Mixed Traffic Models for Dimensioning Radio Resources in GSM/GPRS Networks

CORNEL BALINT(1), GEORGETA BUDURA(1), ADRIAN BUDURA(2)
(1)Communication Department
"Politehnica" University of Timisoara,
Bd. V. Parvan. No. 2
(2)ETA2U Timisoara,
ROMANIA
cornel.balint@etc.upt.ro, georgeta.budura@etc.upt.ro, abudura@eta2u.ro

Abstract: - Dimensioning radio resources in GSM/GPRS networks is particularly important because of the presence of mixed traffic: voice and data. Appropriate models are required especially when the implemented resources allocation strategy is Partial Partitioning. In this paper we propose three mixed traffic models suitable for dimensioning cells using PP scheme. In order to validate our models we define and compare several performance parameters: blocking probability for voice, throughput (total and per user), cell utilization and blocking probability for data. The models based on combined FR and HR voice traffic technique and the DHR voice technique implement an optimal use of resources based on half-rate mobiles capability and re-packing mechanisms. The mixed models we proposed could be used for dimensioning radio resources in GSM/GPRS networks in order to ensure the adequate QoS level for each type of service according to the voice and data traffic loads.

Key-Words: - GSM/GPRS, mixed traffic model, Erlang-B law, blocking probability, Engset law, throughput

1 Introduction

The integration of General Packet Radio Service (GPRS) and Enhanced GPRS into the GSM system raises many problems. The traditional GSM system operates based on circuit-switching technology. A GSM voice call needs the assignment of a single circuit, also called time-slot (TS), for its entire duration because it is a time-division-multiplexing scheme.

The GPRS network allows an end user to send and receive data in packet transfer mode within a *public land mobile network* (PLMN) without using a permanent connection between the *mobile station* (MS) and the external network during data transfer. This way, GPRS optimizes the use of network and *radio resources* (RRs) since, unlike circuit switched mode, no connection between the MS and the external network is established when there is no data flow in progress. The principles defined for the *Global System for Mobile Communications* (GSM) radio interface were kept for GPRS, since the notions of time slot, frame, multiframe, and hyperframe have not changed for GPRS as compared with GSM. The GPRS network, based on PS technology, with a variable throughput is designed for supporting several types of data traffic such as Wap, Web, E-Mail, etc.

Sharing resources between different users and different services is a key concept for GSM/GPRS resources dimensioning.

A multiservice traffic model has to be developed to comply with different interfaces and constrains, like statistical multiplexing and high load threshold applied.

The traffic model must lead to effective dimensioning methods, such as to avoid congestion cases or network over dimensioning.

Lots of previous works have studied traffic modeling in GSM/GPRS networks trying to establish different performance parameters needed for dimensioning purposes. An important element of these networks is the radio interface resources. Dimensioning rules have to be developed to plan and estimate the radio capacity needed for the predicted amount of data users when the radio resources are shared between circuit and packet switched services.

It is well known that GSM operators have dimensioned their networks for voice service in terms of offered voice traffic and blocking probability. The reference model for this system is the Erlang-B formula [1]. This formula gives the proportion of calls that are blocked as a simple function of system capacity and voice traffic intensity.

Usually the data traffic is characterized by bursts and is application dependant. A communication session may last for an extended period of time with intermittent packet transmissions.

Another major problem of dimensioning GSM/GPRS networks is the choice of strategy to partition the available cell capacity between traditional GSM and new GPRS services.

The Radio Resources Manager (RRM) is in charge of optimizing the usage of radio resources, based on a specific resource sharing algorithm.

Three main static resources sharing schemes can be distinguished [2]:

- In the first one, all radio channels are shared between voice and data, as shown in Fig.1. It is called Complete Sharing (CS).

TS (Voice + Data)

Fig.1 Time slots allocation with CS scheme

- In the second one, called Complete Partitioning (CP), time-slots are divided into two sets as indicated in Fig.2 and each type of traffic is allowed to use only its dedicated set.

TS_V	TS_D

Fig.2 Time-slots allocation in CP scheme

In this case the total number of time-slots is given by relation:

$$TS = TS_V + TS_D \tag{1}$$

- The third allocation scheme (Fig.3), known as Partial Partitioning (PP), contains the following channel sets: two sets each one being reserved for strict usage of its dedicated traffic: voice or data and one set shared between voice and data traffic depending on voice and data traffic loads.

TS_V	TS_{VD}	TS_D

Fig.3 Time-slots allocation in PP scheme

According to Fig.3 we have the relation:

$$TS = TS_V + TS_{VD} + TS_D \tag{2}$$

The PP scheme offers many advantages: first, reserving a set of time-slots for each type of traffic allows guaranteeing, as in CP a minimum QoS for each type of traffic. Second, the PP scheme provides a better efficiency than CP which is not suitable for maximizing radio utilization, especially when dealing with a highly varying demand.

Due to these advantages, the PP resource sharing algorithm is widely implemented in a large number of deployed GSM/GPRS networks.

In order to improve the number of voice users that the network can manage, different strategies could be applied in the voice time-slot assignment.

Several papers have been published on traffic modeling and performance evaluation in GSM/GPRS networks. The major works in this field are based on analytical models using queuing theory and continuous-time Markov chains, and assuming an infinite number of users in the cell [1], [3] - [6].

In [7]-[9] analytical models based on discrete-time Markov chains have been proposed and a single type of traffic is considered. It is assumed to be generated by a finite number of users and modeled by an Erlang-like law.

In [2] Dahmouni et al. present an approach for dimensioning GPRS networks based on the modified Engset model.

Recently published papers address the problem of improving the quality of service and the performance parameters based on different strategies regarding the radio resources allocation [10] - [15].

In this paper we implement a mixed voice and data traffic model and define several performance parameters suitable for dimensioning purposes. The model is based on the PP time-slots allocation scheme witch consider the resource sharing between voice and data. In order to optimize the resources used by voice users, we implement three different models for voice traffic taking into consideration the full and half rate capabilities of the mobiles. For data traffic analysis we consider the modified Engset model. Based on the three voice traffic model and on the data traffic model mentioned before, we implement three mixed traffic models. We compare these mixed models based on several performance parameters:

- for voice: blocking probability;
- for data: total throughput, throughput per user, blocking probability and cell utilization.

The mixed models we proposed could be used for dimensioning radio resources in GSM/GPRS networks in order to ensure the adequate QoS level for each type of service according to the voice and data traffic loads.

2 GSM/GPRS System Description

Our paper considers a single cell which supports two types of traffic: GSM voice calls and GPRS data flows.

In traditional circuit-switched GSM networks, on each frequency carrier a 200 kHz bandwidth is shared between 8 voice calls.

GPRS data traffic uses the same radio interface as GSM voice calls, hence, radio resources available in the cell have to be shared among GSM and GPRS traffics. In the GPRS technology a mobile station can use several time-slots simultaneously for one application, in order to perform its transmission with a higher throughput. Each time-slot can be shared among several users by assigning different Temporary Flow Identities (TFI) to the mobile phones. Each TFI identifies a GPRS physical connection called Temporary Block Flow (TBF). Up to 32 TFI's can be allocated per TDMA frame. Data flows are multiplexed by a PCU-based scheduling algorithm. In addition to time-slot partitioning, the GPRS system also allows for time-slot aggregation: for a single mobile user the system can allocate up to *d*-time-slots simultaneously for downlink and up to *u*-time-slots simultaneously for uplink, depending on mobile station capability class ($d+u$).

The choice of the number of TBF's that a PDCH can have in uplink and downlink depends on the operator's choice. For example, in the Alcatel-Lucent technology up to 6 uplink and 10 downlink TBF's are allocated per PDCH.

Our study is focused on the radio allocator which distributes the downlink radio channels among voice calls and GPRS data flows.

When modeling our system we consider the following parameters:

- TS : the number of time-slots of the TDMA partitioned into a contiguous set of TS_V time-slots dedicated to voice calls, TS_{VD} time-slots shared between voice and data and TS_D time-slots dedicated to GPRS; time-slots used by data $TS_D + TS_{VD}$ are on a single TDMA which has a total number of 8 time-slots.
- d (resp. u): is the number of time-slots that can be used simultaneously for downlink (resp. uplink) traffic. All GPRS mobiles have the same radio capability, denoted $d+u$.
- The RLC radio block size represents an important parameter for the GPRS system. In the downlink, IP packets are fragmented and encapsulated into LLC frames by the SGSN. The payload size of each radio block depends on the coding schemes, i.e., the applied radio error protection. The GPRS standard defines four Coding Schemes.

The corresponding sizes of the RLC block radio are indicated in TABLE 1. We have also mentioned the data rate associated with each coding scheme.

TABLE 1

GPRS Coding Schemes	CS-1	CS-2	CS-3	CS-4
RLC block radio (*bytes*)	23	33	39	53
Data rate: $\mu_{GPRS}(kbits/s)$	9.05	13.4	15.6	21.4

- We assume that in the case when there is no available channel, a voice call will be lost on arrival.
- Voice calls have a preemptive priority over data flows on the shared part of the TDMA due to the fact that they generate the largest amount of the revenue in most actual operating systems.
- As a consequence, if all TS_V time-slots dedicated to voice are occupied and all TS_{VD} time-slots are in use with at least one of them allocated to data, then one time-slot assigned to GPRS traffic in the shared part of the TDMA will be reallocated to voice on the arrival of a GSM request.

3 System Models

With Partial Partitioning strategy the available time slots (TS) of the TDMA are partitioned into TS_V time-slots dedicated to voice, TS_D time-slots dedicated to data and TS_{VD} time slots shared between voice and data with a total preemptive priority of voice over data on the shared part.

The system we have implemented contains different models dedicated to voice and data. It is also able to manage the interaction between voice and data according to the priority of voice calls over data calls.

We report on the performance of three system models using the same data model and three different voice models.

3.1 Data Traffic Model

Data traffic can be considered at different timescale levels:

(i) the packets level where the elementary quantities are carried by the network;

(ii) the flow level which is a concept close to the application;

(iii) the session level which is a succession of flows that belong to the same application.

In this paper the data traffic is considered at the flow level timescale. A session is modeled as a series of flows (page downloads) separated by inactivity periods (think times) with no data transfer. The traffic generated by the users represents an ON/OFF process as indicated in Fig.4 [10].

Data traffic is modeled under the assumption that there is a fixed number N of data mobiles in the cell. Each mobile is doing an ON/OFF traffic with an infinite number of pages:

- ON periods correspond to the download of an element like a WAP, a WEB page, an email, a file, etc. Its size is characterized by a discrete random variable X_{on}, with an average value $E[\sigma]$.
- OFF periods correspond to the reading time of the last downloaded element, which is modeled as a random variable T_{off} with an average value of $E[\tau]$ seconds.

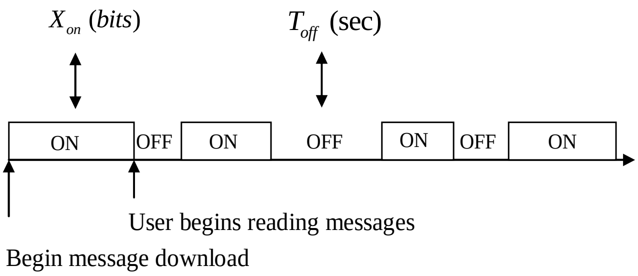

Fig.4 ON/OFF process associated to a session level

- The maximum number of GPRS users in active transfer is given by:

$$n_{\max}(TS_D) = \min(N, 32, mTS_D) \tag{3}$$

m- is the maximum number of users that can use a single time-slot. The typical value we used is $m = 7$.

The data traffic process is based on the Engset model [2] and includes particular specifications as indicated in Fig.5.

This stochastic process describes the number of active users at any point in time and represents a finite state space.

It follows from Fig.5 the transition rate from state j to j+1, λ_j according to eq. (4):

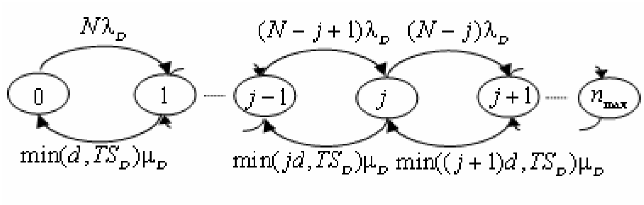

Fig.5 The Engset model applied to data traffic process

$$\lambda_j = (N-j)\lambda_D = (N-j)\frac{1}{E[\tau]}, \quad for\ j = 0,1,\ldots n_{\max}-1 \tag{4}$$

We can express the transition rate of the death process as:

$$\mu_j = \min(jd, TS_D)\mu_D = \min(jd, TS_D)\frac{\mu_{GPRS}}{E[\sigma]}, \quad for\ j = 1,\ldots,n_{\max} \tag{5}$$

As indicated in Fig.5, the state j of the Markov chain corresponds to the number of the data mobiles that are simultaneously in active transfer (i.e., in the *ON* state). The maximum bandwidth capacity they can use is TS_D.

Because of the maximum downloading capacity d of each GPRS mobile, two situations can be distinguished:

(1) If $jd < TS_D$, the available bandwidth is not fully utilized by data mobiles. As a consequence the transition rate from state j to state $j-1$, given by the generated transfer of one mobile, is $jd\frac{\mu_{GPRS}}{E[\sigma]}$;

(2) If $jd \geq TS_D$ the allocator has to share the TS_D time-slots among the j data mobiles and the transition rate from state j to state $j-1$ is $TS_D\frac{\mu_{GPRS}}{E[\sigma]}$;

Let $p_D(j)$ be the steady-state probability that j users are in active transfer. According to the Engset model it is modeled by the closed form below:

$$p_D(j) = p_D(0)\frac{C_N^j}{\prod_{i=1}^{j}\min(d, \frac{TS_D}{i})\frac{i\mu_{GPRS}}{E[\sigma]}}\frac{1}{E[\tau]^j} \tag{6}$$

We can express the steady-state probability in terms of data traffic ρ_D, defined by relation (7):

$$\rho_D = \frac{E[\sigma]}{E[\tau]}\frac{1}{\mu_{GPRS}} \quad (7)$$

$$p_D(j) = p_D(0)\frac{C_N^j}{\prod_{i=1}^{j}\min(d, \frac{TS_D}{i})}\rho_D^j \quad (8)$$

We can observe that the steady-state distribution depends only through the ratio $\frac{E[\sigma]}{E[\tau]}$ on data traffic parameters $E[\sigma]$ and $E[\tau]$.

3.1.1 Performance parameters for data traffic model

Based on distributions given by relation (8) we compute the average performance parameters of the system as follows:

- The average downlink throughput per user (X_u);
- The average downlink total throughput (X);
- The blocking probabilities (B) for data;
- The average cell utilization ($U_{TS_D,N}$).

All these parameters are functions of the data traffic load, ρ_D, the available cell capacity, $TS_D; TS_{VD}$, the user capability d and the total number N of users.

The average total throughput is determined using the expression bellow:

$$X = \sum_{j=1}^{n_{max}} p_D(j)\, j r(j) \quad (9)$$

where $r(j)$ represents the effective bandwidth received by each user:

$$r(j) = \min(d, \frac{TS_D}{j})\mu_{GPRS},\ for \quad j = 1, \ldots, n_{max} \quad (10)$$

From formula (9) we can derive the average throughput per user as:

$$X_u = \frac{X}{E[j]} = \frac{\sum_{j=1}^{n_{max}} p(j)\min(jd, TS_D)}{\sum_{j=1}^{n_{max}} jp(j)}\mu_{GPRS} \quad (11)$$

The data blocking probability can be expressed based on Engset model (Fig.5) as follows:

$$B = p(0)\frac{C_{N-1}^{n_{max}}}{\prod_{i=1}^{n_{max}}\min(d, TS_D / i)}\rho_D^{n_{max}} \quad (12)$$

We consider also the average cell utilization by GPRS users as defined in [2]:

$$U = \sum_{j=1}^{n_{max}} p_D(j)\frac{\min(jd, TS_D)}{TS_D} \quad (13)$$

All these parameters will be used later to define the performance parameters for the mixed traffic model.

3.2 Voice Traffic Models

3.2.1 Classical Erlang Model Applied for Cells with Partial Partitioning

We apply the classical Markov chain model for voice. It is based on the birth-death structure shown in Fig.6 and on the following assumptions:

-New voice calls arrive according to a Poisson process with rate λ_V.

-Call durations are exponentially distributed with mean μ_V.

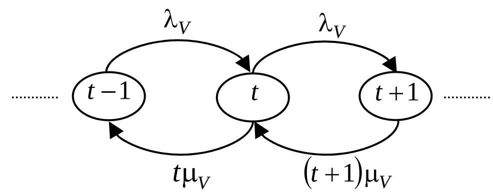

Fig.6 The birth-death model applied to voice traffic process

Base on this model, we have computed the steady-state probabilities given by relation (14) indicating the probability of having t voice calls in active transfer as function of voice traffic intensity $\rho_V = \frac{\lambda_V}{\mu_V}$ and system capacity $TS_V + TS_{VD}$:

$$p_V(t) = \frac{\frac{\rho_V^t}{t!}}{\sum_{i=0}^{TS_V+TS_{VD}}\frac{\rho_V^i}{i!}}, \quad t \in [0, TS_V + TS_{VD}] \quad (14)$$

It is assumed that for each call a full time slot is given. This strategy is also known as full rate assignment.

Based on relation (14) we have computed the Erlang-B [1] formula that gives the call blocking probability necessary to dimension the cell in order to guarantee a minimum QoS for voice traffic:

$$B_{V,PP} = \frac{\dfrac{\rho_V^{TS_V+TS_{VD}}}{(TS_V+TS_{VD})!}}{\sum_{i=0}^{TS_V+TS_{VD}} \dfrac{\rho_V^i}{i!}} \quad (15)$$

3.2.2 Combined FR and HR voice traffic model

A common strategy, called half-rate assignment is to share the same time slot between two users. This increases the number of calls in the system in cases when there are few time slots available. The strategy implementation needs to define a threshold *HRTh* such that when the number of free time slots is less than *HRTh* the calls are assigned at half rate [10].

The problem associated with an HR assignment is that it can force the system into a state in which many slots are assigned at half-rate, but each slot to only one user. Because these time-slots are already allocated to voice calls and due to the priority of voice over data they are not available to data. This could induce inefficiencies in the system when the *PP* strategy is implemented.

The scheme we have proposed in [12] allocates half-rate capable mobiles to full – rate or half-rate channels according to the existing traffic situation in the cell.

If the number of time slots (traffic channels) in the cell is above a predefined threshold, half–rate capable mobiles are allocated to full–rate channels. Otherwise half-rate capable mobiles will be given a half-rate time-slot.

The transitions between the possible states are illustrated in Fig.7

Once a mobile has been allocated to a full/half rate time-slot, the mobile will operate in this mode until the call is terminated.

The procedure drawback is the creation of so-called partially allocated time-slots which are time slots occupied by only one half-rate call.

To make an optimal uses of resources and to avoid the rejection of a call from a mobile that has only full rate capabilities, a re-packing procedure is applied.

In this case, it is necessary to repack two time-slots, each occupied by only one half-rate call, into a single time-slot with two half-rate calls.

For the proposed repacking model it is not possible to find out an analytic expression for the stationary distributions of the process.

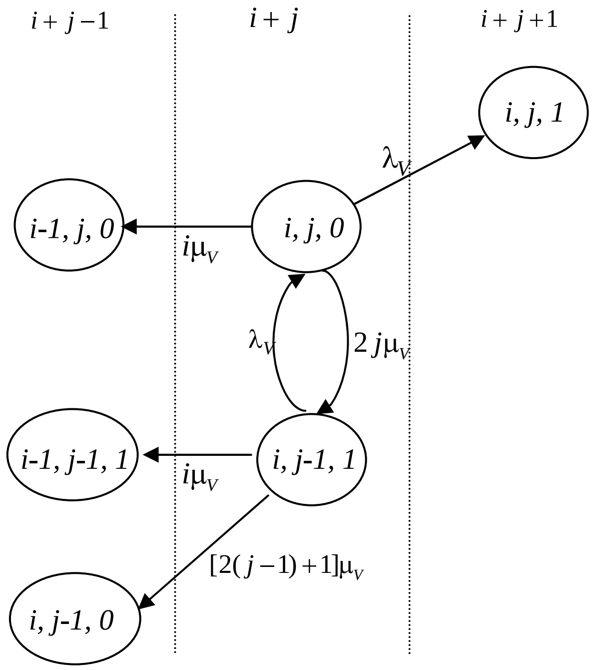

Fig.7 States evolution according to the packing algorithm

Knowing all the sates of the system, the possible transitions between these states and their transition rates, it is possible to construct the ***Q***-matrix of the process and find the stationary distributions solving numerically the equation $\mathbf{P}_V\mathbf{Q}=0$ with the normalization condition $\sum_n P_V(n)=1$. We denoted by $P_V(n)$ the probability of the current state of our model, where *n* depends on tree coordinates: $n(t)=(n_1(t),n_2(t),n_3(t))$.

Based on $P_V(n)$, it is possible to compute the steady-states probabilities $p_V^*(s)$, where *s* represents the number of time-slots occupied by voice calls in the system, by summing $P_V(n)$ over all the states included in the macro state *s*.

$$p_V^*(s) = \sum_{\{i,j,k\}|i+j+k=s} P_V(i,j,k) \quad (16)$$

3.2.3 Full Dynamic Half-Rate Allocation (DHR)

The full DHR procedure is based on the so called half-rate operation feature of mobiles. The DHR technique allocates always half-rate capable mobiles to half-rate channels. Mobiles that are not capable of half-rate will always be allocated to a full-rate channel [15].

The model current state equilibrium distribution $P_{V_{fh}}(n)$ depends, again on three coordinates: $n(t) = (n_f(t), n_h(t), 0;1)$

In this case, the system is a product-form type network [16] and the equilibrium distribution is given by:

$$p_{V_{f,h}}(n) = \frac{\dfrac{\rho_{V_f}^{n_f}\rho_{V_h}^{n_h}}{n_f!n_h!}}{\sum_{n\in S}\dfrac{\rho_{V_f}^{n_f}\rho_{V_h}^{n_h}}{n_f!n_h!}}, \quad n \in S \tag{17}$$

where ρ_{V_f} and ρ_{V_h} represent the traffic for full-rate mobiles respectively the traffic for half-rate mobiles and are defined by:

$$\rho_{V_f} = \frac{\lambda_{V_f}}{\mu} = \frac{\lambda_V(1-c_h)}{\mu} \tag{18}$$

and

$$\rho_{V_h} = \frac{\lambda_{V_h}}{\mu} = \frac{\lambda_V c_h}{\mu} \tag{19}$$

The coefficient c_h represents the percentage of users capable to use half-rate voice coding.

It can be seen that the total voice traffic respects the birth-death model indicated in Fig.6.

$$\rho_{V_f} + \rho_{V_h} = \frac{\lambda}{\mu} = \rho_V \tag{20}$$

For calculating the probabilities given by equation (17) we apply the one dimensional recursion formula independently published by Kaufman and Roberts.

Due to different services (full rate and half rate) current in the system the Kaufman-Roberts is applied to the total number of time-slots occupied by voice in a cell q, $q \in [0, TS - TS_D]$:

$$qp_{V_{f,h}}(q) = \rho_{V_f} p_{V_{f,h}}(q-1) + \\ +\frac{1}{2}\rho_{V_h} p_{V_{f,h}}(q-\frac{1}{2}), \quad q = \frac{1}{2}, 1, \frac{3}{2}, \ldots \tag{21}$$

For the blocking probability we have used the expression proposed by Ross [16]:

$$B_{V_{f,h}} = (1-c_h)[p_{V_{f,h}}(N-\frac{1}{2}) + p_{V_{f,h}}(N)] + \\ c_h p_{V_{f,h}}(N) = (1-c_h)p_{V_{f,h}}(N-\frac{1}{2}) + p_{V_{f,h}}(N) \tag{22}$$

3.3 Mixed traffic models

The basic idea in constructing the mixed voice and data traffic model relies on two assumptions:

(1) the voice calls are independent of GPRS connections;

(2) the voice and data traffic evolve at different time scales.

3.3.1 Performance parameters for mixed traffic

Based on the distributions given by equations (8), (14), (16) and (21) we have computed the average performance parameters of the model.

The mixed traffic model we consider is based on the PP scheme. We also used this model to represent the performance parameters when implementing the CS scheme and making some dimensioning considerations.

The average performance parameters are defined as follows:

- the average throughput per user is expressed as in [2]:

$$X_{u/PP} = \sum_{s=0}^{TS-TS_D} p_V(s) X_u(\min(TS - TS_V, TS - s)) \tag{23}$$

where $p_V(s)$ represent the steady-states probabilities for voice calls and $X_u = \frac{\sum_{j=1}^{n_{\max}} p_D(j)\min(jd, TS_D)\mu_{GPRS}}{\sum_{j=1}^{n_{\max}} jp_D(j)}$ represents the data throughput per user when each service has its dedicated time-slots [12].

When the cell capacity is shared according to PP schemes between voice and data, among the TS_{VD} time slots, those not used by the voice calls may be used for data traffic with a probability equal to the probability that $TS - TS_D - s$ are used by GSM users: $p_V(TS - TS_D - s)$.

In equation (23) we have used three different expressions for $p_V(s)$ according to equations (14), (16) and (21):

- for the total average throughput we used the formula proposed in [17]:

$$X_{PP} = \sum_{s=0}^{TS-TS_D} p_V(s) X(\min(TS - TS_V, TS - s)) \qquad (24)$$

making the same considerations as before and considering: $X = \sum_{j=1}^{n_{\max}} p_D(j) \min(jd, TS_D) \mu_{GPRS}$.

- the data blocking probability is computed similarly to [2] as follows:

$$B_{PP} = \sum_{s=0}^{TS-TS_D} p_V(s) B(\min(TS - TS_V, TS - s)) \qquad (25)$$

where $B = \dfrac{p_D(0) C_{N-1}^{n_{\max}} \rho_D^{n_{\max}}}{\prod_{i=1}^{n_{\max}} \min(d, TS_D / i)}$ represents the probability that TS_D time-slots are being used by $n_{\max}$ users among the other $(N-1)$ users.

For the cell utilization parameter we construct a formula similarly to (23-25) considering the interaction between voice and data.

$$U_{PP} = \sum_{s=0}^{TS-TS_D} p_V(s) U(\min(TS - TS_V, TS - s)) \qquad (26)$$

5 Experimental results and dimensioning aspects

We implement the proposed mixed traffic models by simple programs written in Matlab and experiment various scenarios.

For the data traffic we adopt the following parameters: $E[\sigma] = 5KB$, $E[\tau] = 12s$, GPRS mobile class: 4+1 and CS2 coding scheme ($\mu_{GPRS} = 13,4 kbits/s$).

The voice traffic load ρ_V was considered 5 Erlang.

The considered system is a cell equipped with a single TRX that provides: $TS = 8$, $TS_D = 1$. For the shared part of cell time-slots, TS_{VD}, we used different values.

The throughput per user for the mixed traffic models according to equation (23) is represented in Fig.8. The results obtained using different voice traffic models shows that the best throughput per user is provided by the model based on combined FR and HR voice traffic. The performance of the full DHR voice model depends on the value of c_h coefficient. In that scenario c_h coefficient is equal to 0.25. For c_h values close to 1 the performance of Full DHR model are similar to the combined FR and HR model. For the shared part of available time slots TS_{VD} we have use two different values in order to show the dependency of the performance parameter.

Figure 8 shows that for a large number of GPRS users the total throughput becomes small and independent of voice traffic model as well as of shared part of time slots.

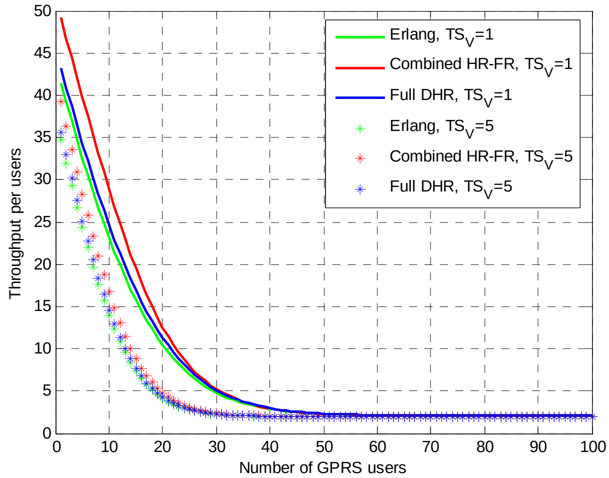

Fig.8 Throughput per user

The total throughput for the mixed traffic models according to equation (24) is represented in Fig.9 using the same conditions as before.

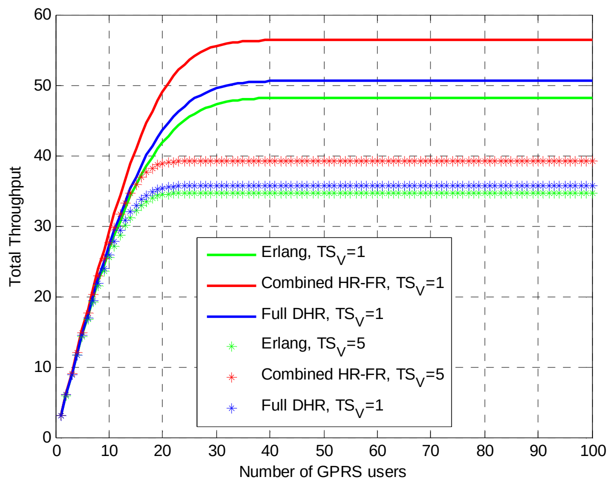

Fig.9 Total throughput

The comparison between the performance measures shows similar results for throughput per user as presented before for total throughput.

The mobile multi-slot capability *d* has a high influence on the total throughput and on the throughput per user in low load cases and becomes negligible in high cell loads.

Figure 10 shows the blocking probability according to equation (25) as a function of the number of GPRS users in the cell.

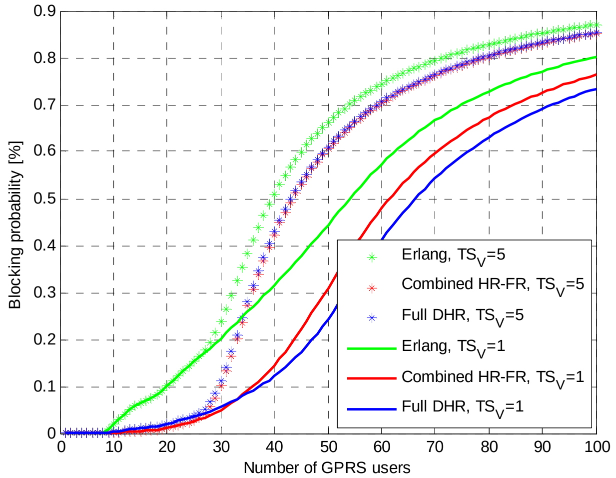

Fig.10 Blocking probability

Figure 11 depicts the cell utilization parameter as defined by equation (26) for a cell with $TS_{VD} = 3$ and combined HR-FR voice traffic model. It shows that cell utilization depends on data traffic load given by $E[\sigma]$.

The blocking probability and the throughput are important parameters for dimensioning purposes. Figures 8-10 show that these parameters depend on the number of GPRS users and on the shared part of time-slots.

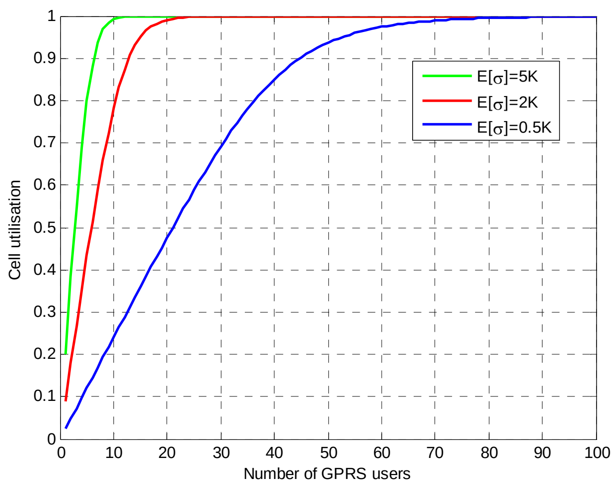

Fig.11 Cell utilization

The choice of TS_{VD} and TS_D influences the quality of service perceived by the data users.

The number of TS_D time-slots should be established in order to guarantee a minimum QoS level for data traffic.

The choice of TS_{VD} is made with the purpose of guarantee a minimum QoS for each type of traffic: voice and data.

In practice it is necessary to dimension the cell for reduced voice traffic loads in order to guarantee a fixed voice call blocking probability and a minimum QoS for data traffic.

As a consequence, a balance between the reduction of offered voice calls and the performance perceived by data users has to be defined by the operator.

Table 2 shows the number of necessary time-slot for different value of voice traffic loads (ρ_V), considering for blocking probability the typical value 2%. We have also considered different models for voice traffic.

The voice models influence the minimum number of time slots required to guarantee a fixed voice blocking probability.

TABLE 2

ρ_V [Erlang]		1,09	3,63	5,83	9.01
TS_V according to:	Erlang B formula	4	8	11	15
	Combined HR-FR	2	5	7	10
	Full DHR, c_h=0	4	8	11	15
	Full DHR, c_h=0,25	3	8	10	14
	Full DHR, c_h=0.5	2	7	9	13
	Full DHR, c_h=0,75	2	6	8	11
	Full DHR, c_h=1	2	5	6	9

6 Conclusions

In this work we have developed analytical models for the performance evaluation of GSM/GPRS cells with partial partitioning strategy. The proposed models deal with mixed traffic voice and data and allow to better measure the performance of the systems according to traffic loads. The model we presented is a general one and permit furthermore the implementation of complete sharing allocation strategy as a particular case

The constructed models are suitable for dimensioning purposes. The comparative analysis we have made shows that the performance parameters are highly dependent on the voice traffic model. Both combined HR-FR and Full DHR voice models are recommended for dimensioning radio resources. The Full DHR model is computational efficient implemented and focus on full-rate and half-rate capabilities of mobile equipments.

References:

[1] L. Kleinrock, *Queuing Systems: Vol. I – Theory*, New-York Wiley, 1976

[2] H. Dahmouni,. B. Morin, S. Vaton, "Performance Modelling of GSM/GPRS Cells with Different Radio Resource Allocation Strategies", *IEEE Wireless Communications and Networking Conference*, March 2005, Volume 3, pp: 1317- 1322

[3] S. Pedraza, J. Romero, J. Munoz, "(E)GPRS Hardware Dimensioning Rules with Minimum Quality Criteria", *Proc. of IEEE VTC* Spring, pp. 391-395, May 2002

[4] C. Lindemann, A. Thummler, "Performance Analysis of the General Packet Radio Service", *Computer Network*, 41, pp. 1-17, Jan., 2003

[5] S. Ni, S. Haggman, "GPRS Performance Estimation in GSM Circuit-Switched Services and GPRS Shared Resources Systems", *WCNC*, Vol.3, pp.1471-1421, 1999

[6] M. Mahdavi, R. Edwards, P. Ivey, "Performance Evaluation of Data Subsystem in GSM/GPRS Using Complete Sharing, *Proc. of London Communications Symposium*, Univ. College of London, 2001

[7] B. Baynat, K. Boussetta, P. Eisenmann, N. Ben Rached, "Discrete-Time Markov Model for EDGE/GPRS Radio Engineering with Finite-length Sessions", *Int. Symp. On Performance Evaluation of Computer and Telecommunication Systems* (SPECTS'2004), San Jose, California, USA, July, 2004

[8] B. Baynat, K. Boussetta, P. Eisenmann, N. Ben Rached, "Towards an Erlang-like Law for the Performance Evaluation of GPRS/EDGE Networks with Finite-Length Sessions", *Proc. of 3rd IFIP-TC6 Networking Conference*, May 2004, pp. 1288-1293

[9] B. Baynat, P. Eisenmann, "Towards an Erlang-like law for GPRS/EDGE network engineering", *Proceedings IEEE ICC*, June 2004

[10] Copca, "An improved model for GSM/GPRS/EDGE performance evaluation", ACM/IFIP LANC 2007, San Jose, Costa Rica

[11] B. Baynat, K. Boussetta, P. Eisenmann, „Performance evaluation of GPRS/EDGE networks: A novel discrete - time Markov model", 5th World Wireless Congress (WWC), San Francisco, USA May, 2004

[12] C. Balint, G. Budura, A. Budura, E. Marza, "Dimensioning Rules Regarding Radio Resources in GSM/GPRS Networks", *WSEAS Transactions on Communications,* Issue 8, Vol 8, 2009, pp. 822-832 *series*, Tom 53(67), Fasc.2, 2008, pp. 85-92

[13] P.M. Papazoglu, A. Karras, R.C. Papademitriou, "Improved Integral Channel Allocation Algorithms in Cellular Communication Systems Enabling Multimedia QoS Services", *WSEAS TRANSACTIONS on COMMUNICATIONS*, ISSN 1109-2742, Issue 10, Volume 7, October 2008, pp. 1014 -1023

[14] R. Dobrescu, D. Hossu, S. Mocanu, M. Nicolae, "New algorithms for QoS performance improvement in high speed networks**",** ISSN: 1109-2742, *WSEAS TRANSACTIONS on COMMUNICATIONS*, Issue 12, Volume 7, December 2008, pp. 1192 -1201

[15] E.M.M. Winands, J. Wieland, S. Sanders, "Dynamic Half-rate Connections in GSM",*AEU – Internationl Journal of Electronics and Communications*, Vol. 60, Issue 7, July 2006 , Eindhoven, pp. 504-512

[16] K. W. Ross, "Multiservice Loss Models for Broadband Telecommunications Networks, Springer–Verlag, Berlin 1995

[17] G. Budura, C. Balint, A. Budura, Radio Resources Dimensioning According to Different Allocation Strategies in GSM/GPRS Networks, *Recent Advances in Computational Intelligence, Man-Machine Systems and Cybernetics* (CIMMACS'09), Puerto de la Cruz, Tenerife, dec. 14-16, 2009, pp. 168-174