Bandwidth Reservation in the Erlang Multirate Loss Model for Elastic and Adaptive Traffic

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***Abstract*—In this paper, we consider a single-link multirate loss system, which accommodates *K* service-classes with different traffic and peak-bandwidth requirements. Calls of each service-class arrive in the system according to a Poisson process and have an exponentially distributed service time. The *K* different service-classes are distinguished in K_e elastic service-classes and K_a adaptive service-classes ($K=K_e + K_a$). Elastic calls can compress their peak-bandwidth by simultaneously increasing their service time, while, adaptive calls can tolerate bandwidth compression without affecting their service time. The system incorporates the bandwidth reservation (BR) policy whereby we can achieve certain quality of service (QoS) for each service-class through a proper bandwidth allocation, defined by the BR parameters. To calculate, in an approximate but efficient way, Call Blocking Probabilities (CBP) and link utilization, we propose a recurrent formula for the determination of the link occupancy distribution. The accuracy of the proposed formula is verified by simulation and is found to be very satisfactory. We also show the consistency and the necessity of the new model.**

Keywords - loss system; blocking probability; reservation; elastic-adaptive traffic; recursive formula.

I. INTRODUCTION

Call-level multirate loss models of a single link that supports elastic and adaptive service-classes have received attention over the last years due to the increase of elastic and adaptive traffic in communication networks and the consequent need for QoS network assessment (e.g., [1]-[11]). Elastic traffic is composed of calls that expand their service time when their bandwidth is compressed. On the other hand, adaptive traffic refers to calls that do not alter their service time in the case of bandwidth compression. Examples of elastic traffic are generally TCP-based applications (FTP, HTTP, STMP), while examples of adaptive traffic are mostly real-time applications, like audio and video streaming, which can be transmitted with an acceptable QoS after bandwidth compression.

The analysis of a single link multirate loss system, which accommodates elastic and adaptive calls that arrive to the system according to a Poisson process and have an exponentially distributed service time has been proposed in [2]. In [2], an arriving call is accepted in the system with its peak-bandwidth requirement, when the occupied link bandwidth does not exceed the capacity of the link. Otherwise, the system accepts this new call by compressing its peak-bandwidth, together with the bandwidth of all in-service calls of all service-classes. Call blocking occurs when the maximum possible bandwidth compression is still not enough to ensure the acceptance of a new call in the system. When an in-service call, whose bandwidth is compressed, departs from the system, then the remaining in-service calls (of all service-classes) expand their bandwidth. The existence of the bandwidth compression/expansion mechanism destroys the Markov chain reversibility and therefore the model of [2] does not have a Product Form Solution (PFS). However, the calculation of CBP and link utilization is based on an approximate but recursive formula for the determination of link occupancy distribution. This formula resembles the classical Kaufman-Roberts formula used in the Erlang Multirate Loss Model (EMLM), where Poisson arriving calls have fixed bandwidth requirements (stream traffic, no bandwidth compression is permitted) and compete for the available link bandwidth under the complete sharing policy [12], [13]. To this end, we name herein the model of [2], Extended EMLM (E-EMLM). The co-existence of stream and elastic traffic in the same link has been considered in [11], but the proposed formulas are not recursive (i.e., do not resemble the Kaufman-Roberts formula).

In this paper, we incorporate into the E-EMLM the BR policy (E-EMLM/BR). The BR policy can achieve CBP equalization among service-classes (either elastic or adaptive), or guarantee a certain QoS for each service-class, by a proper selection of the BR parameters so that each service-class meets a certain bandwidth capacity. The consideration of the BR policy is of paramount importance in multirate communication networks, given that the absence of the BR policy leads to an unfair service (the less required bandwidth, the better CBP). The proposed model does not have a PFS and therefore we provide an approximate recursive formula for the determination of the link occupancy distribution. The latter not only simplifies the calculation of CBP and link utilization but also provides quite satisfactory results compared to simulation. Note that a multirate loss system that accommodates Poisson arriving calls of elastic traffic only has been considered in [1], while the application of the BR policy in that model has been proposed in [14].

The remainder of this paper is as follows: In Section II, we review the E-EMLM. In Section III, we propose the E-EMLM/BR. Section IV is the evaluation section. We present analytical and simulation results of CBP and link utilization of the E-EMLM/BR. We also provide analytical results of the E-EMLM for comparison. We conclude in Section V.

II. REVIEW OF THE E-EMLM

A. *Review of the E-EMLM*

Consider a single link of capacity C bandwidth units (b.u.) that accommodates calls of K service-classes. Let K_e and K_a be the set of elastic and adaptive service-classes ($K_e + K_a = K$), respectively. A call of service-class k ($k = 1,\ldots,K$) follows a Poisson process with arrival rate λ_k and has a peak-bandwidth requirement of b_k b.u. (integer value). Let j be the occupied link bandwidth when a new service-class k call arrives in the link. If $j + b_k \le C$, the call is accepted in the system with its b_k b.u. and remains in the system for an exponentially distributed service time with mean μ_k^{-1}. The new service-class k call is blocked and lost if $j + b_k > T$, where T is the limit (in b.u.) up to which bandwidth compression is permitted. If $T \ge j + b_k > C$ the new call is accepted in the system. However, the assigned bandwidth of all in-service calls, together with the peak-bandwidth requirement of the new call is compressed. After the bandwidth compression of all calls (new and in-service) the system state becomes $j = C$. The compressed bandwidth of the new service-class k call is calculated by:

$$b_k' = r b_k = \frac{C}{j'} b_k \tag{1}$$

where $r \equiv r(\boldsymbol{n}) = C/j'$, $j' = j + b_k = \boldsymbol{nb} + b_k$, $\boldsymbol{n} = (n_1, n_2, \ldots, n_k, \ldots, n_K)$, n_k is the number of in-service calls of service-class k, $\boldsymbol{b} = (b_1, b_2, \ldots, b_k, \ldots, b_K)$ and $j = \sum_{k=1}^{K} n_k b_k = \boldsymbol{nb}$.

Similarly, the compressed bandwidth of all in-service calls is equal to $b_i' = \frac{C}{j'} b_i$ for $i = 1,\ldots,K$. The minimum bandwidth of a service-class k call is given by:

$$b_{k,\min}' = r_{\min} b_k = \frac{C}{T} b_k \tag{2}$$

After the bandwidth compression, all elastic calls increase their service time so that the product (service time) by (bandwidth) remains constant.

The mechanism of bandwidth compression/expansion destroys reversibility in the E-EMLM and therefore no PFS exists. However, in [2] an approximate recursive formula is proposed which determines the link occupancy distribution, $G(j)$, (unnormalized values):

$$G(j) = \begin{cases} 1 & \text{for } \; j = 0 \\ \dfrac{1}{\min(j,C)} \sum_{k \in K_e} \alpha_k b_k G(j - b_k) + \\ \dfrac{1}{j} \sum_{k \in K_a} \alpha_k b_k G(j - b_k) & \text{for } \; j = 1,\ldots,T \\ 0 & \text{for } \; j < 0 \end{cases} \tag{3}$$

where $\alpha_k = \lambda_k / \mu_k$ is the offered traffic-load (in erl) of service-class k.

Based on (3) we can calculate CBP and the link utilization, as follows:

1) The CBP of service-class k, B_k:

$$B_k = \sum_{j = T - b_k + 1}^{T} G^{-1} G(j) \tag{4}$$

2) the link utilization, denoted as U:

$$U = \sum_{j=1}^{C} j G^{-1} G(j) + \sum_{j=C+1}^{T} C G^{-1} G(j) \tag{5}$$

where $G = \sum_{j=0}^{T} G(j)$ is the normalization constant.

III. THE E-EMLM UNDER THE BR POLICY

If we apply the BR policy to the E-EMLM (E-EMLM/BR), then (3) takes the form:

$$G(j) = \begin{cases} 1 & \text{for } \; j = 0 \\ \dfrac{1}{\min(j,C)} \sum_{k \in K_e} \alpha_k D_k(j - b_k) G(j - b_k) + \\ \dfrac{1}{j} \sum_{k \in K_a} \alpha_k D_k(j - b_k) G(j - b_k) & \text{for } \; j = 1,\ldots,T \\ 0 & \text{for } \; j < 0 \end{cases} \tag{6}$$

$$D_k(j - b_k) = \begin{cases} b_k & \text{for } \; j \le T - t(k) \\ 0 & \text{for } \; j > T - t(k) \end{cases} \tag{7}$$

where $t(k)$ is the reserved bandwidth (BR parameter) for service-class k calls (either elastic or adaptive).

The BR policy ensures CBP equalization among different service-classes by a proper selection of the BR parameters. If, for example, CBP equalization is required between calls of three service-classes with $b_1 = 1$, $b_2 = 7$ and $b_3 = 10$ b.u., respectively, then $t(1) = 9$ b.u, $t(2) = 3$ and $t(3) = 0$ b.u. so that $b_1 + t(1) = b_2 + t(2) = b_3 + t(3)$. If $t(k) = 0$ for all k ($k = 1,\ldots,K$) then the E-EMLM results. Furthermore, if $T = C$ then the EMLM results.

The application of the BR policy in the E-EMLM is based on the assumption that the number of service-class k calls is negligible in states $j > T\text{-}t(k)$ and is incorporated in (6) by the variable $D_k(j\text{-}b_k)$ given in (7). The states $j > T\text{-}t(k)$ belong to the so-called reservation space. Note that the population of calls of service-class k in the reservation space may not be negligible. In [15], [16] a complex procedure is implemented in order to take into account this population and increase the accuracy of CBP results in the EMLM and Engset multirate state-dependent loss models, respectively. However, according to [16] this procedure may not always increase the accuracy of the CBP results compared to simulation.

The CBP of service-class k, B_k, in the E-EMLM/BR is given by:

$$B_k = \sum_{j=T-b_k-t(k)+1}^{T} G^{-1}G(j) \tag{8}$$

Having obtained the values of the link occupancy distribution, $G(j)$, according to (6) we can calculate the link utilization according to (5).

Note that if the link accommodates only elastic service-classes then the link occupancy distribution can be determined by the following recursive formula [14]:

$$G(j) = \begin{cases} 1 & \text{for } \ j = 0 \\ \dfrac{1}{\min(j,C)} \sum\limits_{k \in K_e} \alpha_k D_k(j-b_k) G(j-b_k) & \text{for } \ j = 1,\dots,T \\ 0 & \text{for } \ j < 0 \end{cases} \tag{9}$$

where the values of $D_k(j\text{-}b_k)$ are calculated by (7).

Furthermore, if the link accommodates only stream traffic (i.e., calls of all service-classes cannot compress their bandwidth) then the link occupancy distribution is given by [17]:

$$G(j) = \begin{cases} 1 & \text{for } \ j = 0 \\ \dfrac{1}{j} \sum\limits_{k \in K} \alpha_k D_k(j-b_k) G(j-b_k) & \text{for } \ j = 1,\dots,C \\ 0 & \text{for } \ j < 0 \end{cases} \tag{10}$$

where T=C and the values of $D_k(j\text{-}b_k)$ are calculated by (7).

IV. APPLICATION EXAMPLE - EVALUATION

In this section, we present an application example of the new model, E-EMLM/BR, and the existing model, E-EMLM. Through the E-EMLM/BR we obtain analytical CBP and link utilization results, and we compare them with the corresponding simulation results, in order to reveal the accuracy of the proposed model. We also compare the analytical CBP and link utilization results of the E-EMLM/BR with those obtained by the E-EMLM to reveal the consistency and the necessity of the proposed model. As far as simulation results are concerned, they are mean values of 7 runs; no reliability ranges are presented, because they are very small. The simulation language used is Simscript II.5 [18].

As an application example, we consider a single link of capacity C = 100 b.u., that accommodates calls of four service-classes, with the following traffic characteristics:

1st service-class: α_1 = 12 erl, b_1 = 1 b.u.
2nd service-class: α_2 = 6 erl, b_2 = 2 b.u.
3rd service-class: α_3 = 3 erl, b_3 = 4 b.u.
4th service-class: α_4 = 2 erl, b_4 = 10 b.u.

Calls of the 1st and 2nd service-class are elastic, while calls of the 3rd and 4th service-class are adaptive. The limit T, up to which bandwidth compression of all calls is permitted, takes two different values T = 120 and T = 140 b.u. In the first case, the minimum proportion of the required peak-bandwidth takes the value: $r_{\min}$= C/T=100/120=5/6. Similarly, in the second case: $r_{\min}$= C/T=100/140=5/7.

When the BR policy is applied in the E-EMLM/BR, we choose the BR parameters $t(1)$=9, $t(2)$=8, $t(3)$=6 and $t(4)$=0 in order to achieve CBP equalization among the four service-classes, since: b_1+ $t(1)$=b_2+$t(2)$=b_3+$t(3)$=b_4+$t(4)$.

In the x-axis of all figures, traffic loads α_1, α_2, α_3 and α_4 increase in steps of 2, 1, 0.5 and 0.25 erl, respectively. In this way, Point 1 represents the vector (α_1, α_2, α_3, α_4) = (12.0, 6.0, 3.0, 2.0) while Point 7 is (α_1, α_2, α_3, α_4) = (24.0, 12.0, 6.0, 3.5). In Figs. 1-4, we consider the value T = 120 b.u and present the analytical and simulation CBP results of the four service-class calls, respectively, in the case of the E-EMLM/BR. For comparison, we give the corresponding analytical CBP results of the E-EMLM. The value T = 140 b.u is considered in Figs. 5-8. Due to CBP equalization achieved by the aforementioned BR parameters, the analytical CBP results of the E-EMLM/BR are exactly the same in Figs. 1-4. The same happens in Figs. 5-8. The differences between the CBP results of the E-EMLM/BR and the E-EMLM show the consistency and the necessity of the E-EMLM/BR. Finally, in Fig. 9, we consider both values of T and present the analytical and simulation results of the link utilization in the case of the E-EMLM/BR. For comparison, we give the corresponding analytical results for the E-EMLM.

All figures show that the analytical and simulation CBP results of the E-EMLM/BR are very close; this fact reveals the accuracy of the E-EMLM/BR. In addition, the comparison of Fig. 1 with Fig. 5, Fig. 2 with Fig. 6, Fig. 3 with Fig. 7 and Fig. 4 with Fig. 8 shows that the increase of T reduces the values of CBP of each service-class; this fact shows the consistency of the E-EMLM/BR. Furthermore, note that the choice of the BR parameters that achieve CBP equalization, actually favors calls of the 4th service-class only (see Figs 1-4 and Figs 5-8, where the CBP of the first three service-classes increase in the E-EMLM/BR compared to the corresponding CBP results in the E-EMLM). As far as the link utilization results of Fig. 9 are concerned, they show that the compression/expansion mechanism increases the link utilization, since it decreases CBP.

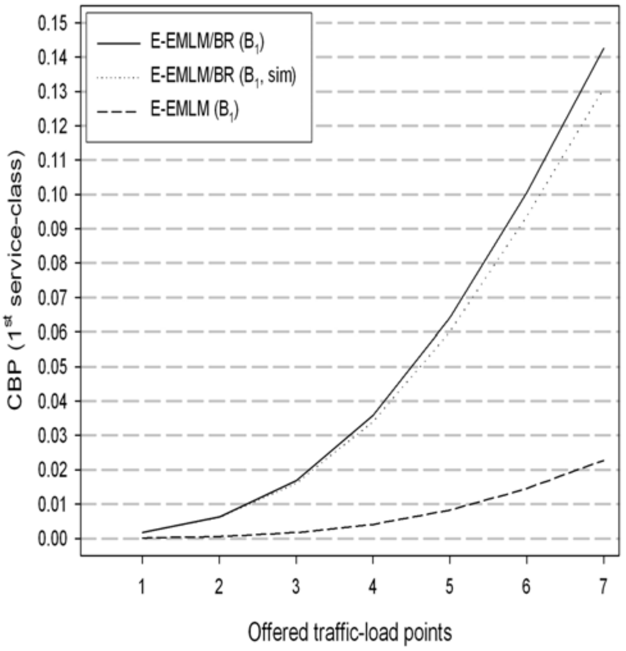

Figure 1. CBP of the 1st service-class (E-EMLM, E-EMLM/BR, T=120).

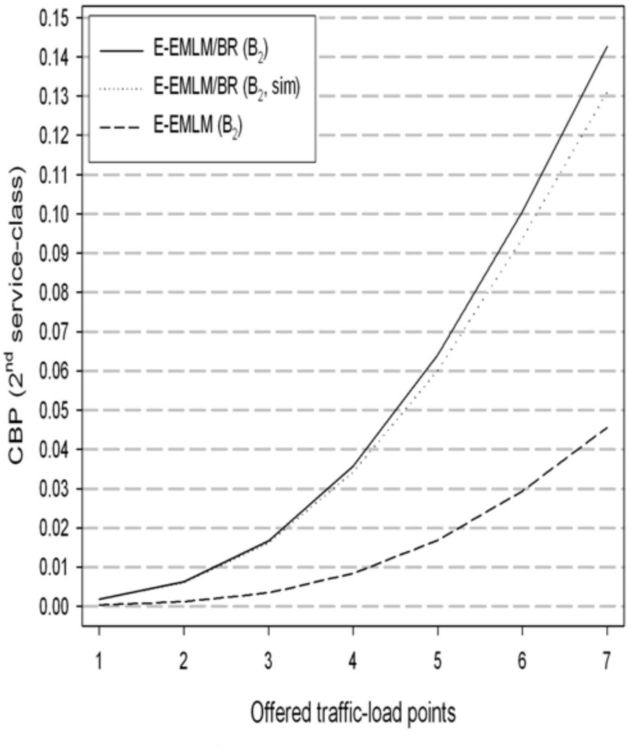

Figure 2. CBP of the 2nd service-class (E-EMLM, E-EMLM/BR, T=120).

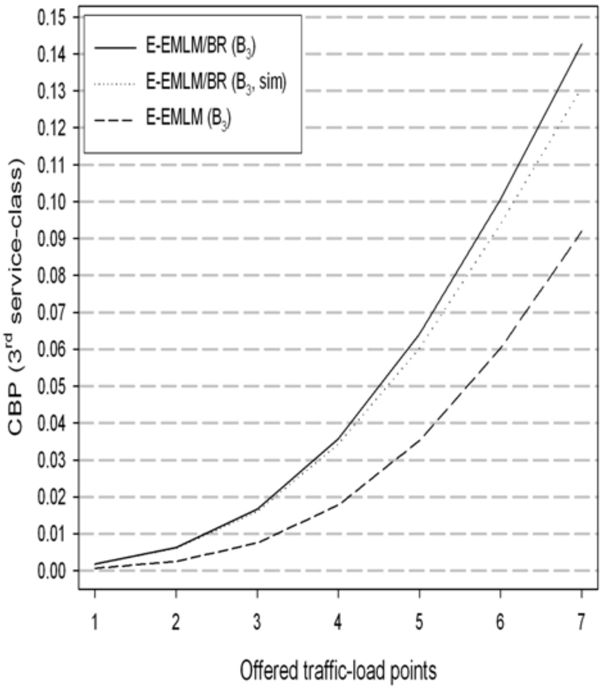

Figure 3. CBP of the 3rd service-class (E-EMLM, E-EMLM/BR, T=120).

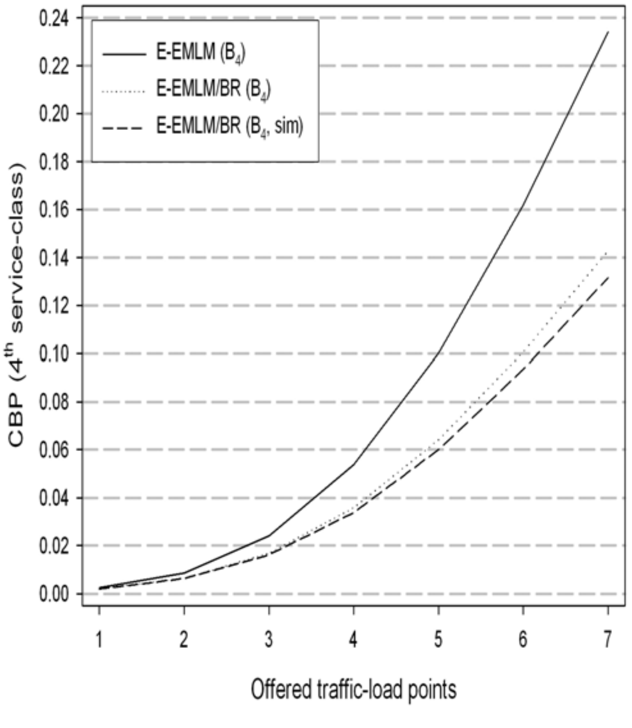

Figure 4. CBP of the 4th service-class (E-EMLM, E-EMLM/BR, T=120).

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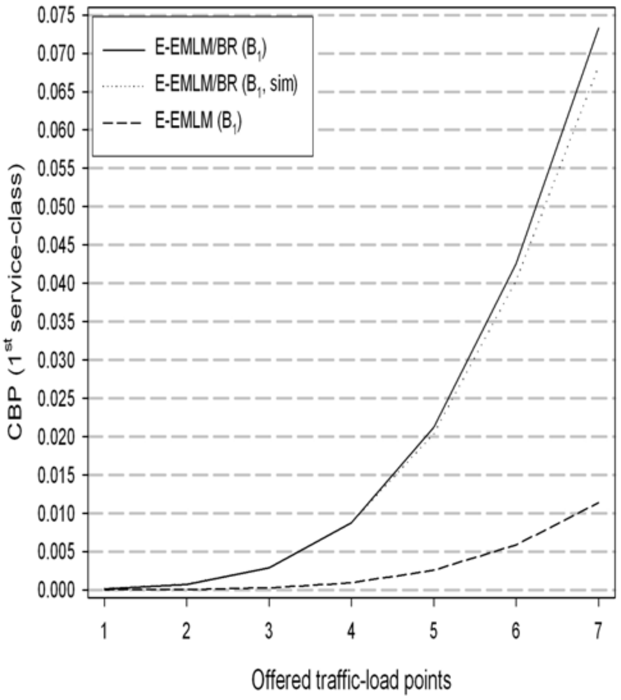

Figure 5. CBP of the 1st service-class (E-EMLM, E-EMLM/BR, *T*=140).

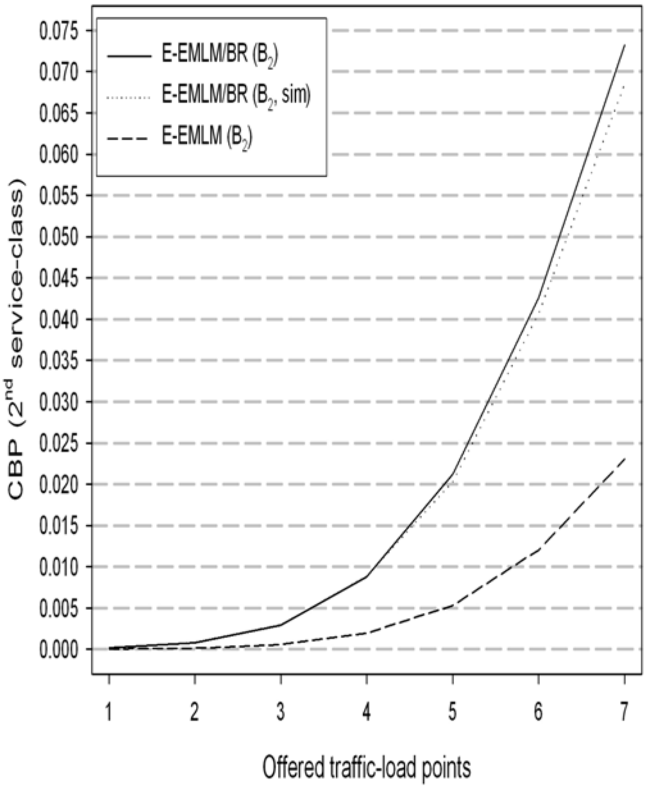

Figure 6. CBP of the 2nd service-class (E-EMLM, E-EMLM/BR, *T*=140).

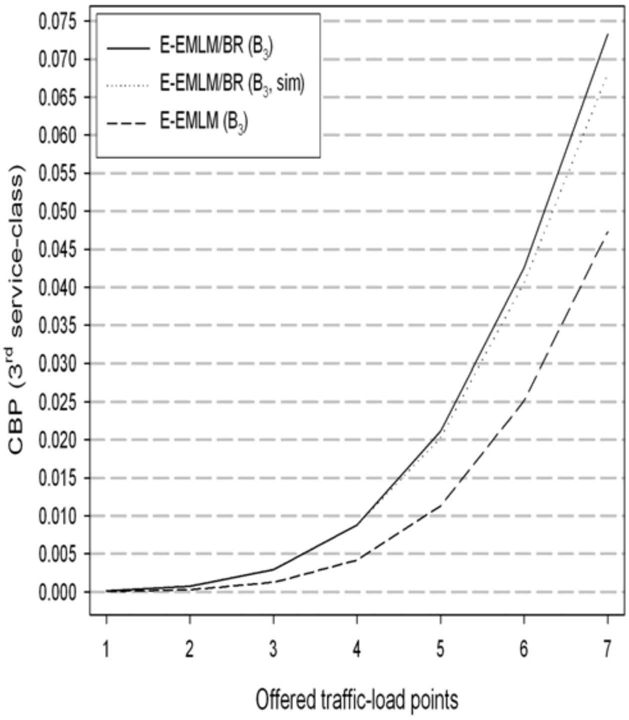

Figure 7. CBP of the 3rd service-class (E-EMLM, E-EMLM/BR, *T*=140).

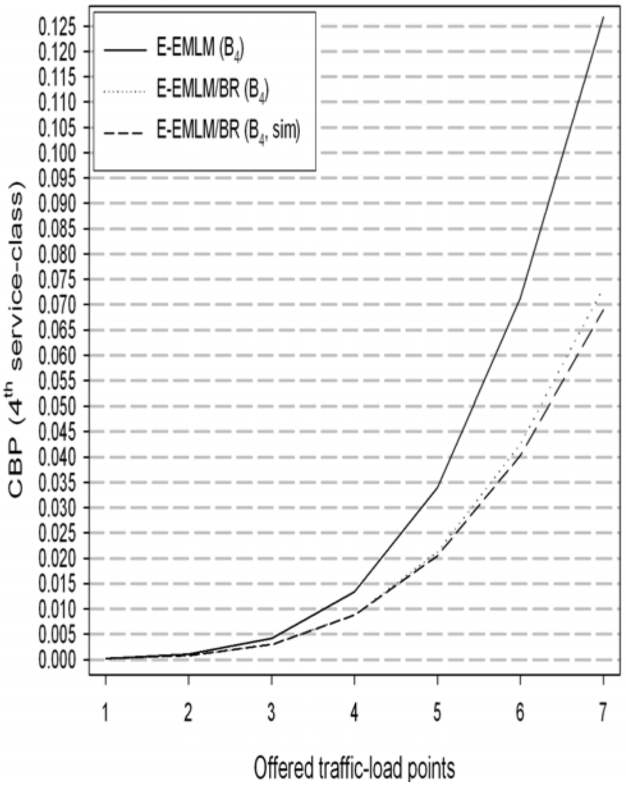

Figure 8. CBP of the 4th service-class (E-EMLM, E-EMLM/BR, *T*=140).

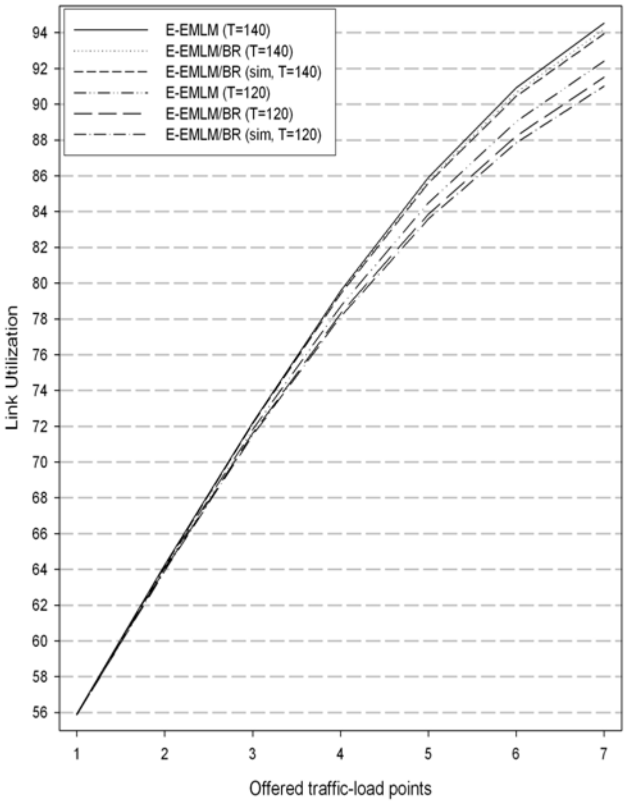

Figure 9. Link Utilization (E-EMLM, E-EMLM/BR, *T*=120 and *T*=140).

V. CONCLUSION

We propose an analytical model for the recursive calculation of CBP and link utilization in a single communication link, which accommodates multirate traffic of elastic and adaptive calls that follow a Poisson process, under the bandwidth reservation policy. This policy is used in order to achieve certain QoS among elastic and adaptive calls, or obtain equalization of call blocking probabilities. Simulation results verify the analytical CBP and link utilization results, and prove the accuracy of the proposed model. The comparison between the analytical results of the proposed model (E-EMLM/BR) and the corresponding results of the existing model (E-EMLM), prove the necessity and the consistency of the new model. A future extension of this model is the consideration of a mixture of random (Poisson) and quasi-random traffic under the BR policy. Quasi-random traffic, i.e., traffic generated by a finite number of sources (in contrast to random traffic, which assumes an infinite number of traffic sources), is a necessary assumption to many realistic network configurations.

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