Mobility Impact on Data Service Performance in GPRS Systems

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Abstract

In this paper we describe an analytical approach to derive the packet delay distribution in a cell of a wireless network operating based on the general packet radio service (GPRS) standard. Based on that, the average packet delay and packet loss probability are also computed. Our approach is based on a decomposition of system behavior into short-term and long-term behaviors to simplify the analytical modeling thanks to the quasi-stationary behavior of the data packet queueing process. In addition to the effect of voice call handoffs, the impact of packet forwarding and dedicated data channels on data service performance is also taken into consideration. The performance estimates produced by the analytical approach are compared with those generated by simulation experiments which confirms the relative accuracy of the analytical approach.

Index Terms

General packet radio service (GPRS), data service, performance evaluation.

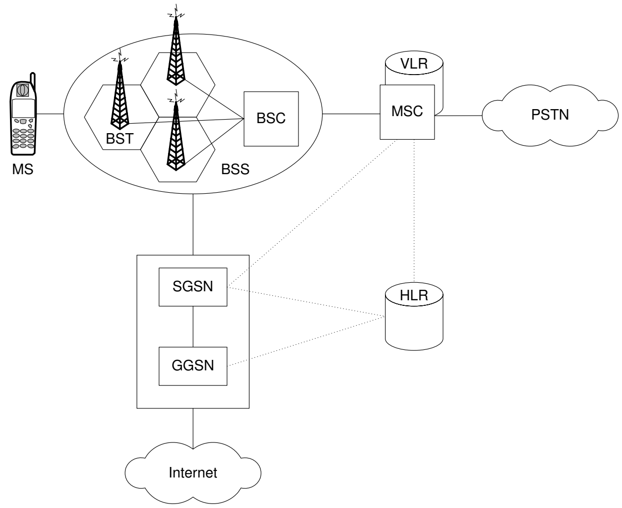

Fig. 1. GSM/GPRS architecture.

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I. Introduction

Due to the current economic situations wireless operators have differed investments for the deployment of new wireless technologies. In order to survive in this condition, operators and manufacturers are trying to identify ways to efficiently use the deployed resources rather than overprovisioning their networks as they did in the recent past [1]. General packet radio service (GPRS) [2] is a new bearer service designed as an extension to the GSM network, which greatly improves and simplifies the wireless access to packet data networks such as the Internet [3].

The architecture of GPRS in a GSM system is shown in Fig. 1. Each base station subsystem (BSS) consists of several base transceiver stations (BTS) and a base station controller (BSC) in charge of monitoring and controlling associated BTSs. When either voice or data traffic is originated at the mobile station (MS), it is transported over the air interface to the BTS, and from BTS to the BSC, in the same way as a standard GSM call. However, at the output of BSC, voice is sent to mobile switching center (MSC) per standard GSM, and data is sent to a new entity called serving GPRS support node (SGSN). The SGSN is in charge of one or more BSS and delivers GPRS packets to mobile stations within its service area. The gateway GPRS support node (GGSN) acts as an interface to external data networks such as the Internet. To keep track of user information and location, two databases, namely home location register (HLR) and visitor location register (VLR), are provided. The HLR maintains the information of all the registered subscribers while the VLR has the information of those subscribers currently located in its area.

In this paper, we develop an analytical approach to compute the packet delay and loss probability of data service in a GSM/GPRS cellular network for an extended version of this paper). The rest of the paper is organized as follows. Section II reviews the existing work on performance evaluation of GPRS systems. In section III, we describe the system model and clarify our assumptions. System analysis is presented in section IV. Section V presents some numerical results, and finally, section VI concludes the paper.

II. Related Work and Motivation

In a more general context, voice and data integration has been studied by researchers for more than two decades. These studies were initiated in wireline networks [4], [5] and recently moved to wireless networks as well [1], [3], [6]–[8]. In wireless cellular networks, several new issues mostly related to the mobility of users and wireless channel effects have been raised which did not exist in previous work on wireline networks.

An integrated voice/data wireless system with finite buffer for data traffic has been considered in [7]. System is described by a two-dimensional Markov chain and balance equations are given. These equations can be numerically solved to find the interesting performance parameters. A similar system based on the movable boundary approach is investigated in [6]. Handoff effect of voice traffic is considered but it is assumed that data packets waiting in queue can not handoff. Fluid flow analysis has been applied in [8] while only the effect of voice handoff has been taken into consideration. More specifically, [1] and [3] investigated a GPRS system with voice handoffs only. A two-dimensional continues time Markov chain has been formulated in [1] to describe the system behavior. Queueing of voice calls has been investigated in detail in [3] without considering the queueing of data traffic.

In this paper, we focus on the performance of GPRS data service with buffering and dedicated channels for data traffic while we consider the effect of reneging data packets due to the corresponding user handoff. We consider the effect of handoffs for both voice and data traffic.

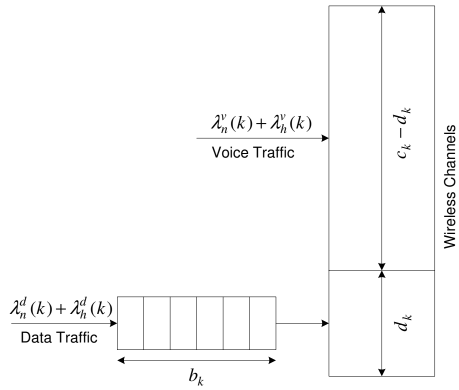


Fig. 2. Base station architecture.

The salient feature of our approach is that it considers the impacts of queueing, reneging and dedicated channels on data service performance while provides product-form solutions for major performance parameters. Our objective is to show the effect of handoffs on the performance of GPRS data traffic which is neglected by other researchers.

III. System Model

The system under consideration is a GSM/GPRS network, in which the users move along an arbitrary topology of M cells according to the routing probability r_{ij} (from cell i to cell j). Fig. 2 shows the base station architecture in cell k with c_k channels, where d_k channels are dedicated to GPRS data traffic and the rest, $c_k - d_k$ channels, are shared by voice and data traffic. In the shared part, voice traffic has priority over data traffic and can preempt data traffic.

In GPRS, available channels are divided into control channels and data channels. To initiate packet transfer (either uplink or downlink), an mobile station negotiates with the network for the required radio resources in the access and assignment phase via control channels. After this phase, the mobile station starts transmitting data packets to the network via data traffic channels according to the agreed resource assignment.

In our model, if there is no free channel upon initiating the resource request, the request will be queued in a finite buffer to be server later according to FIFO scheduling. If a mobile station hands off to a neighboring cell, all of its associated requests for packet transmission which are waiting in queue will be immediately removed from the queue and forwarded to the destination cell for service. We assume that packet handoff can not happen during the actual packet transmission due to the short length of data packets. If such an event happens at transmission time, it is the responsibility of lower layer protocols to assure the correct packet delivery. In terms of queueing terminology, packets are impatient until the beginning of their service.

The assumptions and parameters involved in this model are stated below.

1) The new voice call and data packet arrivals into cell k are Poisson distributed with rates $\lambda_n^v(k)$ and $\lambda_n^d(k)$.
2) The residence time of a mobile station in cell k is assumed to be exponentially distributed with means $1/\eta_k^v$ and $1/\eta_k^d$ for voice and data, respectively. A queued data packet is removed from the queue and is forwarded to the new cell, if the corresponding mobile station leaves the service area of the original cell before transmission.
3) The handoff call arrivals into cell k are assumed to be Poisson distributed with rates $\lambda_h^v(k)$ and $\lambda_h^d(k)$.
4) The transmission time of a GPRS packet in cell k is assumed to be exponentially distributed with mean $1/\mu_k^d$, where one channel serves the packet. Queued messages are served according to FIFO scheduling. The call holding time of a voice call is assumed to be exponentially distributed with mean $1/\mu_k^v$.
5) Define the *mobility factor* to be the ratio of the mean service (or call holding) time to the mean residence time , i.e., $\alpha_k^v = \eta_k^v/\mu_k^v$ and $\alpha_k^d = \eta_k^d/\mu_k^d$.
6) A finite buffer with capacity b_k packets is provided in each cell k for GPRS packets only.

In the real word, the cell residence time distribution may not be exponential but exponential distributions are widely used in research papers [1], [3], [6]–[8] and do provide the mean value analysis, which indicates the performance trend of the system. Our focus in this paper is on the performance of GPRS data traffic, hence handoff prioritization is not considered for voice calls.

IV. Analysis

Performance analysis of the GPRS can be accomplished by describing the system as a two-dimensional Markov chain corresponding to voice and data dynamics. This approach is computationally too complex and usually there is no closed-form expression for the performance parameters (see for example [1], [6], [7]). On the other hand, performance analysis based on simulations is prohibitively time consuming due to the significant difference in the time-scale of voice and data dynamics [5].

In GSM/GPRS systems the mean holding time of voice calls is much larger than the mean service time of data packets, hence voice calls evolve slowly compare to the data buffer dynamics. Therefore, the data queueing process exhibits transient behavior immediately after any change in the number of active voice calls, but will eventually settle into steady-state behavior. As an alternative approach, we take the advantage of this quasi-stationary behavior of the data queueing process to approximately evaluate the performance of data service in GPRS systems by decomposing the system behavior into short-term and long-term behaviors.

A. Long Term Behavior

Let $\boldsymbol{p}_k$ denote the stationary state probability vector of the Markov chain describes the number of active voice calls in cell k. Using balance equations, it is obtained that

$$\boldsymbol{p}_k(i) = \frac{1}{i!}\left(\frac{\lambda_n^v(k)+\lambda_h^v(k)}{\mu_k^v+\eta_k^v}\right)^i \boldsymbol{p}_k(0), \qquad 1 \le i \le c_k - d_k \tag{1}$$

where

$$\boldsymbol{p}_k(0) = \left[1 + \sum_{i=1}^{c_k-d_k} \frac{1}{i!}\left(\frac{\lambda_n^v(k)+\lambda_h^v(k)}{\mu_k^v+\eta_k^v}\right)^i\right]^{-1}. \tag{2}$$

Consequently, the call blocking probability of voice calls is given by

$$B_k = \boldsymbol{p}_k(c_k - d_k). \tag{3}$$

In a GPRS system, the number of channels that can be assigned to serve data packets is the sum of dedicated data channels, d_k, and those channels not used by voice calls. Let $\boldsymbol{\pi}_k$ denote the steady state probability vector of the number of channels that are available for GPRS data service in cell k, then

$$\boldsymbol{\pi}_k(m) = \boldsymbol{p}_k(c_k - d_k), \qquad m = d_k, d_k+1, \ldots, c_k. \tag{4}$$

B. Short Term Behavior

Assume that the number of channels serving GPRS packets in a cell k is fixed and equal to m with probability $\boldsymbol{\pi}_k(m)$ given by (4). Each packet requires one channel for transmission. Let s_i denote the state of the cell where $i\,(0 \le i \le m + b_k)$ indicates the number of GPRS packets in the cell which are being served or waiting in the queue. Fig. 3 shows the state transition

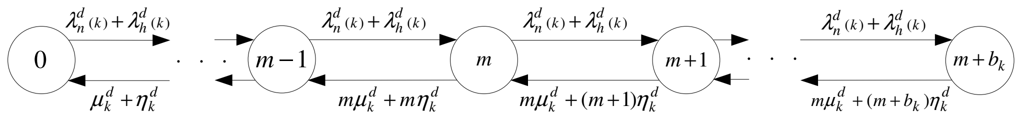


Fig. 3. Packet queueing state transition diagram.

diagram of the cell. Also, let $\delta_k^m(i)$ denote the transition rate from state s_i to state s_{i-1} when m channels serve the data packets, i.e.,

$$\delta_k^m(i) = \begin{cases} i\mu_k^d, & 0 \le i \le m \\ m\mu_k^d + (m-i)\eta_k^d, & m \le i \le m+b_k \end{cases} \tag{5}$$

Using balance equations, the steady-state probability vector $\boldsymbol{q}_k^m$ is given by

$$\boldsymbol{q}_k^m(i) = \prod_{j=1}^{i}\left(\frac{\lambda_n^d(k)+\lambda_h^d(k)}{\delta_k^m(j)}\right)\boldsymbol{q}_k^m(0), \quad 1 \le i \le m+b_k \tag{6}$$

Using the normalizing condition $\sum_{i=0}^{m+b_k}\boldsymbol{q}_k^m(i)=1$, it is obtained that

$$\boldsymbol{q}_k^m(0) = \left[1+\sum_{i=1}^{m+b_k}\prod_{j=1}^{i}\left(\frac{\lambda_n^d(k)+\lambda_h^d(k)}{\delta_k^m(j)}\right)\right]^{-1}. \tag{7}$$

A packet is lost when the data buffer is full upon its arrival. Therefore, the packet loss probability, L_k^m, is simply given by

$$L_k^m = \boldsymbol{q}_k^m(m+b_k). \tag{8}$$

C. Packet Delay Distribution

Define the packet delay as the time between the acceptance of a packet in a cell and the time its service starts in that cell. Let W_k^m denote the delay of an arriving packet in steady-state where m channels are serving GPRS packets in cell k. We are interested in finding the probability distribution of W_k^m

$$F_{W_k^m}(\tau) = \Pr(W_k^m \le \tau) \tag{9}$$

or, equivalently, the probability density function

$$f_{W_k^m}(\tau) = \frac{d}{d\tau}F_{W_k^m}(\tau). \tag{10}$$

where $\tau \in \Re^+$ throughout this paper.

Consider the service part of the cell and let S denote the duration between the time that all m data channels become busy and the time that the first channel is released. The probability distribution function of S is expressed as

$$F_S(\tau) = 1 - e^{-m\mu_k^d \tau} \tag{11}$$

The cell residency time of a packet, R, is determined by the time the corresponding portable remains in the cell. Therefore, the probability distribution function of R is expressed as

$$F_R(\tau) = 1 - e^{-\eta_k^d \tau} \tag{12}$$

Assume that a data packet d_i arrives to the cell when the cell is in state s_i, i.e., there are i packets already in the cell. If $0 \leq i < m + b_k$ then packet d_i is accepted and the cell state will change into s_{i+1}, i.e. there will be $i+1$ packets in the cell. If $i < m$ then d_i will be immediately served otherwise it must wait in the queue for $(i - m + 1)$ packet departures (either transmission or handoff). Let W_i denote the delay of d_i under the condition that d_i will not handoff prior to its service commences.

Suppose we temporarily view the cell as consisting of i packets (which are ahead of d_i). Then the time required for the packet population to decrease from j to $j-1$ is exponentially distributed with rate parameter $\delta_k^m(j)$. The probability that the arriving packet does not hand off into another cell during the interval of time required to drive the packet population from j to $j-1$ is given by $\delta_k^m(j)/\delta_k^m(j+1)$ for $m \leq j \leq i$. Therefore, the probability that d_i does not hand off into another cell before it is being transmitted, β_i, is given by

$$\begin{aligned} \beta_i = \Pr(W_i \leq R) &= \prod_{j=m}^{i} \frac{\delta_k^m(j)}{\delta_k^m(j+1)} \\ &= \frac{\delta_k^m(m)}{\delta_k^m(i+1)}, \qquad m \leq i \leq m + b_k \end{aligned} \tag{13}$$

Notice that, $\beta_i = 1$ for $i < m$. Consequently, the probability that d_i hands off before transmission is given by $1 - \beta_i$.

According to [9] we can write

$$\Pr(W_i \leq \tau) = \begin{cases} 1, & \text{if } i < m \\ \Pr(W_{i-1} + S \leq \tau \,|\, W_{i-1} \leq R), & \text{if } i \geq m \end{cases} \tag{14}$$

where S and R are defined by (11) and (12), respectively. We now proceed to derive the probability distribution function of W_i. Let

$$F_{W_i}(\tau) = \Pr(W_i \leq \tau) \tag{15}$$

and

$$f_{W_i}(\tau) = \frac{d}{d\tau} F_{W_i}(\tau). \tag{16}$$

If $i < m$ clearly packet delay is zero, hence, $f_{W_i}(\tau) = 0$. Thus, for the rest of derivation, we consider only the case of $i \geq m$ to simplify the equations. Using (14) we have

$$\begin{aligned} F_{W_i}(\tau) = & \frac{1}{\Pr(W_{i-1} \leq R)} \\ & \times \int_0^\tau F_S(\tau - t)(1 - F_R(t)) f_{W_{i-1}}(t)\, dt \end{aligned} \tag{17}$$

or, equivalently,

$$f_{W_i}(\tau) = \frac{(m\mu_k^d) e^{-m\mu_k^d \tau}}{\beta_{i-1}} \int_0^\tau e^{-m\mu_k^d t} e^{-\eta_k^d t} f_{W_{i-1}}(t)\, dt \tag{18}$$

By substituting $f_{W_{i-1}}(t)$ recursively in (18), it is obtained that

$$f_{W_i}(\tau) = \frac{(m\mu_k^d)^{i-m+1}}{(i-m)! \prod_{j=m}^{i-1} \beta_j} \left(\frac{1 - e^{-\eta_k^d \tau}}{\eta_k^d} \right)^{i-m} e^{-m\mu_k^d \tau} \tag{19}$$

Using (13), $f_{W_i}(\tau)$ is expressed as

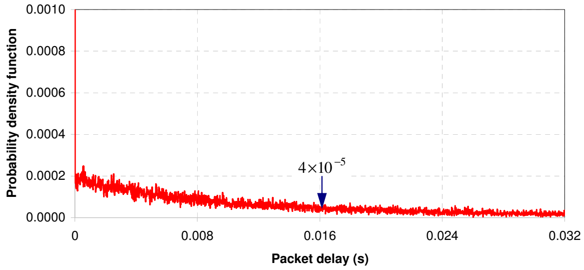
$$f_{W_i}(\tau) = \frac{\prod_{j=0}^{i-m} \delta_k^m (m+j)}{(i-m)!} \left(\frac{1 - e^{-\eta_k^d \tau}}{\eta_k^d} \right)^{i-m} e^{-m\mu_k^d \tau} \tag{20}$$

Finally, the steady-state probability distribution of W is given by

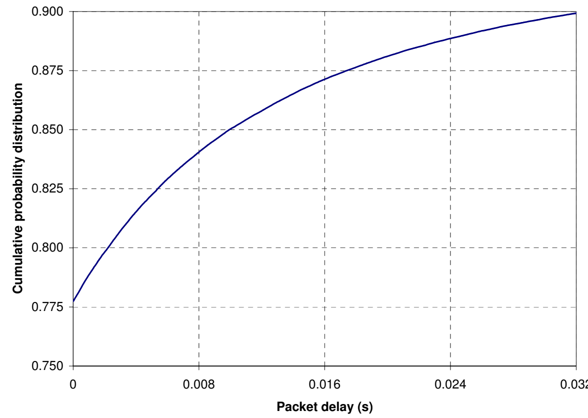
$$f_{W_k^m}(\tau) = \sum_{i=m}^{m+b_k-1} \boldsymbol{q}_k^m(i) f_{W_i}(\tau). \tag{21}$$

D. *Average Packet Delay*

As expressed in (20), packet delay is exponentially deceasing with time, hence, an average value should be a sufficiently accurate measure of the actual delay. Fig. 4 shows the actual measurements from a simulated GPRS network (please see section V for detailed simulation parameters) in which $c_k = 7$, $d_k = 1$, $b_k = 20$ and $\alpha_k^v = 1.8$. For this simulation, the average packet delay found to be $16\, ms$. As observer from Figs. 4(a) and 4(b), the probability of having packet delays greater than the average delay ($16\, ms$) is very small. In particular, $32\, ms$ is the



(a) Packet delay density function ($f_{W_k}(\tau)$).



(b) Packet delay distribution function ($F_{W_k}(\tau)$).

Fig. 4. Packet delay distribution.

90% delay bound. After all, our approach is approximate and such estimations will not affect its performance severely.

Therefore, in this subsection we intend to drive a closed form expression for average packet delay. Although it is possible to find the average packet delay using (20) and (21), we apply a direct derivation method which gives more insight into the system behavior. As previous subsection, consider packet d_i which is accepted in state s_i at time t. We are interested in finding the average delay of d_i denoted by $E[W_i]$ under the condition that d_i will not hand off before transmission. It is obvious that

$$E[W_i] = 0, \qquad i < m \tag{22}$$

therefore, we consider only the case of $i \geq m$ in the following discussion. Packet d_i must wait for $(i - m + 1)$ packet departures before getting service. Among these $(i - m + 1)$ packets, the first one will leave the cell at time $t + t_i$, the second at time $t + t_i + t_{i-1}$, and finally, the $(i - m + 1)$th at time $t + t_i + \cdots + t_m$. Hence, the delay of d_i is $T_i = \sum_{j=m}^{i} t_j$, where the probability distribution of t_j is given by

$$F_{t_j}(\tau) = 1 - e^{-\delta_k^m(j)\tau}. \tag{23}$$

Consequently, we have

$$\begin{aligned} E[W_i] &= E[T_i | W_i \leq R] \\ &= \frac{E[T_i \text{ and } W_i \leq R]}{\Pr(W_i \leq R)} \end{aligned} \tag{24}$$

Using (23), it is obtained that

$$E[t_j] = \frac{1}{\delta_k^m(j)} \tag{25}$$

therefore,

$$\begin{aligned} E[T_i \text{ and } W_i \le R] &= E\big[\sum_{j=m}^{i} t_j \text{ and } W_i \le R\big] \\ &= \left(\frac{\delta_k^m(m)}{\delta_k^m(i+1)}\right)\sum_{j=m}^{i}\frac{1}{\delta_k^m(j)} \end{aligned} \tag{26}$$

Substituting (26) in (24) gives

$$E[W_i] = \sum_{j=m}^{i}\frac{1}{\delta_k^m(j)} \tag{27}$$

Finally, the steady-state average packet delay $E[W_k^m]$ is expressed as

$$E[W_k^m] = \sum_{i=m}^{m+b_k-1} \boldsymbol{q}_k^m(i)\sum_{j=m}^{i}\frac{1}{\delta_k^m(j)} \tag{28}$$

E. Handoff Arrival Rate

We use the iterative approach widely used in literature (for example, see [3] and [10]) to find the voice call handoff rate $\lambda_h^v(k)$ and data packet handoff rate $\lambda_h^d(k)$ into cell k as follows.

1) Voice Call Handoff Rate: In cell j, the probability that a voice call will attempt to hand off is $P_H^v(j) = \eta_j^v/(\mu_j^v + \eta_j^v)$, hence the handoff rate of voice calls out of cell j is given by

$$(\lambda_v^j + \nu_v^j)(1 - B_j)P_H^v(j). \tag{29}$$

The mobile users move along the service area of M cells according to the routing probability r_{jk}. Using (29), the handoff rate of voice calls into cell k is given by

$$\lambda_h^v(k) = \sum_{j\neq k} r_{jk}\big[\lambda_n^v(j) + \lambda_h^v(j)\big]\big[1 - B_j\big]P_H^v(j). \tag{30}$$

Iteration can be used to obtain $\lambda_h^v(k)$. Starting with an initial value of $\lambda_h^v(k)$, we calculate B_k using (3). This value is then substituted in (30) to obtain a new value for $\lambda_h^v(k)$. This process is repeated until the value of $\lambda_h^v(k)$ converges.

2) Data Packet Handoff Rate: Following the same approach for the handoff voice calls, the handoff rate of data packets moving into cell k can thus be derived as

$$\lambda_h^d(k) = \sum_{j \neq k} r_{jk} \left[\lambda_n^d(k)(j) + \lambda_h^d(k)(j) \right] P_H^d(j) \tag{31}$$

where $P_H^d(j)$ is the probability that a waiting data packet in a cell will attempt to hand off and is given by

$$P_H^d(j) = \sum_{i=m}^{m+b_j-1} (1-\beta_i) \boldsymbol{q}_j^m(i) \tag{32}$$

where β_i is given by (13). Starting with an initial value of $\lambda_h^d(k)$, we first derive $P_H^d(j)$ using (32). From $P_H^d(j)$, a new value for $\lambda_h^d(k)$ can be calculated. This procedure is iterated until the value of $\lambda_h^d(k)$ converges.

F. Approximate System Behavior

The approximate system behavior is obtained by the aggregation of short term behavior with respect to the long term behavior. Let $E[W_k]$ and L_k denote the average packet delay and loss probability in cell k, then

$$E[W_k] = \sum_{m=d_k}^{c_k} \boldsymbol{\pi}_k(m) E[W_k^m] \tag{33}$$

$$L_k = \sum_{m=d_k}^{c_k} \boldsymbol{\pi}_k(m) L_k^m \tag{34}$$

where L_k^m and $E[W_k^m]$ are given by (8) and (28). Similarly, we can compute the approximate packet delay distribution using (21),

$$f_{W_k}(\tau) = \sum_{m=d_k}^{c_k} \boldsymbol{\pi}_k(m) f_{W_k^m}(\tau). \tag{35}$$

V. Numerical Results

An event-driven simulation was developed to verify the accuracy of the analysis. The simulation considered a two-dimensional GSM/GPRS network, in which the coverage area is partitioned into seven cells, as shown in Fig. 5. Opposite sides wrap-around to eliminate the finite size effect. We assumed that the mobile users move along the cell areas according to a uniform routing table, i.e. all cells are equally chosen for handoff, although the simulation can accommodate general

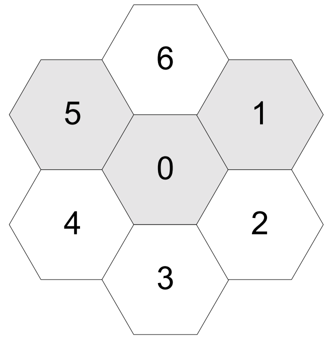


Fig. 5. Simulation model.

cases. To simplify our results, only the exponential cell residency and transmission times were considered. Besides, for ease of illustrating the results, we assumed that for any cell k

$$\rho_v = \frac{\lambda_n^v(k)}{\mu_k^v} = \frac{\lambda_v}{\mu_v}, \quad \rho_d = \frac{\lambda_n^d(k)}{\mu_k^d} = \frac{\lambda_d}{\mu_d} \\ c = c_k, \quad d = d_k, \quad b = b_k, \quad \alpha = \alpha_k^v. \tag{36}$$

where $\rho_v(\rho_d)$ indicates the offered voice (data) load.

We assume that there is one frequency carrier (or seven channels) per cell, i.e., $c = 7$. Furthermore, in all the cases that have been simulated, $\rho_v = 3$, $1/\mu_v = 180s$ and $\mu_d/\mu_v = 10^4$. This set of parameters assures an acceptable level of call blocking for voice calls ($\approx 5\%$). Table I shows the simulated configurations and their corresponding voice call blocking probability.

The first set of simulations depicted in Fig. 6 represents the GPRS performance for different mobility factors over a wide range of GPRS offered loads ($\rho_d = 1, 2, 3, 4$). Three mobility profiles, namely, high mobility ($\alpha = 5.0$), moderate mobility ($\alpha = 1.8$) and low mobility ($\alpha = 0.2$) have been considered (see Table I: *Mobility effect*). As shown in these figures, both packet loss and average packet delay decrease by increasing the mobility factor. This is due to the fact that the buffer occupancy times increase as the mobility decreases, resulting in the associated increases in packet loss probability and delay.

The second set of simulations in Fig. 7 shows the effect of data buffer size on GPRS performance for the moderate mobility configuration (see Table I: *Buffer size effect*). Observed from Fig. 7(a), the packet loss probability is almost insensitive to the buffer size for the simulated range of loads. In contrast, average packet delay significantly increases by increasing the buffer

TABLE I

VOICE CALL BLOCKING PROBABILITY.

Profile		P_B	
Effect	Parameter	Simulation	Analysis
	$\alpha = 0.2$	0.045 $\pm$ 0.005	0.051
Mobility factor	$\alpha = 1.8$	0.041 $\pm$ 0.004	0.041
$(b = 20, d = 1)$	$\alpha = 5.0$	0.031 $\pm$ 0.002	0.032
	$b = 20$	0.041 $\pm$ 0.004	0.041
Buffer size	$b = 50$	0.041 $\pm$ 0.004	0.041
$(\alpha = 1.8, d = 1)$	$b = 100$	0.041 $\pm$ 0.004	0.041
	$d = 0$	0.022 $\pm$ 0.002	0.019
Dedicated channels	$d = 1$	0.041 $\pm$ 0.004	0.041
$(\alpha = 1.8, b = 20)$	$d = 2$	0.077 $\pm$ 0.005	0.079

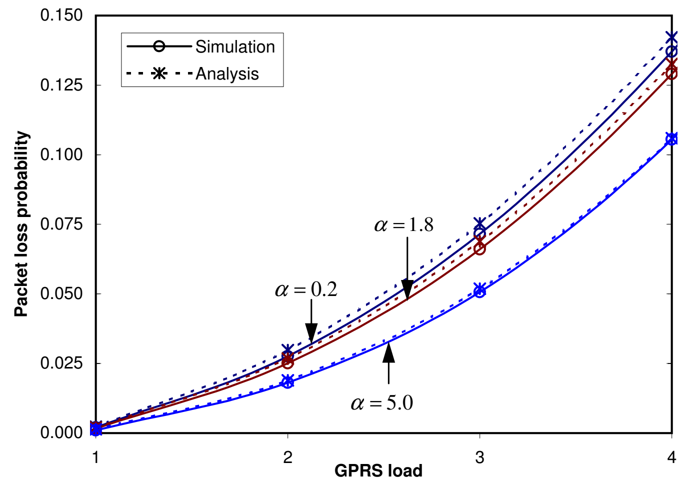
size as shown in Fig. 7(b). Notice that in these simulations, there is only one dedicated data channel, thus the GPRS load of $\rho_d = 4.0$ is relatively a high load.

The third set of simulations in Fig. 8 shows the effect of dedicated data channels on GPRS performance for the moderate mobility and small buffer size configuration (see Table I: *Dedicated channels effect*). As expected, increasing the number of dedicated channels significantly improves the data performance. The interesting part of these figures is the case of $d = 0$ which shows that, in fact, GPRS service can utilize the GSM wireless resources while providing an acceptable data service for delay-tolerant applications.

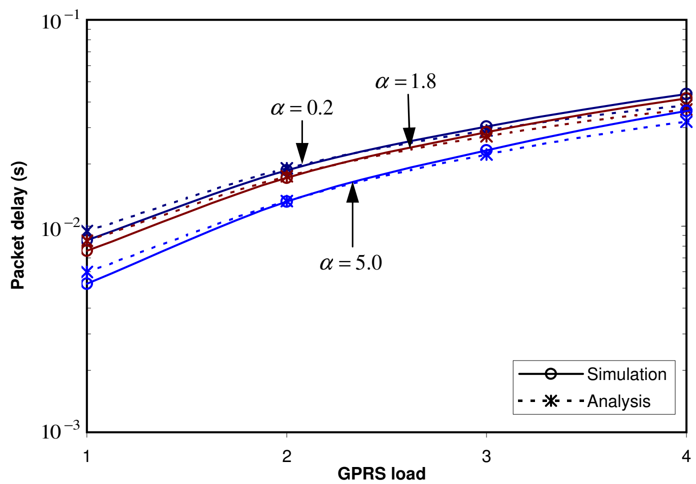
Finally, as observed form all the presented simulation results, the approximate analysis provides rather accurate results for packet loss probability. However, its accuracy for average packet delay depends on the offered GPRS load. Increasing the offered load decreases the accuracy of the presented approximate analysis.

VI. CONCLUSION

In this paper, we analyzed the performance of GPRS data service with buffering and dedicated channels for data traffic while we considered the effect of reneging data packets due to the corresponding user handoff. Through analysis and simulation we showed that the impact of handoff on GPRS performance is not negligible in contrast to what is usually assumed in literature. For future work, we consider extending the presented analysis to more general cases



(a) Packet loss probability.



(b) Packet delay.

Fig. 6. Mobility effect.

such as non-exponential cell residence times and more realistic packet arrival processes such as Markov modulated Poisson process.

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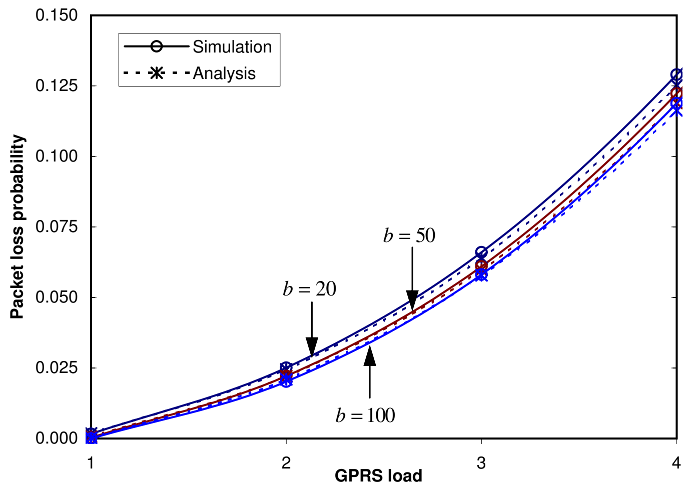
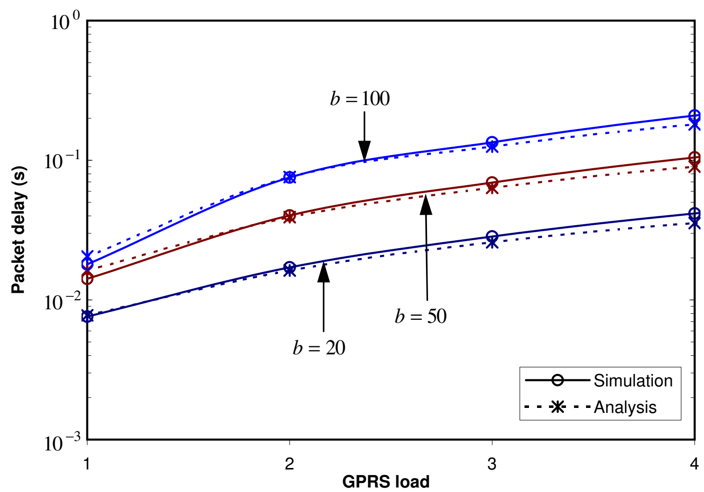


(a) Packet loss probability.



(b) Packet delay.

Fig. 7. Buffer size effect.

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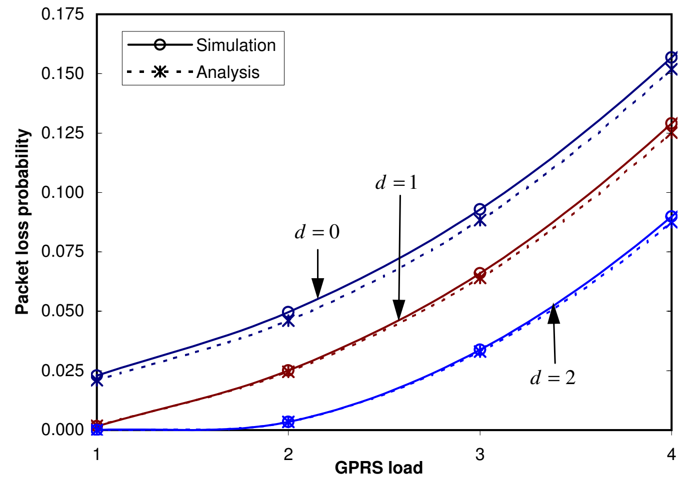
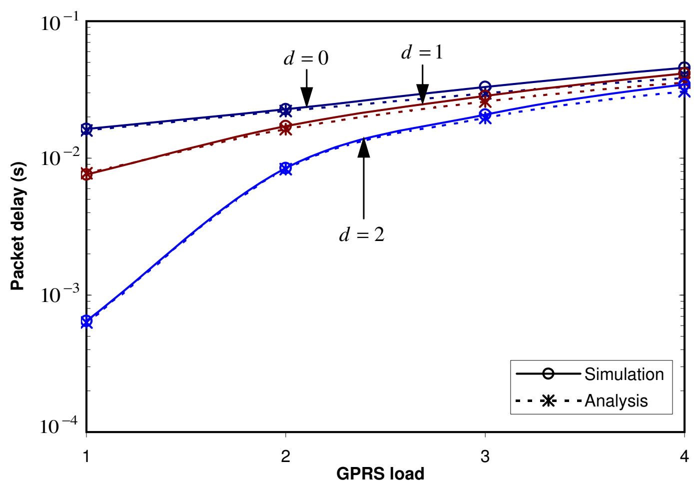


(a) Packet loss probability.



(b) Packet delay.

Fig. 8. Dedicated channel effect.

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