The Impact of User Mobility on Data Service Performance in GPRS Systems

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***Abstract*— In this paper we describe an analytical approach to derive the average packet delay and packet loss probability in a cell of a wireless network operating based on the GSM/GPRS standard. This analytical approach is based on the decomposition of system behavior to short-term and long-term behavior to simplify the analytical modeling. In addition to voice call handoffs, the impact of handoff and guard channels for data traffic is also taken into consideration in the analysis. 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.**

I. Introduction

General Packet Radio Service (GPRS) [1] 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 [2]. 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.

In a more general context, voice and data integration in wireless networks has been recently investigated by wireless research community. An integrated voice/data wireless system with finite buffer for data traffic has been considered in [3], where the system is described by a two-dimensional Markov chain which can be only numerically solved. A similar system based on the movable boundary approach is investigated in [4] without considering handoff for data packets waiting in queue. Fluid flow analysis has been applied in [5] while only the effect of voice handoff has been taken into consideration. More specifically, [6] and [2] investigated a GPRS system with voice handoffs only. A two-dimensional continues time Markov chain has been formulated in [6] to describe the system behavior. Queueing of voice calls has been investigated in detail in [2] without considering the queueing of data traffic.

In this paper, we focus on the performance of GPRS data service with buffering and guard channels for data traffic while we consider the effect of reneging data packets due to the corresponding user handoff. The salient feature of our approach is that it considers the impacts of queueing, reneging and guard channels on data service performance while provides product-form solutions for major performance parameters. The rest of the paper is organized as follows. In section II, we describe the system model and clarify our assumptions. System analysis is presented in section III. Section IV presents some numerical results, and finally, section V concludes the paper (please refer to [7] for more details).

II. 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). In each cell k with c_k channels, d_k channels are reserved for 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. Our focus in this paper is on the performance of GPRS data traffic, hence handoff prioritization is not considered for voice calls. 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. We assume that packet handoff can not happen during the actual packet 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. Also, the call holding time of a voice call is assumed to be exponentially distributed with mean $1/\mu_k^v$.
5) The *mobility factor* is defined as the ratio of the handoff rate to the service rate, 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.

III. Analysis

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. 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.

A. Long Term Behavior

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

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

where $\boldsymbol{p}_k(0)$ can be found using the normalizing condition $\sum_{i=0}^{c_k-d_k} \boldsymbol{p}_k(i) = 1$. Consequently, the call blocking probability of voice calls is given by $B_k = \boldsymbol{p}_k(c_k - d_k)$. 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

$$\boldsymbol{\pi}_k(m) = \boldsymbol{p}_k(c_k - d_k), \qquad m = d_k, d_k+1, \ldots, c_k. \quad (2)$$

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 (2). 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. Also, let $\delta_k^m(i)$ denote the transition rate from state s_i to state s_{i-1}, i.e.,

$$\delta_k^m(i) = \begin{cases} i\mu_k^d, & 0 \le i \le m \\ m\mu_k^d + (m-i)\eta_k^d, & m \le i \le m+b_k \end{cases} \quad (3)$$

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

$$\boldsymbol{q}_k^m(i) = \prod_{j=1}^{i}\left(\frac{\lambda_n^d(k)+\lambda_h^d(k)}{\delta_k^m(j)}\right)\boldsymbol{q}_k^m(0), \quad 1 \le i \le m+b_k \quad (4)$$

where $\boldsymbol{q}_k^m(0)$ can be found using the normalizing condition $\sum_{i=0}^{m+b_k} \boldsymbol{q}_k^m(i) = 1$. 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 $L_k^m = \boldsymbol{q}_k^m(m+b_k)$.

C. Average Packet Delay

Define the packet delay as the time between the acceptance of a packet in a cell and the time its service starts. Let W_k^m denote the delay of an arriving packet in steady-state where m channels are serving GPRS packets. Assume that a data packet d_i arrives to cell k when the cell is in state s_i. If $0 \le i < m+b_k$ then packet d_i is accepted and the cell state will change into s_{i+1}. 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 $m \le j \le i$. Therefore, the probability that d_i does not hand off into another cell before it is being transmitted, β_i, is given by

$$\beta_i = \Pr(W_i \le R) = \prod_{j=m}^{i}\frac{\delta_k^m(j)}{\delta_k^m(j+1)} = \frac{\delta_k^m(m)}{\delta_k^m(i+1)} \quad (5)$$

where R is a random variable representing the cell residency time of a typical packet. Notice that $\beta_i = 1$ for $i < m$. If $i < m$, packet delay is zero, hence, for the rest of derivation, we consider only the case of $i \ge m$ to simplify the equations.

Packet d_i must wait for $(i-m+1)$ 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

$$F_{t_j}(\tau) = 1 - e^{-\delta_k^m(j)\tau}. \quad (6)$$

Consequently, we have

$$E[W_i] = E[T_i | W_i \le R] = \frac{E[T_i \text{ and } W_i \le R]}{\Pr(W_i \le R)} \quad (7)$$

Using (6), it is obtained that $E[t_j] = 1/\delta_k^m(j)$, therefore,

$$E[T_i \text{ and } W_i \le R] = \left(\frac{\delta_k^m(m)}{\delta_k^m(i+1)}\right)\sum_{j=m}^{i}\frac{1}{\delta_k^m(j)} \quad (8)$$

Substituting (8) in (7) gives $E[W_i] = \sum_{j=m}^{i} 1/\delta_k^m(j)$. Finally, the steady-state average packet delay $E[W_k^m]$ is expressed as

$$E[W_k^m] = \sum_{i=m}^{m+b_k-1} \boldsymbol{q}_k^m(i)\sum_{j=m}^{i}\frac{1}{\delta_k^m(j)} \quad (9)$$

We use the iterative approach of [4] to find the voice call handoff rate $\lambda_h^v(k)$ and data packet handoff rate $\lambda_h^d(k)$ into cell k.

D. Approximate System Behavior

The approximate system behavior is obtained by aggregating the short term behaviors 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

$$E[W_k] = \sum_{m=d_k}^{c_k} \boldsymbol{\pi}(m)E[W_k^m] \quad (10)$$

$$L_k = \sum_{m=d_k}^{c_k} \boldsymbol{\pi}(m)L_k^m \quad (11)$$

where L_k^m and $E[W_k^m]$ are computed as described before.

IV. 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. 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

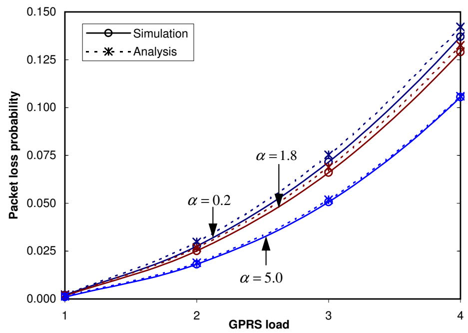

Fig. 1. Mobility effect: packet loss.

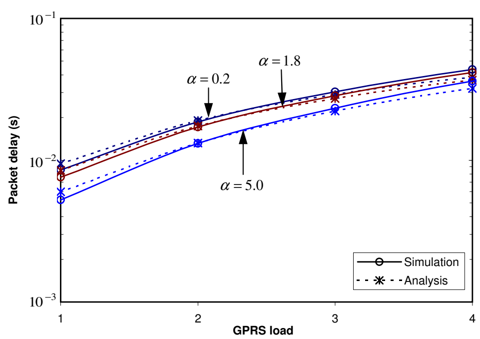

Fig. 2. Mobility effect: packet delay.

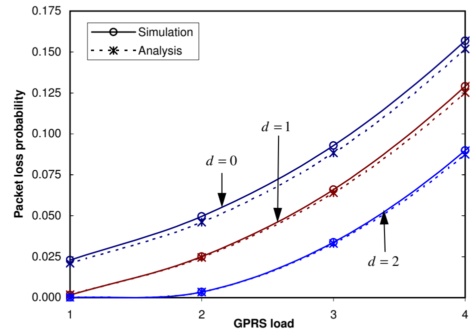

Fig. 3. Guard channels effect: packet loss.

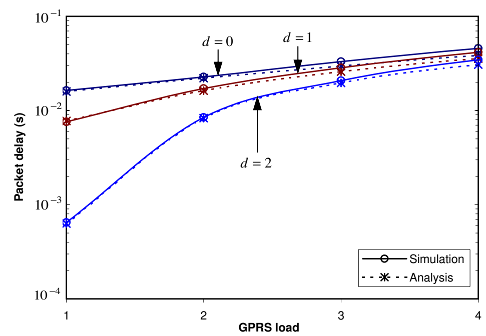

Fig. 4. Guard channels effect: packet delay.

routing matrix, in which all cells are equally chosen for handoff, although the simulation can accommodate general cases. Besides, for ease of illustrating the results, we assumed that for any cell k

$$\rho_v = \frac{\lambda_n^v(k)}{\mu_k^v} = \frac{\lambda_v}{\mu_v}, \quad \rho_d = \frac{\lambda_n^d(k)}{\mu_k^d} = \frac{\lambda_d}{\mu_d}$$
$$c = c_k, \quad d = d_k, \quad b = b_k, \quad \alpha_v = \alpha_k^v, \quad \alpha_d = \alpha_k^d. \tag{12}$$

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 ($\approx 5\%$).

The first set of simulations depicted in Figs. 1 and 2, represents the GPRS performance for different mobility factors for a wide range of GPRS traffic loads ($\rho_d = 1, 2, 3, 4$). Three mobility configurations, namely, high mobility ($\alpha = 5.0$), moderate mobility ($\alpha = 1.8$) and low mobility ($\alpha = 0.2$) have been used, where $\alpha = \alpha_v$. 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 Figs. 3 and 4 shows the effect of data guard channels on GPRS performance for the moderate mobility configuration. As expected, increasing the number of guard 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.

V. Conclusion

In this paper, we analyzed the performance of GPRS data service with buffering and guard 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 typically assumed in literature. As the future work, we are investigating the packet delay distribution which is of more interest to network control and management.

References

[1] 3GPP TS 23.140, "General packet radio service (GPRS); service description; stage 2; release 5," v5.0.0, 2002.

[2] P. Lin and Y.-B. Lin, "Channel allocation for GPRS," *IEEE Trans. Veh. Technol.*, vol. 50, no. 2, pp. 375–384, Mar. 2001.

[3] H. Wu, L. Li, B. Li, L. Yin, I. Chlamtac, and B. Li, "On handoff performance for an integrated voice/data cellular system," in *Proc. IEEE PIMRC'02*, vol. 5, Lisboa, Portugal, Sept. 2002, pp. 2180–2184.

[4] Y.-R. Haung, Y.-B. Lin, and J.-M. Ho, "Performance analysis for voice/data integration on a finite-buffer mobile system," *IEEE Trans. Veh. Technol.*, vol. 49, no. 2, pp. 367–378, Mar. 2000.

[5] D.-S. Lee and C.-C. Chen, "QoS of data traffic with voice handoffs in a PCS network," in *Proc. IEEE GLOBECOM'02*, vol. 2, Taipei, Taiwan, Nov. 2002, pp. 1534–1538.

[6] M. A. Marsan, P. Laface, and M. Meo, "Packet delay analysis in GPRS systems," in *Proc. IEEE INFOCOM'03*, vol. 2, San Francisco, USA, Mar. 2003, pp. 970–978.

[7] M. Ghaderi and R. Boutaba, "Mobility impact on data service performance in GPRS systems," School of Computer Science, University of Waterloo, Tech. Rep. CS-2004-08, Feb. 2004.