Modelling and Performance Evaluation of Wireless Networks

G.H.S. Carvalho[12], R.M. Rodrigues[1], C.R.L. Francês[1], J.C.W.A. Costa[1], and S. V. Carvalho[2]

[1] Electrical and Computing Engineering Department,
Universidade Federal do Pará-UFPA,
Belém/PA, Brazil.
{ghsc, rmr, rfrances, jweyl}@ufpa.br
http://www.deec.ufpa.br/lea/index.htm
http://www.deec.ufpa.br/laca/index.php

[2] Laboratory of Computing and Applied Mathematics-LAC,
Instituto Nacional de Pesquisas Espaciais-INPE,
São José dos Campos/SP, Brazil.
{ghsc, solon}@lac.inpe.br
http://www.lac.inpe.br/

Abstract. Integration between voice services and data services brought about new concepts in modelling and performance evaluation of wireless networks. In this paper it is proposed a new approach to deal with that putting together a formal method called Statecharts and a Continuous Time Markov Chain (CTMC)[3]. From the specification of the system made in Statecharts it is automatically generated a CTMC, and then evaluated the performance measures. The advantages of this technique are better representation of the behavior of the system without ambiguity and with consistency.

1 Introduction

The growth of Internet has stimulated an increasing demand for wireless data services. However, circuit-switched data services were not able to satisfy user's and service provider's requirements. This drawback has been overcome by implantation of packet switching based overlays to existing cellular mobile networks, being a evolutive step towards the third-generation (3G) mobile communication systems.

In this paper it is proposed a new approach for modelling and performance evaluation of wireless networks, which combines the Statecharts and a Continuous Time Markov Chain (CTMC) for specifying and solving the resource allocation in Global System for Mobile communications/General Packet Radio Service (GSM/GPRS) networks, respectively. Three resource allocation schemes are modelled and analyzed. Their results are compared to simulation results and it may be seen a good agreement between them.

[3] This work was partially supported by CNPq.

A lot has been written about GSM/GPRS networks. In [1] it is investigated how many PDCH must be allocated to carry GPRS data traffic. In [2] four resource allocation schemes are studied. It showed that Dynamic Resource Allocation (DCA) schemes outperform Fixed Resource Allocation (FCA) schemes.

The remainder of this paper is organized as follows: Sections 2 and 3 present a overview of the GSM/GPRS network and Statecharts, respectively. Section 4 describes the modelling process of GSM/GPRS resource allocation, while analytical and simulation results are presented in Section 5. Finally, in Section 6, conclusions are draw about the proposed model.

2 GSM/GPRS Network

GPRS is a enhancement of GSM network improving its data capabilities and providing connection with external Packet Data Network (PDN) as X.25 network, Internet, and others [3]. As a packet-switched technology, GPRS only allocates physical channel (PDCH) when there are data transfers over the air interface. Unused GSM radio channels may be allocated as on-demand PDCH. To ensure the integrity of transmitted data packets four Coding Schemes (CS) are defined: CS-1 (9.05 kbit/s), CS-2 (13.4 kbit/s), CS-3 (15.6 kbit/s), and CS-4 (21.4 kbit/s).

3 Statecharts

Statecharts are a visual formalism that was designed to deal with complex reactive systems. These systems are characterized by being large event drive systems and reacting to stimuli received from external and internal medium. Statecharts are the extension of the conventional state diagrams including orthogonality (concurrency), hierarchy (depth), and an appropriated communication mechanism (broadcast communications). Its elements are: states, events, transitions, labels, and expressions. More details see [4].

4 Modelling Resource Allocation in GSM/GPRS Networks

4.1 Resource Allocation Scheme 1

In the first scheme, the radio resource are completely shared between voice and data service. In addition, voice service has preemptive priority over data service, and data packets are accommodated in the buffer while waiting for service. The arrival process of GSM voice calls and GPRS data packets follow a Poisson process with mean λ_{V} and λ_{P}, respectively [2, 5]. Their service time are exponentially distributed with mean $t_{\mathrm{h}} = 1/\mu_{\mathrm{V}}$ and $t_{\mathrm{P}} = 1/\mu_{\mathrm{P}}$ [2, 5]. The number of available radio channels in BTS is N while the buffer size is B_{S}.

The Statecharts specification that performs these functions is illustrated in Fig. 1. The sub-states of this specification are described bellow:

1. **Source**: Source generator of GSM voice calls and GPRS data packets requests. It has a single sub-state called 'Ready'. inc_ch and inc_bf associated actions fire new arrivals in the orthogonal components **Voice Channel** and **Buffer**, respectively.
2. **Voice Channel**: It has two single sub-states – 'Free' and 'Busy'. Throughout the inc_ch action is fired a new call arrival that may change the status of this component either from 'Free' to 'Busy' or from 'Busy' with v to $v+1$ GSM voice calls.
3. **Buffer**: This template has similar behavior to template **Voice Channel**. The dec_bf action decrements one GPRS data packet in the buffer by means of the events *cond* 1 and *cond* 2, while the inc_bf action increments one GPRS data packet in the buffer by means of events *cond* 3 and *cond* 4.
4. **Packet Channel**: This template has similar behavior to **Voice Channel** and **Buffer**. The events, which control its behavior (status) are:
   (a) Event (Cond 1): It will change the status from 'Free' to 'Busy' if it is true that there is available resource ($v < N$) and there is, at least, one GPRS data packet in the buffer ($Buffer.Busy$).
   (b) Event (Cond 2): It will change the status from 'Busy' with p to 'Busy' with $p+1$ GPRS data packets if it is true that there is available resource ($v < N$) and there is, at least, one GPRS data packet in the buffer ($Buffer.Busy$), and the number of GPRS data packets currently in service is less than the available resources ($p < N - v$).
   (c) Event (Cond 3): It will change the status from 'Busy' with $p+1$ to 'Busy' with p GPRS data packets if either a GPRS data packet finishes its service ($p\mu_{\mathrm{p}}(p > 1)$) or it is true that there is not available radio resource ($p = N - v$) and an arrival of GSM voice call takes a place (inc_ch).
   (d) Event (Cond 4): It will change the status from 'Busy' with 1 to 'Free', if either the unique GPRS data packet finishes its service (μ_{p}) or it is true that there is not available resource ($p = N - v$) and the number of GPRS data packets currently in service is 1 and an arrival of GSM voice call takes a place (inc_ch).

The process of generating a CTMC from a Statecharts specification corresponds to construct an infinitesimal generator Q, which contains all transition rates among states. At a given time, a state is defined by the combination of variables (q, v, p) that refer to the current number of GPRS data packets in the buffer, the current number of GSM voice calls in service, and the current number of GPRS data packets in service, respectively. The steady-state probability $\pi = (\pi_0, \pi_1, \cdots, \pi_{\mathrm{max}})$ may be evaluated through the matrix equation $\pi.Q = 0$ together with the normalization condition $\sum_i \pi_i = 1$. In this work we have used Gauss-Seidel method to get the steady-state probability.

The blocking probability of a GSM voice call and GPRS data packet are given by (1) and (2), respectively.

$$P_{\mathrm{bv}} = \sum_{q=0}^{B_s} \pi_{q,N,F} \quad . \tag{1}$$

$$P_{\mathrm{bd}} = \sum_{q+v+p=N+B_s} \pi_{q,v,p} \ . \tag{2}$$

The Preemption and Dropping Probability of GPRS data packets are given by (3) and (4), respectively.

$$P_{\mathrm{pd}} = \frac{1}{\lambda_{\mathrm{p}}(1-P_{\mathrm{bd}})} \sum_{\substack{v+p=N \\ \& p\geq 1}} \lambda_{\mathrm{v}} \pi_{q,v,p} \ . \tag{3}$$

$$P_{\mathrm{dd}} = \frac{1}{\lambda_{\mathrm{p}}(1-P_{\mathrm{bd}})} \sum_{\substack{v+p=N \\ \& p\geq 1}} \lambda_{\mathrm{v}} \pi_{B_s,v,p} \ . \tag{4}$$

The mean waiting time of GPRS data packets that is given by (5), while the mean throughput of GPRS data packets is given by (6).

$$W_{\mathrm{qd}} = \frac{\sum_{q=1}^{B_s} \sum_{v=0}^{N} \sum_{p=0}^{N-v} q\pi_{q,v,p}}{\lambda_{\mathrm{p}}(1-P_{\mathrm{bd}})[1+P_{\mathrm{pd}}(1-P_{\mathrm{dd}})]} \ . \tag{5}$$

$$T_{\mathrm{h}} = \lambda_{\mathrm{p}}(1-P_{\mathrm{bd}})[(1-P_{\mathrm{pd}})+P_{\mathrm{pd}}(1-P_{\mathrm{dd}})] \ . \tag{6}$$

4.2 Resource Allocation Scheme 2

The only difference between this resource allocation scheme from the one before is the number of available channels dedicated to GPRS (N_p). Therefore, in this model no more than $N - N_p$ voice call will be accepted. So that the performance measures (1)–(6) must be adapted to include it.

4.3 Resource Allocation Scheme 3

This resource allocation scheme is completely different from the others. GSM voice call are taken to the buffer, while GPRS data packets are directly taken to the radio channels. There is not preemptive priority of voice service over data service.

The Statecharts specification that represents this system is showed in Fig. 2.

The blocking probability of GSM voice call and GPRS data packet are given by (7) and (8), respectively. The mean waiting time of GSM voice call is given by (9), while the mean throughput of GPRS data packets is given by (10).

$$P_{\mathrm{bv}} = \sum_{q+v+p=N+B_s} \pi_{q,v,p} \ . \tag{7}$$

$$P_{\mathrm{bd}} = \sum_{q=0}^{B_s} \sum_{v+p=N} \pi_{q,v,p} \ . \tag{8}$$

$$W_{\mathrm{qv}} = \frac{\sum_{q=1}^{B_s} \sum_{v=0}^{N} \sum_{p=0}^{N-v} q\pi_{q,v,p}}{\lambda_{\mathrm{v}}(1-P_{\mathrm{bv}})} \ . \tag{9}$$

$$T_{\mathrm{h}} = \lambda_{\mathrm{p}}(1-P_{\mathrm{bd}}) \ . \tag{10}$$

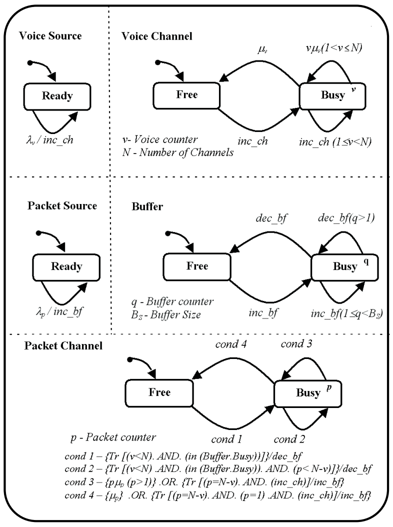

Fig. 1. Statecharts specification of the resource allocation scheme 1

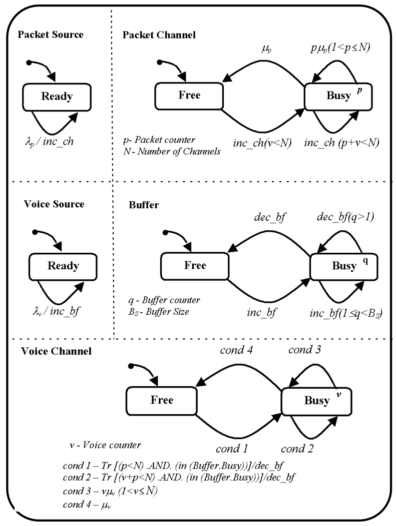

Fig. 2. Statecharts specification of the resource allocation scheme 3

5 Performance Evaluation

One cell with 8 radio channels is considered. One radio channel will used for signaling. So seven traffic channels will be available ($N = 7$) [2]. The buffer size is set to be 7. All GPRS data packets have the same priority in addition to carrying their service out in a single slot manner. According to literature the GPRS size packet is exponentially distributed with mean 2 x 13.4 kbit, resulting in a mean service time of 2 seconds (s) for CS-2, while the mean GSM voice call holding time is set to be 180 s [5]. The GSM/GPRS traffic load varies from 2.5 to 7.5 Erlang each. The confidence level used in the simulation runs was 95 %.

Regarding voice service, it may be seen in Fig. 3 that resource allocation scheme 3 outperforms scheme 1 and 2. Also, scheme 1 has lower blocking probability of GSM voice call than scheme 2 because there are no radio channels dedicated to GPRS. In Fig. 4 it is showed that a GSM voice call has to wait approximately 1 minute to be served for higher values of GSM/GPRS traffic load in scheme 3. Regarding to data service, it may be seen from Fig. 5 to Fig. 8 that the resource allocation 2 outperforms 1 and 3. It happens because there are some radio channels dedicated to carry out data traffic. In addition, resource allocation scheme 3 has the worst performance for data services, because the GPRS data packets are only served if there are available radio channels.

6 Conclusions

In this paper it is proposed a new analytical approach to deal with voice and data integration in wireless network putting together the formal method Statecharts

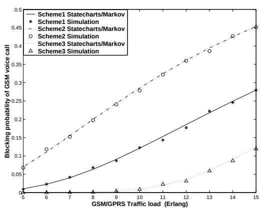

Fig. 3. Blocking probability of GSM voice call vs GSM/GPRS traffic load

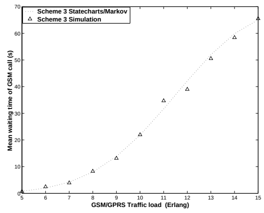

Fig. 4. Mean waiting Time of GSM voice call vs GSM/GPRS traffic load

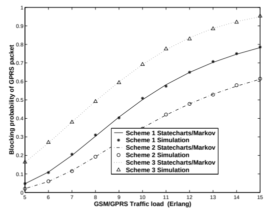

Fig. 5. Blocking probability of GPRS data packet vs GSM/GPRS traffic load

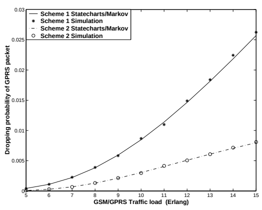

Fig. 6. Dropping probability of GPRS data packet vs GSM/GPRS traffic load

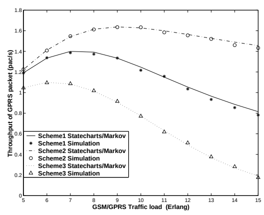

Fig. 7. Mean throughput of GPRS data packet vs GSM/GPRS traffic load

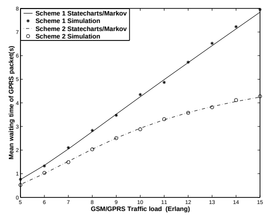

Fig. 8. Mean waiting Time of GPRS data packet vs GSM/GPRS traffic load

and a CTMC. Regarding GSM/GPRS networks, it must be notice that a trade-off has to be established to satisfy both data service QoS and voice service QoS. Possible enhancement in this model follows the following direction: multiclass queueing system with non exponential service time and inter arrival time of data packets in order to characterize a environment of 3G wireless networks.

References

1. Lindermann, C., and Thummler, A.: Performance Analysis of the General Packet Radio Service, 21st International Conference on Distributed Computing Systems (2001) 673–680
2. Lin, P., Lin., Y.B.: Channel Allocation for GPRS, IEEE Transaction on Vehicular Technology, Vol. 50, No. 2 (2001) 375–387
3. Yacoub, M. D.: Wireless Technology: Protocols, Standards, and Techniques, CRC Press (2002)
4. Harel, D.: Statecharts: a visual formalism for complex systems, Science of Computer Programming, Vol. 8 (1987) 231-274
5. Chen, W.Y., Wu, J.L.C., Lu, L.L.: Performance Comparision of Dynamic Resource Allocation With/Without Channel De-Alloccation in GSM/GPRS Networks, IEEE Communication Letters, Vol. 7, No. 1, (2003) 10–12