Performance Modelling of a Wireless GSM/GPRS Cell under Partial Sharing Scheme*

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Abstract. Novel analytic and simulation methodologies are devised for the performance modelling and evaluation of a wireless GSM/GPRS cell with bursty multiple class flows of voice calls and data packets subject to a traffic handling partial sharing scheme (PSS). In this context, a delay network model is proposed consisting of two interacting multiple class GE-type delay systems, namely a GSM GE/GE/c/c loss system with c servers and a GPRS GE/GE/1/N/PS delay system with finite capacity N and discriminatory processor share (PS) transfer rule. The principle of maximum entropy (ME) is used to characterize analytic solutions, subject to appropriate GE-type delay theoretic mean value constraints and closed form expressions for state and blocking probability distributions are obtained. Furthermore, related simulation programs in Java are developed. Typical numerical examples are included to compare the ME solutions against simulation and to study the effect of bursty multiple class traffics upon the performance of the cell.

Keywords: Global System for Mobile Telecommunication (GSM), General Packet Radio Service (GPRS), wireless GSM/GPRS cell, partial sharing scheme (PSS), quality-of-service(QoS), maximum entropy (ME) principle, performance evaluation, generalized exponential (GE) distribution.

1 Introduction

Cost-effective algorithms for queueing and delay network models under various traffic handling schemes are widely recognized as powerful and realistic tools for the performance evaluation and prediction of complex mobile networks with ever increasing volumes of multimedia traffic.

Most of the published performance studies in the field are based on simulation modelling and numerical solution of Markov models covering different traffic scenarios, mostly at voice call level, with single or multiple service classes(e.g.,[1-3]). Notably, Foh et al [3] proposed a single server infinite capacity queue for modelling GPRS data packet traffic in a Markovian environment and applied

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matrix geometric methods for the computation of the performance metrics. More recently, Kouvatsos et al [4] presented an analytic framework, based on the principle of maximum entropy (ME) [5], for the performance modelling and evaluation of a wireless GSM/GPRS cell with a generalized exponential (GE) type of bursty traffic under a complete partitioning scheme (CPS).

Simulation modelling is an efficient tool for studying detailed system behaviour but it becomes costly, particularly as the system size increases. Markov models on the other hand provide greater flexibility. However, associated numerical solutions may suffer from several drawbacks, such as restrictive assumptions of Poisson arrival process and/or state space explosion, limiting the analysis to small mobile systems.

In this paper novel analytic and simulation delay network methodologies are devised for the performance evaluation of a delay network model (DNM) representing a wireless GSM/GPRS cell with bursty flows of voice calls and data packets subject to a traffic handling partial sharing scheme (PSS). The network model consists of two interacting multiple class GE-type delay systems, namely, a GSM GE/GE/c/c loss system with $c (> 1)$ servers and a GPRS single sever GE/GE/1/N/PS delay system with finite capacity $N (> 1)$ and processor share (PS) transfer rule. The principle of ME is used to characterize analytic solutions, subject to appropriate GE-type delay theoretic mean value constraints, leading into decomposition of the DNM into two individual but interacting systems each of which can be analyzed in isolation. Subsequently, closed form expressions for state and blocking probability distributions are obtained. Furthermore, the Java programming language is used to carry out detailed network model simulations at 95% confidence intervals.

Section 2 presents a GSM/GPRS architecture with potential spots of congestion together with a proposed DNM under PSS. An overview of the ME analysis of the GE/GE/c/c and GE/GE/1/N/PS delay systems is highlighted in Section 3. Typical numerical validation results are included in Section 4. Concluding remarks follow in Section 5.

Remarks on the GE-Type Distribution

The GE-type distribution is of the form [5]

$$F(t) = P(X \leq t) = 1 - \tau e^{-\tau vt}, \quad \tau = 2/(1 + C^2), \quad t \geq 0 \quad (1)$$

where X is an interevent time random variable and $\{1/v, C^2\}$ are the mean and squared coefficient of variation (SCV) of the interevent times, respectively.

The GE distribution has a counting compound Poisson process (CPP) with geometrically distributed batch sizes with mean $1/\tau$. It may be meaningfully used to model the inter-arrival times of bursty multiple class mobile connections with different minimum capacity demands. Note that an IP packet length distribution is known to be non-exponential and should at least be described by the mean, $1/v$, and SCV, C^2 . This is because IP packets are restricted by the underlying physical network, such as Ethernet and ATM, and thus, they have different packet lengths, typically 1500 bytes and 53 bytes, respectively.

The GE distribution may also be employed to model short range dependence (SRD) traffic with small error. For example, an SRD process may be approximated by an ordinary GE distribution whose first two moments of the count distribution match the the corresponding first two SRD moments. This approximation of a correlated arrival process by an uncorrelated GE traffic process may facilitate (under certain conditions) problem tractability with a tolerable accuracy and, thus, the understanding of the performance behaviour of external SRD traffic in the interior of the network. It can be further argued that, for a given buffer size, the shape of the autocorrelation curve, from a certain point onwards, does not influence system behaviour (c.f., [3]). Thus, in the context of system performance evaluation, an SRD model may be used to approximate accurately long range dependence (LRD) real traffic.

2 A DNM for a GSM/GPRS Cell under PSS

Efficient traffic handling schemes for wireless GSM/GPRS cells are of crucial importance for the support of mobile multimedia applications with quality-of-service (QoS) guarantees. Resources for GPRS traffic can be reserved statically or dynamically whereas a combination of both is possible. Different cell capacity partitioning schemes for handling the transmission of voice calls/data packets can be defined. In such environment, partitions of the available bandwidth may be created for GSM and GPRS traffics. For GPRS traffic, a complete partition is used for different data services. However, some data packets may be allocated higher priority and, therefore, they can be given higher share of the available bandwidth. Whenever voice calls and data packets share bandwidth, voice calls are always given preemptive priority over data packets. Two main GSM/GPRS call/data handling schemes are described below.

- *Complete partitioning scheme (CPS)* divides the total cell capacity to serve simultaneously GSM and GPRS traffics. As a consequence, the GSM and GPRS systems can be analyzed separately.
- *Partial sharing scheme (PSS)* allocates a fixed number of channels for data traffic and the remaining channels are shared by both voice calls and data packets with preemptive service priority for voice calls.

Focusing on the PSS, a simplified GSM/GPRS wireless cell architecture can be seen in Fig. 1. The User Equipment (UE) can generate traffic consisting of GSM voice calls and GPRS data packets which go through the same Base Station (BS) but each of them will have its own Um and Gb radio interfaces. A joint bandwidth management procedure under PSS is in operation. Potential spots of congestion and delays are often attributed to the constraints imposed by the Base Station Controller (BSC) and the Serving GPRS Support Node (SGSN) dealing with GSM voice and GPRS data traffics, respectively.

A number of bufferless channels may be allocated to the GSM partition which can be clearly seen as a loss system for multiple class voice calls. An admitted voice call requires the assignment of a single channel for its entire duration. Moreover, the GPRS traffic is packet based and, therefore, each connection will attempt to

Fig. 1. A GSM/GPRS wireless cell architecture with a PSS system of queues

use the complete available bandwidth. As soon as there are more active channels, it is the responsibility of the SGSN to ensure that bandwidth is shared fairly among them. Thus, the GPRS data partition can be modelled by a PS delay system where all data connections may belong to different classes and share the total available capacity. These classes may have their own characteristics such as maximum or minimum data rates, delay sensitivity, service discrimination, arrival rates, inter-arrival-time variability and transferable file (data) length. Under PSS, there is a joint bandwidth management procedure according to which free GSM channels are acquired dynamically to increase the transmission capacity of the GPRS partition until the arrival of new voice calls.

A DNM of a GSM/GPRS cell under PSS can be seen in Fig. 2. The CPP with geometrically distributed batches is used to represent bursty GSM and GPRS multiple class arrival processes (or, equivalently GE-type interarrival times) of voice calls and data packets, respectively. Moreover, GE distributions are used to describe the call durations and packet channel transmission times. In the context of this work, only up link traffic streams are considered.

The GSM partition may be generally modelled by a classical pseudo-birth death GE/GE/c/c loss system with multiple voice call streams. On the other hand, the GPRS partition can be modelled by a single server GE/GE/1/N/PS system with a finite capacity, N , for the transmission of multiple class data packets under discriminatory PS rule. This is feasible as all admitted data

connections will share simultaneously the available GPRS bandwidth according to assigned priorities. Physically, the GPRS system is capable of allocating all available channels to one connection (subject to some battery restrictions). Also, in case of multiple connections, one time slot (channel) can be shared by eight different connections [6].

The joint bandwidth management protocol of the PSS is implemented under the following traffic handling operational conditions: At any given time, free

Fig. 2. A DNM of a wireless GSM/GPRS cell under PSS

GSM channels belonging to the GE/GE/c/c loss system are used (temporarily) to increase the transmission capacity of the GPRS GE/GE/1/N/PS delay system. However, new arrivals of voice calls, with a preemptive priority over the data packets, will cause the immediate release of some or all GSM channels, as appropriate, from the GPRS partition to the loss system for their own immediate transmission. Subsequently, the transmission capacity of the GPRS system will be progressively either reduced or increased, as appropriate. Note that, in the absence of available capacity under PSS, both voice calls and data packets will be lost on arrival.

3 Delay Theoretic Performance Analysis of a Wireless GSM/GPRS Cell under PSS

The proposed analytic DNM of Fig. 2 consists of the multiple class GE/GE/c/c loss system interacting under PSS with the multiple class GE/GE/1/N/PS delay system. An overview of the ME methodology, as applied to the analysis of the aforementioned systems, is presented below. Details of mathematical proofs associated with key analytic GE-type results can be found in [7].

Notation

For each class i ($i = 1, 2, \dots, R, R > 1$) let

$\{1/\lambda_i, C_{ai}^2\}, \{1/\mu_i, C_{si}^2\}$ be the mean and SCV of the interarrival and service time distributions, respectively.

Moreover, let at any given time at equilibrium

n_i be the number of either voice calls at the GE/GE/c/c loss system or data packets at the GE/GE/1/N/PS delay system;

$\mathbf{n} = (n_1, n_2, \dots, n_R)$ be joint state of either GE/GE/c/c or GE/GE/1/N/PS systems, (n.b., $\mathbf{0} = (0, \dots, 0)$);

Ω be the set of all feasible states $\mathbf{n}$;

π_i be the blocking probability that an arrival of class i will find either the GE/GE/c/c or GE/GE/1/N/PS systems at the full capacity.

The form of the state probability distribution, $P(\mathbf{n})$, $\mathbf{n} \in \Omega$, can be characterized by maximizing the entropy functional $H(\mathbf{P}) = -\sum_{\mathbf{n}} P(\mathbf{n}) \log P(\mathbf{n})$, subject to prior information expressed in terms of the normalization and, for each class i ($i = 1, 2, \dots, R$), the marginal constraints of either server utilization for a GE/GE/1/N/PS delay system under discriminatory PS rule or, state probabilities $P(0), P(1), \dots, P(c-1)$ for a GE/GE/c/c loss system, mean number of voice calls and/or data packets, as appropriate and full buffer state probabilities for either system satisfying the flow balance equations, namely

$$\lambda_i(1 - \pi_i) = \mu_i U_i, \quad i = 1, \dots, R \quad (2)$$

where U_i is the steady state probability of having customers of class i in the system. By employing Lagrange's method of undetermined multipliers, the following solutions are obtained:

$$P(\mathbf{n}) = \begin{cases} \frac{1}{Z} \frac{\left(\sum_{j=1}^R n_j - 1\right)!}{\prod_{j=1}^R n_j!} \left(\prod_{j=1}^R x_j^{n_j}\right) \left(\sum_{i=1}^R n_i g_i y_i^{f_i(\mathbf{n})}\right), & \text{GE/GE/1/N/PS} \\ \frac{1}{Z} \prod_{i=1}^R \left\{ \prod_{k=1}^c g_{ik}^{h_{ik}(\mathbf{n})} y_{ik}^{f_{ik}(\mathbf{n})} \right\} x_i^{n_i}, & \text{GE/GE/c/c} \end{cases} \quad (3)$$

where $Z = 1/P(0)$, is the normalizing constant, $\{g_i, x_i, y_i, i = 1, 2, \dots, R\}$ and $\{g_{ik}, y_{ik}, i = 1, 2, \dots, R; k = 1, 2, \dots, c\}$ are the Lagrangian coefficients corresponding to the aforementioned constraints per class, respectively and $h_{ik}(\mathbf{n})$, $f_{ik}(\mathbf{n})$ and $f_i(\mathbf{n})$ are suitable auxiliary functions defined as: $h_{ik}(\mathbf{n}) = 1$ if $(n_i \geq k \text{ and } k \leq c - \sum_{\ell=1}^{i-1} n_\ell, k = 1, 2, \dots, c)$ or 0 otherwise; $f_{ik}(\mathbf{n}) = 1$ if $(h_{ik}(\mathbf{n}) = 1 \text{ and } \sum_{i=1}^R n_i = c, k = 1, 2, \dots, c)$ or 0 otherwise and $f_i(\mathbf{n}) = 1$ if $\sum_{i=1}^R n_i = N, i = 1, 2, \dots, R$ or 0 otherwise. Note that, the Lagrangian coefficients $\{x_i, g_i, g_{ik}, \forall i, k\}$ can be approximated analytically by making asymptotic connections to the corresponding GE-type infinite capacity systems [7]. Moreover, the Lagrangian coefficients $\{y_i, y_{ik} \forall i, k\}$ can be determined via flow balance equation (2).

From ME solution (3), and after some manipulation, the aggregate state probabilities can be obtained by

$$P(n) = \begin{cases} \frac{1}{W} \left(\sum_{i=1}^R g_i x_i y_i^{f_i(\mathbf{n})}\right) X^{n-1}, \quad n \in [1, N], & \text{GE/GE/1/N/PS} \\ \frac{1}{W} \sum_{\mathbf{n} \in A_n} \prod_{i=1}^R \left\{ \prod_{k=1}^c g_{ik}^{h_{ik}(\mathbf{n})} y_{ik}^{f_{ik}(\mathbf{n})} \right\} x_i^{n_i}, & \text{GE/GE/c/c} \end{cases} \quad (4)$$

where $W = 1/P(0)$, $X = \sum_{i=1}^R x_i$ and $A_n = \{n : \sum_{i=1}^R n_i = n\}$. Moreover, focusing on a tagged voice call or data packet, as appropriate, within an arriving bulk and applying GE-type probabilistic arguments, the blocking probabilities

$\{\pi_i, i = 1, 2, \dots, R\}$ can be approximated by

$$\pi_i = \begin{cases} \sum_{n=0}^N \delta_i(n)(1 - \sigma_i)^{N-n} P(n), & GE/GE/1/N/PS \\ \sum_{n=0}^c \delta_i(n)(1 - \sigma_i)^{c-n} P(n), & GE/GE/c/c \end{cases} \quad (5)$$

where $\delta_i(0) = \frac{r_i}{r_i(1 - \sigma_i) + \sigma_i}$, $\delta_i(n) = 1 (\forall n > 0)$, $\sigma_i = 2/(1 + C_{ai}^2)$ and $r_i = 2/(1 + C_{si}^2)$.

By using the blocking probabilities $\{\pi_i, i = 1, 2, \dots, R\}$ and the flow balance condition (2), after some manipulation, recursive relationships for the computation of Lagrangian coefficients $\{y_i, y_{ik} \forall i, k\}$, can be obtained (c.f., [7]).

GPRS Weighted Average Performance Measures

GPRS data packets will receive under PSS variable transmission capacity depending on the availability of free GSM channels. Thus, an average performance statistic for data packet of class i , say, S_{GPRS}^i (e.g., class utilisation, mean number of data packets per class, etc) of the $GE/GE/1/N/PS$ delay system can be clearly determined by the weighted average measure S_{GPRS}^i , given by

$$S_{GPRS}^i = \sum_{l=0}^c S_{GPRS}^{l,i} P_{GSM}(n=l), i = 1, 2, \dots, R \quad (6)$$

where $P_{GSM}(\cdot)$ is the aggregate steady state probability of the number of voice calls in the $GE/GE/c/c$ loss system and $\{S_{GPRS}^{l,i}, l = 0, 1, 2, \dots, c\}$ are estimated values of statistic S_{GPRS}^i corresponding to the maximum available mean GPRS transfer rates $\{\mu_{GPRS}^i + (c-l)\mu_{GSM}, l = 0, 1, 2, \dots, c\}$, under PSS with $\{\mu_{GSM}, \mu_{GPRS}^i\}$ being the initially allocated aggregate class i transfer rates to the GSM $GE/GE/c/c$ loss system and the GPRS $GE/GE/1/N/PS$ delay system, respectively.

Remarks

The proposed analytic $GE/GE/1/N/PS$ delay model differs from and, in some respect, extends overall the MMPP/M/1 delay model suggested by Fol et al. [3]. Although the latter model incorporates a Markov modulated Poisson arrival process (MMPP), nevertheless it is only applicable to a single class of data packets, assumes exponential transmission times and, being an infinite capacity delay model, does not capture the adverse blocking effect on system performance. Moreover, the GE -type delay model can be solved via closed-form expressions as opposed to those requiring computationally demanding matrix geometric methods.

4 Numerical Results

This section presents typical numerical experiments to illustrate the credibility of the ME methodology against simulation and also to demonstrate the applicability of ME solutions, as simple and cost-effective performance evaluation tools,

Fig. 3. GPRS class 2 utilization for GE/GE/1/N/PS delay system at overall GSM utilization of 40 % (Experiment 1-Input Data: $\{\lambda = 1.0, \mu = 0.58, c = 6, Ca^2 = 2, Cs^2 = 1\}$ for GSM and $\{N = 20, \lambda_1 = 0.3, \mu_1 = 2.92, \mu_2 = 0.58, Ca_1^2 = 2, Ca_2^2 = 3, Cs_1^2 = 4, Cs_2^2 = 4\}$ for GPRS).

Fig. 4. Effect of varying degrees of SCV on mean number of GPRS data packets at overall GSM utilization of 50 % (Experiment 1-Input Data: $\{\lambda = 1.0, \mu = 0.58, c = 6, Ca^2 = 2, Cs^2 = 1\}$ for GSM and $\{N = 20, \lambda_1 = 0.3, \lambda_2 = 0.05, \mu_1 = 2.92, \mu_2 = 0.58, Cs_1^2 = 4, Cs_2^2 = 4\}$ for GPRS).

for assessing the effect of bursty multiple class traffics upon the performance of the wireless cell. Note that the Java programming language was used to carry out the simulation analysis of the DNM of Fig. 2 at 95 % confidence intervals.

Two experiments have been devised. Experiment-1 (c.f., Figs. 3-5) deals with an aggregate class of GSM voice calls and two GPRS classes of data packets having different mean sizes, namely, 62.5 KBytes (class 1, e.g., web browsing) and

Fig. 5. Effect of varying degrees of arrival rate λ_1 on the aggregate GPRS data packets blocking probability at overall GSM utilization of 40 % (Experiment 1-Input Data: $\{\lambda = 1.0, \mu = 0.58, c = 6, Ca^2 = 2, Cs^2 = 1\}$ for GSM and $\{N = 20, \lambda_2 = 0.05, \mu_1 = 2.92, \mu_2 = 0.58, Ca_1^2 = 2, Ca_2^2 = 3, Cs_1^2 = 4, Cs_2^2 = 4\}$ for GPRS).

Fig. 6. GPRS class 3 of utilization for GE/GE/1/N/PS delay system at overall GSM utilization of 40 % (Experiment 2-Input Data: $\{\lambda = 1.0, \mu = 0.58, c = 6, Ca^2 = 2, Cs^2 = 1\}$ for GSM and $\{N = 20, \lambda_1 = 0.3, \lambda_2 = 0.0, \mu_1 = 2.92, \mu_2 = 0.58, \mu = 14.01, Ca_1^2 = 2, Ca_2^2 = 3, Ca_3^2 = 2, Cs_1^2 = 4, Cs_2^2 = 4, Cs_3^2 = 4\}$ for GPRS).

12.5 KBytes (class 2, e.g., email). Experiment-2 (c.f., Figs. 6,7) includes a study involving aggregate class GSM voice calls and three GPRS classes of data packets with different mean sizes given by 300 KBytes (class 1, e.g., video stream), 62.5 KBytes (class 2, e.g., web browsing), 12.5 KBytes (class 3, e.g., email). It is assumed that both GSM and GPRS partitions consist of one frequency providing total capacity of 171.2 Kbps. Note that the comparative study makes use of

Fig. 7. Effect of varying degrees of SCV on mean number of GPRS data packets at overall GSM utilization of 50 % (Experiment 2-Input Data: $\{\lambda = 1.0, \mu = 0.58, c = 6, Ca^2 = 2, Cs^1 = 1\}$ for GSM and $\{N = 20, \lambda_1 = 0.2, \lambda_2 = 0.05, \lambda_3 = 2.0, \mu_1 = 2.92, \mu_2 = 0.58, \mu = 14.01, Cs_1^2 = 4, Cs_2^2 = 4, Cs_3^2 = 4\}$ for GPRS).

varying GPRS traffic values of mean arrival rates and SCV of the interarrival times.

As the GE/GE/c/c loss system is unaffected, under PSS, by the GPRS partition, without the loss of generality, the comparative study focuses on marginal performance metrics of GPRS utilization, mean number of data packets per class together and the aggregate GPRS blocking probability of the GE/GE/1/N/PS delay system. It can be observed (c.f., Figs. 3-7) that, over a wide range of parameterisation, the ME results are slightly pessimistic but very comparable to those obtained via simulation. Moreover, it can be seen that the interarrival time SCV has an inimical effect on the performance metrics of GPRS data packets (c.f., Figs. 4,7). Note that additional validation tests involving a multiple GPRS class GE/GE/1/N/PS delay system with a discriminatory PS rule together with a multiple GSM class GE/GE/c/c loss system can be seen in [7].

Remarks

The credibility of the ME results, as reliable GE-type or generalized geometric (GGeo)-type approximations [5], against those obtained from the simulation of more complex correlated traffic models, such as Markov Modulated Batch Bernoulli Process (MMBBP) and Batch Renewal Process (BRP), is beyond the scope of this paper and will be the subject of further study.

5 Conclusions

Novel analytic and simulation methodologies are devised for the performance modelling and evaluation of a wireless GSM/GPRS cell with bursty multiple

class flows of voice calls and data packets subject to a traffic handling PSS. In this context, a DNM is proposed consisting of two interacting multiple class systems, namely, a GSM GE/GE/c/c loss system with c multiple servers and a GPRS GE/GE/1/N/PS delay system with discriminatory PS transfer rule. The principle of maximum entropy (ME) is used to characterize new analytic solutions, subject to appropriate GE-type delay theoretic mean value constraints. Subsequently, closed form expressions for state probability distributions and related performance metrics are determined. Furthermore, simulation programs developed in Java are employed to validate the credibility of the ME solutions against simulation results at 95% confidence intervals and also verify the adverse effect of bursty traffics upon the performance of the cell. It was observed that the ME analytic results are comparable to those of simulation for a wide range of parametrization.

The analytic methodology of ME, subject to queueing and/or delay theoretic mean value constraints, provides simple and robust analytic building block tools for the performance modelling and prediction of wireless cells and networks.

The proposed DNM can be extended to specify alternative operational interpretations of the joint management bandwidth protocol of PSS. Current work in progress focuses on the GSM/GPRS enhancement of the Universal Mobile Telecommunication System (UMTS) network architecture.

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