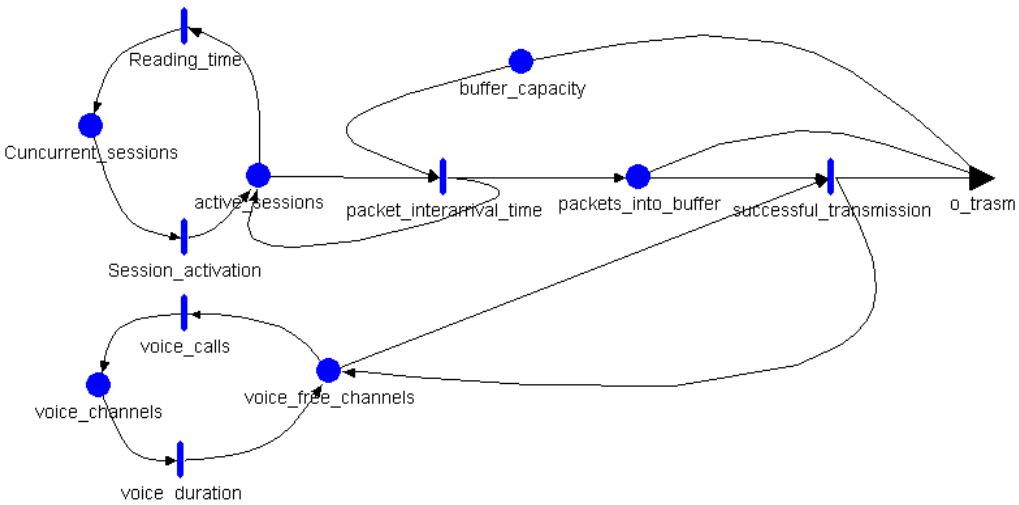


Figure 3. GPRS performance sub model

Referring to figure 3, if at least one token is in place *concurrent_session* a data packet session is opened, by the firing of *session_activation* activity. As a consequence one token is added in place *active_session*. Named *D,* the number of maximum simultaneously active data packet sessions and named *d*, the number of currently opened data packet sessions, a new session can be opened at the condition that $d < D$. Inside an open data packet session, data packets arrive with the rate of *packet_interarrival_time* activity and are queued into *packets_into_buffer* place. As a first step, we assume that one data packet has the length of one radio block, so each data packet increments the buffer by one unit (one radio block) at the condition that the buffer is not full (if $b < B$, where b is the current values of the radio blocks in the buffer and B is the buffer capacity). Such a condition is controlled by the marking of *buffer_capacity* place. The radio blocks queued in the buffer are transmitted during the same set of 4 TDMA frames by the *successful_transmission* activity which keep into account that the radio block that can be served by the currently available channels (the ones not being occupied by voice).

3.4. GPRS composed model

The GPRS composed model (figure 4) computes dependability measures, such as denial of packet data service. The composed model joins GPRS performance sub model (figure 3) and the availability sub model (figure 2). The model is composed by the two atomic sub models that are joined (through the *JOIN* construct), by sharing common places (*shared places)*. So it works as a SAN composed by the places of both the sub models that, actually, thanks to the trick of common places, is simulated through the two separate sub models (even though not completely separated since the number of tokens is the same in the common places with the same name in each sub model). In case of GPRS, the denial of service does not directly measure the loss of information contained in data packets because they can be accumulated into a queue and retransmitted. Then, for GPRS connection, it has been also computed the probability of data packet loss for

exceeding the buffer capacity and the probability of data packet loss for exceeding the maximum number of data packet sessions which can be simultaneously opened.

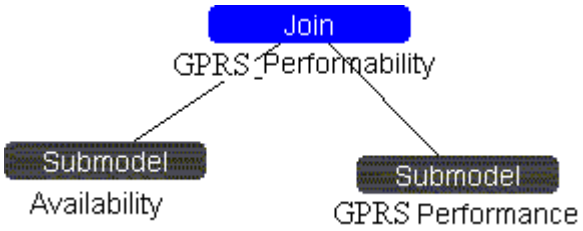
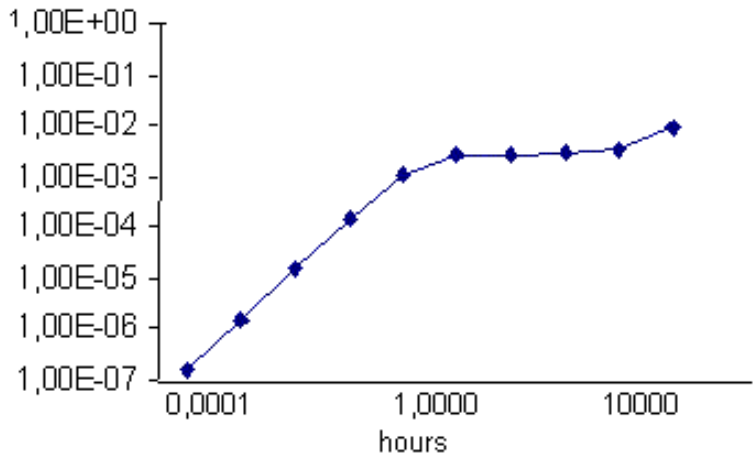


Figure 4. GPRS composed model

3.5. Some numerical results

Different dependability measures for GPRS connection have been computed, by executing GPRS composed model with input parameters and data provided by the application field. When actual data were missing it has been made reference to [1], [2], [3]. Figure 5 shows an example of such measures: Total unavailability versus time. The total unavailability of the Base Station System (BSS) which is equivalent to the total unavailability of the PMN. PMN availability measures and, in general, measures of other dependability attributes and of the timeliness of the PMN, have to be predicted in order to verify if they weaken the dependability requirements of whole PMN based application (i.e. a real time safety related tele-control system, a tele-medical assistance system for large national crisis, etc…).



Figurte 5. Total unavailability

The result is good or evil depending on the application: if the communications between a Remote Mobile Node and a Tele Control Centre must be performed as "real time" communications then the result could be critical and a way to improve the performance of the system should be to enlarge the number of communication channels (the Base Station bandwidth), thing that in emergency situations (with the network decimated by some catastrophic event) is not suggestable; while if communications must be performed as "best effort" communications, i. e. with no time bonds (within certain limits) to deliver the message, (as for a GPRS service) then the result obtained is quite good.

4.0. CONCLUSIONS

PMN availability and performability measures have been computed for GPRS service. PMN availability measures and, in general, measures of other dependability attributes and of the timeliness of the PMN, have to be predicted in order to verify if they weaken the dependability requirements of whole PMN based application (i.e. a real time tele-control or tele-medical assistance system, etc…).

Modular sub models, hierarchically composed, have been built by using Stochastic Activity Networks. The Stochastic Activity Networks formalism offers analytical solutions, either time dependent or steady state. The analytical solution suffers of the well known state space explosion problem. That is partially recoverable by using the composition of models or simulative solutions, both supported by SAN. To compute dependability measures on larger wireless telecommunication metworks (such as for GPRS service at urban, regional or national level) ad hoc network simulators on which inject adverse events, such as random failures and congestion events, may be needed.

Two different layers of modelling have been implemented. At first layer, two separate sub models to compute pure unavailability and pure performance measures have been built. Then at second layer of modelling, a composed model joining the availability and the performance sub models have been obtained. Some dependability measures have been presented.

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