GPRS Systems Performance Analysis

Fátima de Lima Procópio Duarte, Antonio A.F. Loureiro,
Leonardo Barbosa e Oliveira, Cláudio Márcio de Souza Vicente
Federal University of Minas Gerais, Belo Horizonte, MG, Brazil

Abstract— **The increasing interest on the possibility of accessing information anytime, anywhere, associated with the development of modern portable equipments, is stimulating the mobile network evolution. This is a gradual evolution, from the firt mobile network generation, 1G, towards the fourth generation, 4G, passing through 2G, 2.5G, and 3G. Higher video, voice and image transmission capacities are reached on each generation. GSM (*Global System for Mobile Communications*) is a 2G technology, while GPRS (*General Packet Radio Services*) is a 2.5G technology. This work compares the capacity of both GSM and GPRS networks. Experimental results obtained through simulation are described, in which the number of mobile stations as well as the traffic generation rate are varied. The main results show that with the GPRS there is a greater number of mobile stations transmitting simultaneously, as it allows a multi-slot allocation. There is also an performance analysis of the GPRS environment. The delay, jitter and throughput are the performance parameters analyzed. The GPRS ideal empirical release time is indicated.**

I. Introduction

Consulting personal information and work anywhere, anytime, are the major mobile computing advantages. As the mobile networks become more popular, the demand for them becomes bigger as well. Multimedia applications, for example, need high bandwidth for data, voice and image transmission. In order to solve this demand for higher capacities with quality of service as a goal, the mobile networks are under constant evolution.

The first cellular system generation, 1G, uses FDMA technology and it is associated with analog systems. The AMPS (*Advanced Mobile Phone Service*) is an example from this generation. The 2G cellular networks are based on TDMA and CDMA. The IS-136 (*Interim Standard*), D-AMPS (*Digital Advanced Mobile Phone Service*) and GSM (*Global System for Mobile Communications*) are examples from this generation. HSCSD (*High Speed Circuit Switched Data*), GPRS (*General Packet Radio Service*) and EDGE (*Enhanced Data rates for GSM Evolution*) represent an evolution towards 3G technologies. HSCSD is the circuit switched GSM network evolution reaching 57.6 kbits/s rates, obtained from a four-consecutive-time-slot concatenation. The GPRS allows packet switching and multi-slot operations per user. EDGE represents a big evolution towards 3G and it is considered a “2.75G” technology. Its transmission rate reaches 384 kbits/s. It does not use the conventional modulation system GMSK (*Gaussian minimum-shift keying*) that is used by HSCSD and GPRS. It uses the 8PSK (*eight-phase-shift keying*), witch allows higher air interface transmission rates. The goal of 3G systems is to provide better voice, data and image transition services. ITU’s (*International Telecommunication Union*) 3G standardization project is known as the IMT-2000 (*International Mobile Telecommunications by 2000*) [1], [2]. ITU [3] proposed a 3G system that guarantees global roaming with W-CDMA (*Wideband Code Multiple Access*) technology. CDMA2000 and UMTS (*Universal Mobile Telecommunication System*) are two of the main standardization systems submitted to ITU [4]. While higher capacities can be obtained basically by a bigger spectral availability or by new air interfaces, data transmission can be done through an extension over the 2G networks, characterizing the 2.5G technologies. In many cases it is possible to provide better rates just with some software and addition of network nodes. 2.xG technologies, such as GPRS, HSCSD, and EDGE satisfy higher rate requirements in 2G networks. Being a circuit switched system, GSM offers a transmission rate of just 9.6 kbits/s, which limits its services and supported applications. GPRS is an efficient system that introduces packet switching over the GSM air interface. It allows 170 kbits/s rates and it is ideal to burst transmissions, typical in Internet applications.

GPRS networks have an efficient radio resource multiplexing system, allow system utilization by a great number of users, and are currently being installed all over the world. Questions related to Quality of Service (*QoS*) and to bandwidth allocation policies are still opened. The GPRS specification offers possibilities of parameter choices by the system operator, which directly affects the network performance. Thus, the GPRS performance analysis under different scenarios is fundamental to parameter optimization, with a consequent resource utilization improvement.

The main goals of this work are the evaluation of the GPRS performance for different parameters and scenarios as well as the comparison of the capacity of GSM and GPRS systems. We have used the ns-2 (*Network Simulator*) tool [5] in the performance analysis. The simulator ns-2 has been largely employed in the evaluation of different communication protocols in the literature.

The results indicate that, by having a smaller time to liberate idle slots, the transmission capacity grows. We have obtained a greater number of users who could transmit simultaneously at a higher transmission rate. We show that with four TDMA frames to free an idle channel, the GPRS performance is superior to GSM’s one. The GPRS allows 19 users to share a channel, whereas GSM allows only seven.

The rest of this paper is organized as follows. Section II presents an overview of GPRS. Section 3 describes the ns-2 GPRS simulator. The simulation model and experimental results are presented in Section 4. Finally, Section 5 concludes the paper.

II. GPRS

GPRS is a mobile network technology based on packet data transport and routing, considerably reducing connection estab-

The authors are with the Computer Science Department, Federal University of Minas Gerais, Belo Horizonte, MG, Caixa Postal 702, 30123–970 Belo Horizonte, MG, Brazil, Phone: +55 31 3499-5860 Fax: +55 31 3499-5858. E-mails: {fatima,loureiro,leob,cmsv}@dcc.ufmg.br.

lishment and finishing time. Spectral efficiency can be obtained through the simultaneous distribution of packets to multiple users and through the possibility of slot utilization by more than one user, thus obtaining higher rates. The small burst transmission requests intercalated with long idle periods are more indicated to this kind of technology than to one that is circuit oriented.

GPRS needs some modifications on the GSM architecture to make data encapsulation possible. For packet switching addition, two new nodes are added to the GSM structure, as depicted in Fig. 1 [8].

- **SGSN** (*Serving GPRS Support Node*): It has security, access control and mobile units' location-aware functions.
- **GGSN** (*Gateway GPRS Support Node*): It is an interface node with PDNs (*Packet Data Networks*) like Internet and X.25. It provides data routing to and from mobile stations, and is connected to SGSN through a GPRS core network based on IP.

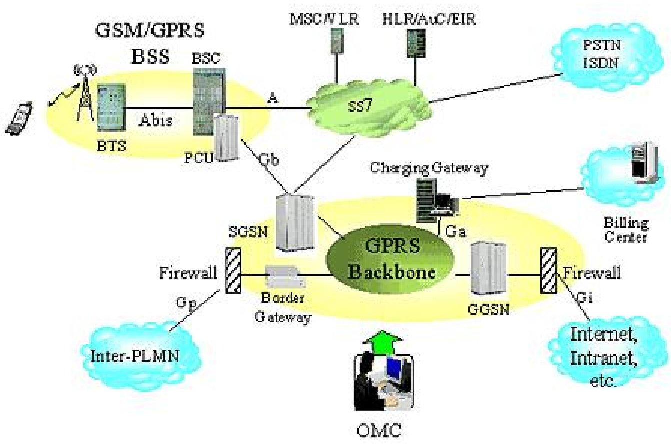

Fig. 1. GPRS System Architecture

Packet switching indicates that radio resources are used only when users are really receiving or sending data. It is not necessarily to keep a dedicate channel to a mobile user during a long time. Many users can share it concurrently. This indicates that, with GPRS, a great number of users can share the same cell bandwidth. The exact number of simultaneous users depends on the kind of applications and the manner that data is being transmitted.

A. GPRS Stack Protocols

GTP (*GPRS Tunneling Protocol*) is a protocol that performs IP and X.25 packet data encapsulation and tunneling between SGSN and GGSN. GTP uses TCP for X.25, or UDP for IP, for example. IP is the GPRS backbone network layer protocol.

SNDCP (*Subnetwork Dependent Convergent Protocol*) is between SGSN and an MU (Mobile Unit). It maps network layer protocol characteristics to the LLC (*Logical Link Protocol*) layer. LLC provides a logical link layer between the MU and the SGNS.

The physical layer and the DLL (*Data Link Layer*) perform the radio communication between an MU and the GPRS network. The DLL is divided into LLC and RLC/MAC (*Radio Link Control/Medium Access Control*) between an MU and a BSS (*Base Station System*),

The LLC is responsible for flow control, ciphering, sequence control, and fragmentation of superior layer PDUs before handling them to RLC. It can be used with or without confirmation,

RLC is responsible for segmentation and reconstruction of LLC PDUs, and controls the QoS. The MAC layer is responsible for data transmission through the radio interface. It multiplexes a physical channel between many MUs and allows that an MU use in parallel many physical channels, through allocation of multiple time slots.

B. The GPRS Air Interface

The GPRS physical channels are based on the same GSM TDMA structure, sharing time slots and frequencies (1800 and 1900 MHz). A time slot can be used either by GPRS or by GSM. One or more channels from the GSM pool can be dedicated to GPRS traffic. These channels are called PDCH (*Packet Data Channel*). The basic PDCH transmission unit is a radio block of 456 bits, which is transmitted on 4 time slots, measuring 4 TDMA frames. One PDCH is structured in multiple frames, each with 52 TDMA frames, allowing 12 radio blocks to compose a multiple frame.

It is possible to have more users than PDCHs transmitting data simultaneously because the PDCHS are allocated dynamically, during idle periods. Besides this, an MU can transmit over multiple parallel PDCHs. This GPRS characteristic allows higher transmission rates and better performance when compared to GSM.

III. The GPRS Module in NS

In this section, we describe how the network stack protocol of the wireless model was implemented in the ns simulator. We start by briefly describing the functions of those modules.

LL (*Link Layer*). It is responsible for simulating the data link layer protocols. A significant function of the layer is to set the MAC destination address in the MAC header of the packet. In the current implementation, the ns simulator simply passes packets down to and up from the MAC. In addition, it has an ARP (*Address Resolution Protocol*) module connected to it which resolves all IP to hardware MAC address conversions.

ARP. This module receives queries from the Link Layer. If the ARP has the MAC address for the destination, it writes it into the MAC header of the packet. Otherwise, the protocol broadcasts an ARP query, and caches the packet for a period of time. For each unknown destination MAC address there is a buffer for a single packet only. In case any additional packets are to sent to the same destination through ARP, an overrun occurs.

IFQ (*Interface Queue*). It is a queue which gives priority to routing protocol packets. It also supports a filter over all packets in the queue that enables it to remove unwanted ones.

MAC. The MAC protocols implemented are 802.11, 802.3, CSMA and *multihop*.

The focus of the implementation is the simulation of the LL, RLC and MAC Layers, and the management of radio resources.

Mobile nodes can be configured as GPRS MU or GSM MU. However, while for the former one, they (MU´s) release slots when there is no active packet transfer, the latter one retains their slots until the end of the call. Each time, only one frequency can be used (transmit/receive packets) by an MU. In contrast, the BS can transmit/receive on many simultaneous frequencies.

In order to add these functionalities to the simulator, the RLC Layer has been introduced, and the LL and MAC Layers have been altered in the mobile structure of the ns. The features that were implemented are:

- LL: Fragmentation and re-assembly of user Layer PDUs and acknowledge mode as options; a *stop-and-wait* retransmit mechanism;
- RLC: Fragmentation and re-assembly of LL PDUs and a selective retransmit mechanism;
- MAC: Different *uplink* and *downlink* frequencies; each TDMA frame with 8 time slots; slot allocation by request and slot release.

In the ns, the size of a GPRS Radio Block (RB) is 200 bytes and it is transmitted over four slots — of 50 bytes each — in consecutive frames. It is transmitted 50 bytes—one (simulated) RLC PDU, in each slot (1 slot = 0.577 ms).

IV. Simulation Results

In this section, we describe experimental results for GPRS systems performance evaluation, using the ns-2 simulation tool. Several GPRS scenarios were modeled. The goal was the GPRS performance measurement and evaluation under some variables such as traffic generator, transport protocol, traffic load and slot release time.

Four types of experiments were performed with the following purposes: (A) evaluate the GPRS performance under distinct slot release time; (B) study the influence of traffic generator and the transport protocol type over the GPRS performance; (C) compare GSM and GPRS capacities and (D) measure the impact of increasing the traffic load on the channel delay, jitter and throughput.

Each simulation was executed during 20 to 40 seconds. In all scenarios only one channel was used - each one with 8 time slots - shared among MU's (Mobile Unit) and one BS (Base Station). The burst time and idle time parameters were fixed at 500 ms, the ns GPRS module default value.

Below, we describe each type of experiment performed and the results obtained.

A. Slot Release Time Variation

The GPRS ns module implements a mechanism that if an MU does not transmit during 4 consecutive TDMA frames, it's slot is released, so that it can be used by another MU. The release time varied was from 4 to 1 frames, allowing an increase in the channel transmission capacity. It was noted that with the release time of 2 TDMA frames, an increase in the channel capacity and in the GPRS performance were obtained. This change enabled a greater number of MU transmitting simultaneously as well as higher traffic generation rates. Table I shows these results.

Figures 2 to 4 show the network performance for the release time variation.

We can observe looking at Figures 2 to 4 that:

- Figure 2 shows that for the release times of 1 and 2 frames, the delay has a proportional increase to the number of nodes increase. But for 3 and 4 frames, it is not proportional. This can be explained by the fact that when there are more concurrent users, it is necessary to release idle slots as soon as possible.
- Figure 3 shows that the release times of 1 and 2 frames obtain the best performance when considering jitter.
- Figure 4 shows that the best throughput is obtained when the release time is 2 frames.
- Although 1 and 2 frames are good values for the release time, it is better to avoid the 1 frame release time, because it is not sufficient to detect an idle slot. This can be seen in Figure 4, that shows best throughput values for 2 frames.

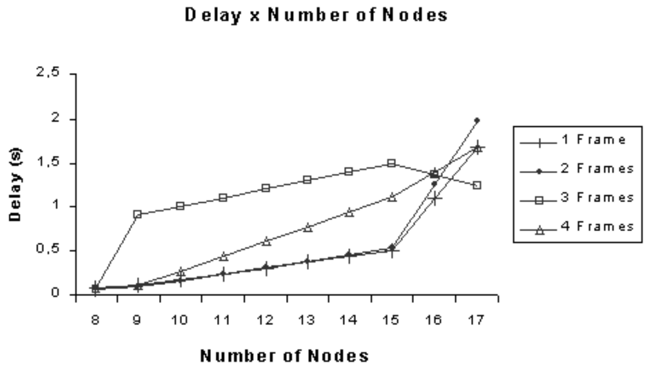

Fig. 2. Average Delay per Packet

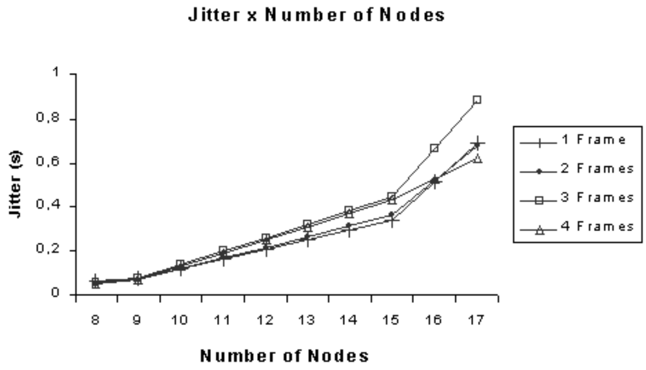

Fig. 3. Jitter

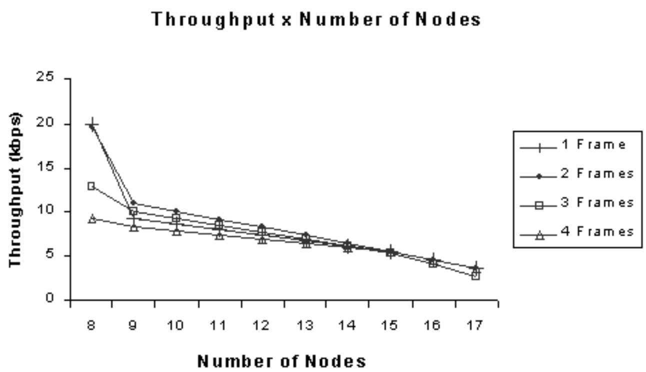

Fig. 4. Throughput

TABLE I
SLOT RELEASE TIME VARIATION PERFORMANCE

1 Frame						2 Frames					
MUs	Rate kbits/s	Delay	Jitter	Throughput kbits/s	Delivery Rate	MUs	Rate kbits/s	Delay	Jitter	Throughput kbits/s	Delivery Rate
8	22	0.0729	0.0599	19.91	90.5%	8	22	0.0634	0.0574	19.67	89%
9	10	0.1024	0.0755	9.3	93%	9	12	0.0866	0.0696	11.05	92%
15	6	0.5082	0.3418	5.5	91%	15	6	0.5343	0.3627	5.46	91%
17	4	1.6819	0.6925	3.68	92%	17	4	1.9880	0.6780	3.68	92%
18	2	0.8691	0.4538	1.95	97.5%	18	2	0.8942	0.5686	1.88	94%
3 Frames						4 Frames					
MUs	Rate kbits/s	Delay	Jitter	Throughput kbits/s	Delivery Rate	MUs	Rate kbits/s	Delay	Jitter	Throughput kbits/s	Delivery Rate
8	14	0.0695	0.0586	12.96	92%	8	10	0.0734	0.0502	9.33	93%
9	11	0.0912	0.0758	10.06	91%	9	9	0.1034	0.0687	8.35	92%
15	6	1.494	0.4434	5.38	89%	15	6	1.1136	0.4321	5.45	91%
17	3	1.2398	0.8851	2.66	88%	17	4	1.6819	0.625	3.68	92%

B. *Application and Transport Protocol Variation*

In these experiments, we assess the GPRS performance when applications generate CBR or Exponential traffic using UDP and TCP transport protocols. Four different scenarios were simulated: (1) Exp/TCP: Exponential traffic with TCP; (2) Exp/UDP: Exponential traffic with UDP; (3) CBR/TCP: CBR traffic with TCP; and (4) CBR/UDP: CBR traffic with UDP. Table II shows the results obtained.

Comparing CBR with exponential traffic, we can observe that the exponential traffic always has a better traffic rate and more MUs transmitting simultaneously. We can also observe that with UDP the traffic rates are greater than with TCP. The throughput obtained with UDP is higher than that obtained with TCP for any number of MUs and any kind of application traffic (CBR or exponential). The choice of transport protocols does not have any influence over the system's maximum capacity measured in MUs simultaneous transmission. The exponential traffic over UDP scenario obtained the best performance metrics during simulations.

C. *Comparison of GPRS and GSM Capacities*

GPRS allows 19 users to share a single channel since it has new allocation and multiplexing mechanisms. GSM allows only 7 users, which is the number of slots for a channel data transmission. When there are 8 to 19 users transmitting simultaneously, the traffic rate gets worse, as Table I shows.

GPRS accepts almost a 170 kbits/s traffic, but due to memory constraints it was possible to simulate the maximum traffic of 30 kbits/s. For a scenario with 7 MUs generating a traffic of 30 kbits/s, after 20 seconds we simulated a transmission at 3 MUs. The other four continued transmitting during another 20 seconds. The GPRS throughput was 10% higher than that obtained with GSM. This can be easily explained by the fact that GPRS utilizes three slots released while GSM does nothing with them.

D. *Load Increase Impact over GPRS*

We studied the impact of the load increase done by a progressive simulated traffic increase over the channel. The experiments were executed with the number of users equal to the number of available slots (7) and with the number of users greater than the number of available slots. For each experiment, the traffic generation rate was varied from 2 to 29 kbits/s. The GPRS performance was measured by the delay, jitter and throughput parameters. For the load variation, the type of traffic was varied too, as well as the transport protocol.

Figures 5 to 15 show the results when the network is under the maximum load, measured by the number of simultaneous user and transmition rate.

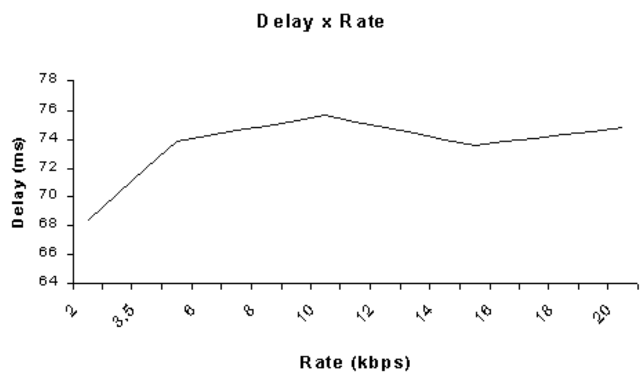

Fig. 5. Average Delay per Packet for 8 MUs

Based on these experiments, we have the following analysis:

- Figure 5 shows that there is an increase in the delay when increasing the network load with higher rates. There is a point in the graph (16kbps/s) that gets a lower delay. This can be interpreted by a point after some retransmissions.
- Figure 6 shows that the jitter is almost constant for any transmission rate.
- Figure 7 shows that the throughput increase is linear with the

TABLE II
MAXIMUM CAPACITY REACHED THROUGH SIMULATIONS

Exponential Traffic over TCP					Exponential Traffic over UDP				
MUs	Rate kbps/s	Throughput kbps/s	Loss kbits	Delivery %	MUs	Rate kbps/s	Throughput kbps/s	Loss kbits	Delivery %
9	24	10.55	13.45	43.98	9	28	14.76%	13.24	52
15	13	5.54	7.46	42	15	14	7.28	6.72	52
17	10	5.63	4.37	56	17	11	10.56	0.44	96
19	10	5.92	4.08	59	10	9.74	0.26	97	
CBR Traffic over TCP					CBR Traffic over UDP				
MUs	Rate kbps/s	Throughput kbps/s	Loss kbits	Delivery %	MUs	Rate kbps/s	Throughput kbps/s	Loss kbits	Delivery %
8	8	7.46	0.53	93	8	10	9.33	0.66	93
9	8	7.5	1.5	83	9	9	8.34	0.65	92
15	3	2.99	0.005	99.8	15	6	5.45	0.54	90
17	2	1.87	0.12	93	17	4	3.75	0.24	93

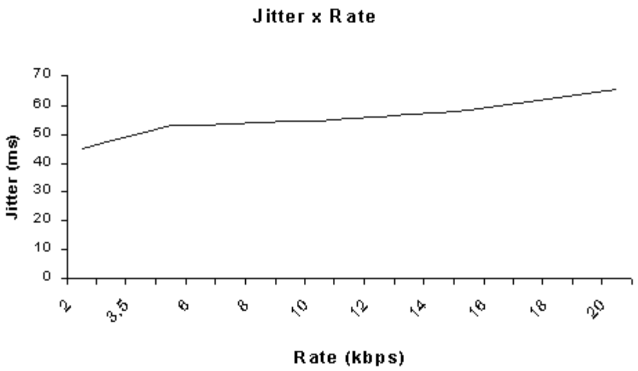

Fig. 6. Jitter for 8 MUs

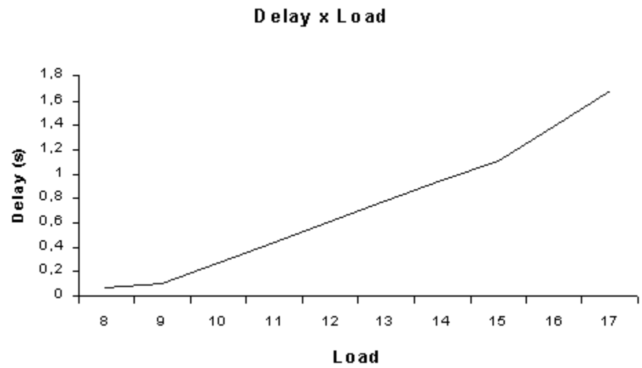

Fig. 8. Average Delay per Packet for CBR Traffic over UDP

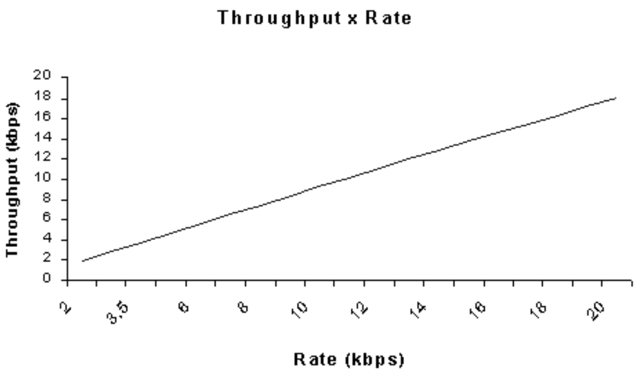

Fig. 7. Throughput for 8 MUs

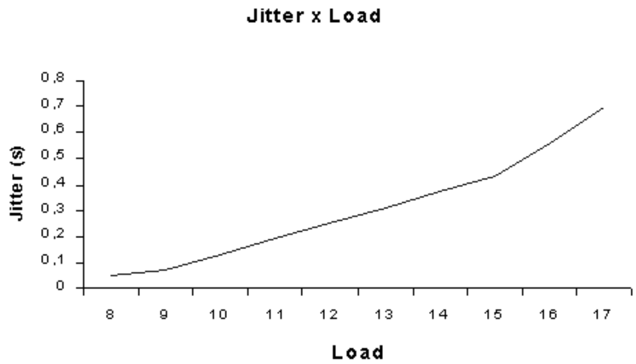

Fig. 9. Jitter for CBR Traffic over UDP

transmission rate for a small number of MU's(8).

- The average packet delay tends to be high when the release time is equal to one TDMA frame and the transmission rates are high, because there are more collisions during transmission requests. It is stable until the rate reaches 20 kbits/s. For an intensive traffic, Fig. 5, the average packet delay is lower (between 54 and 64 ms) than for a 7 MUs traffic (between 68 ms and 78 ms).
- Delay, Jitter and Throughput gets worse when the number of users gets bigger. For CBR traffic, the throughput is almost the same as the traffic generation rate, when there are few users, but it gets worse when the number of users increases. For EXP traffic, the delay, the jitter and the throughput are get worse when the number of users increases, but they don't present a linear

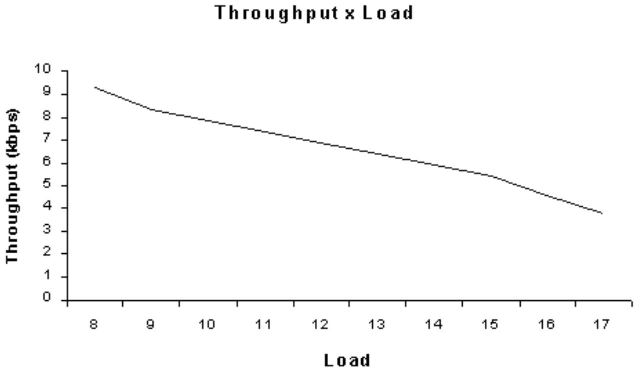

Fig. 10. Throughput for CBR Traffic over UDP

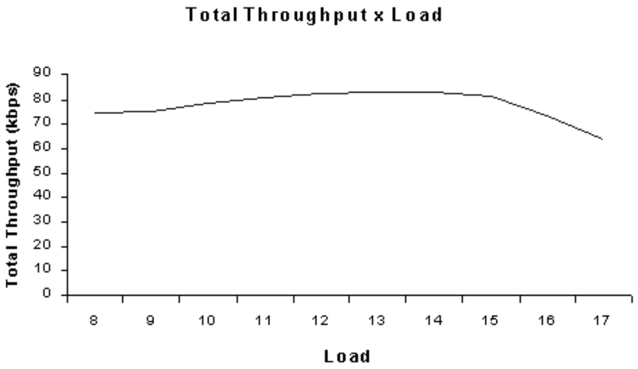

Fig. 11. Total Throughput for CBR Traffic over UDP

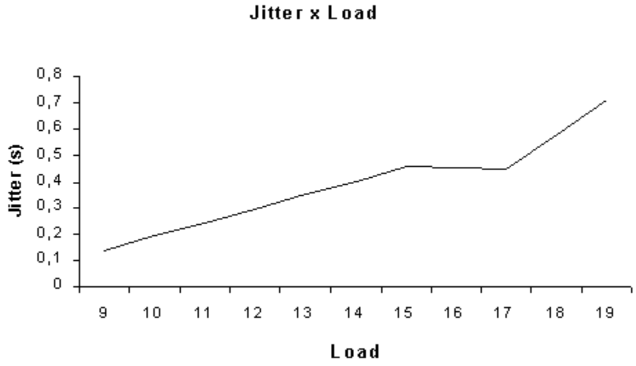

Fig. 13. Jitter for Exponential Traffic over TCP

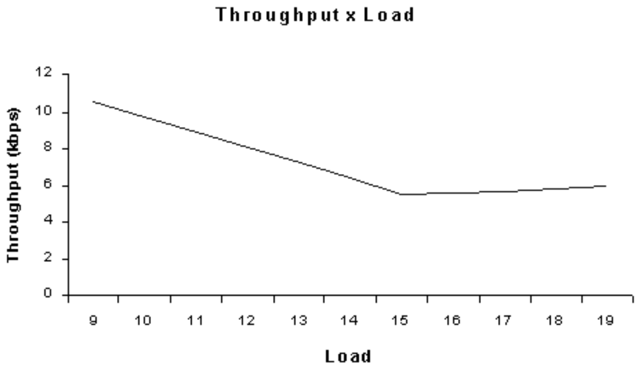

Fig. 14. Throughput for Exponential Traffic over TCP

curve. As the EXP traffic is not homogeneously distributed during time, the network performance reflects this.

• Figures 11 and 15 show the total throughput obtained at the BS. These values reflect the maximum processing capacity at the BS.

V. Conclusion

This paper presented a simulation model for an GPRS environment, using the ns-2 simulation tool. The performance evaluation of GPRS in different scenarios, as well the comparison between the capacity of GPRS and GSM were the focus of this work.

The main results are highlighted below:

• Through a release/allocation mechanism of idle slots for an user, GPRS presents better performance than GSM. A result was obtained in which a single frequency channel was shared amongst 19 simultaneous users, whereas in GSM the number of users was exactly the number of slots — in this case, 7.

The GPRS improved throughput rate by 10% over GSM due to the fact that it made use of released slots from MUs that inter-

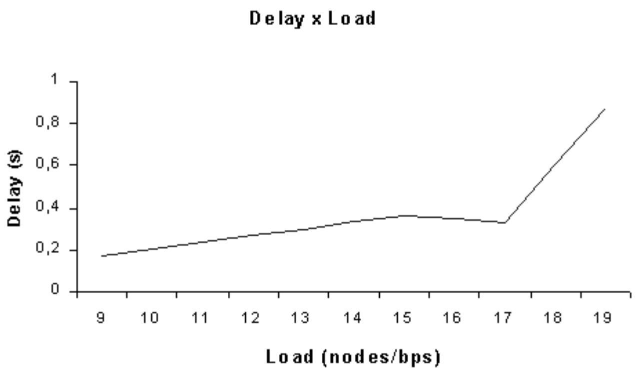

Fig. 12. Average Delay per Packet for Exponential Traffic over TCP

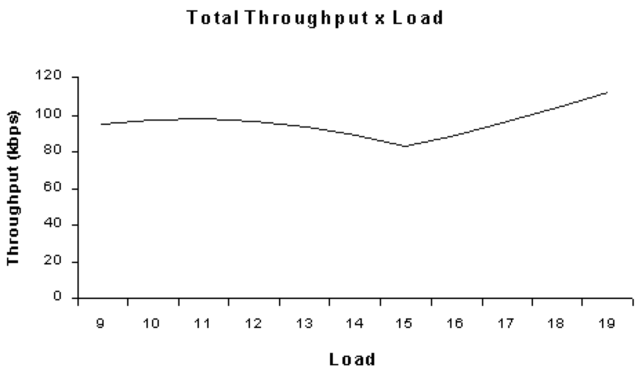

Fig. 15. Total Throughput for Exponential Traffic over TCP

rupted their calls before the end of the simulation.
Since GSM MU holds a slot previously allocated during all connections, idle slots cannot be reallocated as it is in GPRS. Consequently, the use of radio resources is restricted.

- In respect to the release time of an idle slot in GPRS, we can see that under the workload of the maximum number of users and traffic generation rate, the best option for the slot release time is 2 frames.
- When using the same structure, the GPRS performance is similar to GSM when there are few users transmitting.
- The transport layer protocol does not have any influence in the number of mobile units that can transmit simultaneously. But the kind of traffic generated by the application does. The exponential traffic, in conjunction with UDP protocol, has presented the best performance of the experiments. So this paper recomends the UDP transport protocl as the GPRS one.
- There are some saturation points for any load increase over a GPRS channel. This paper tried to recognize this channel performance under load variation. Some results indicated that the maximum number of users for a GPRS channel is 19, but with a transmission rate of 10 kbps, while for 8 users the maximum rate allowed by the simulation system was 22 kbps.

Some suggestions of further work are the implementation of the GPRS backbone and the incorporation of an QoS architecture specification. EGPRS will also be incorporated in our future studies.

REFERENCES

[1] Lee, Lin-Nan and Sun, Feng-Wen and Karimullah, Khalid and Eroz, Mustafa and Hammons, Roger. Third genmeration wireless communication technologies. In Rajamani Ganesh, Kaveh Pahlavan, and Zoran Zvonar, editors, *Wireless Multimedia Network Technologies*, chapter 2, pages 24–44. Kluwer Academic Publishers, 2000.

[2] CDMA Development Group. 3G Fact Sheet. http://www.cdg.org/3gpavilion/overview.asp, June 2000.

[3] ITU. IMT-2000. http://www.itu.int/imt/.

[4] Mohemad Almaimani, Puntrika Korsuwana, Michael Twine, and Joseph Mendelsohn. IMT-2000: A Comparative Analysis of cdma2000 and UTRA.

[5] The VINT Projetc. The ns Manual. http://www.isi.edu/nsnam/ns/ns-documentation.html, September 2001.

[6] Ms. Richa Jain. GPRS Simulations using ns-Network Simulator. Dual Degree Dissertation of the India Institute of Technology, June 2001.

[7] Kelvin Lopes Dias and Djamel Fauzi Sadok. Internet Móvel: Tecnologias, Aplicações e QoS. In *Minicurso - Simpósio Brasilerio de Redes de Computadores*, Florianópolis, S.C., Brazil, May 2001.

[8] Usha Communications Technology. GPRS - General Packet Radio Service. White Paper on http://www.iec.com.