# QoS Equalization in a Multirate Loss Model of Elastic and Adaptive Traffic with Retrials

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***Abstract*—In this paper, we consider a single-link modeled as a loss system, which accommodates multirate traffic of elastic and adaptive calls. Calls arrive in the link according to a Poisson process, have a peak-bandwidth requirement while their service time is exponentially distributed. If the available link bandwidth is lower than the peak-bandwidth requirement of a new call, then the call can retry to be connected in the link with reduced bandwidth, one or more times (single/multi-retry loss model). If the available link bandwidth is still lower than the last bandwidth requirement of the call, then the call can be accepted in the link by compressing the bandwidth of all in-service calls (of all service-classes) together with its last bandwidth requirement. In this multirate loss system, we study the effect of the bandwidth reservation (BR) policy on Call Blocking Probabilities (CBP) and link utilization. The BR policy achieves CBP equalization among calls of different service-classes, or guarantees a certain quality of service for each service-class. The proposed single/multi-retry loss models under the BR policy do not have a product form solution, and therefore we propose approximate recursive formulas for the efficient calculation of CBP and link utilization. Simulation results validate the results obtained by the analytical models.**

***Keywords-Poisson process, elastic/adaptive traffic, call blocking, reservation, recurrent formula.***

## I. INTRODUCTION

Multirate loss models based on recursive formulas provide an efficient way for the call-level QoS assessment in modern communication networks which accommodate elastic and adaptive traffic. In-service calls whose bandwidth can tolerate compression while at the same time their service time increases (so that the product *service time* by *bandwidth* is constant) compose elastic traffic. Adaptive traffic is a variation of elastic traffic in the sense that in-service adaptive calls tolerate bandwidth compression without altering their service time. The call-level analysis of a single link that behaves as a loss system and accommodates elastic and adaptive calls of different service-classes is based on the classical Erlang Multirate Loss Model (EMLM) ([1]-[2]).

In the EMLM, calls arrive in the link according to a Poisson process (i.e., an infinite number of traffic sources is assumed) and compete for the available bandwidth under the Complete Sharing (CS) policy. According to the CS policy, new calls are blocked and lost only if their required bandwidth is higher than the available bandwidth of the link. Accepted calls cannot compress their assigned bandwidth and remain in the link for an arbitrarily distributed service time [1]. The calculation of the steady-state probabilities in the EMLM is based on a formula that has a Product Form Solution (PFS). The latter leads to an accurate calculation of Call Blocking Probabilities (CBP) via the well-known Kaufman-Roberts recursive formula [1], [2]. The existence of this recursive formula has led to numerous extensions of the EMLM in wired (e.g., [3]-[7]), wireless (e.g., [8]-[11]) and optical networks (e.g., [12]-[15]). In [16], an extension of the EMLM is proposed, whereby blocked calls can immediately retry one or more times (Single- and Multi-Retry Loss Model, SRM and MRM, respectively) to be connected in the link by requesting less bandwidth units (b.u.). A retry call is blocked and lost if its last bandwidth requirement is still higher than the available bandwidth of the link. In [17], an extension of [16] is considered, whereby a single link accommodates elastic and adaptive traffic with single/multi retrials. We name the models of [17], Elastic-Adaptive Single-Retry Loss Model (EA-SRM) and Elastic-Adaptive Multi-Retry Loss Model (EA-MRM). Contrary to [16], if the available link bandwidth is less than the last bandwidth requirement of a retry call, the system compresses this bandwidth down to a minimum proportion of the last bandwidth requirement, together with the bandwidth of all in-service calls of all service-classes. If the resulting bandwidth requirement is not higher than the available link bandwidth, the retry call is accepted; otherwise is blocked and lost. When a call, whose bandwidth is compressed, departs from the system, then the remaining in-service calls expand their bandwidth. Due to retrials/compression, the EA-SRM and EA-MRM do not have a PFS. However, in [17], approximate recursive formulas are proposed for the calculation of the link occupancy distribution and CBP. In [18], elastic/adaptive calls have several bandwidth requirements and request for bandwidth, upon their arrival, according to the occupied link bandwidth (i.e., calls do not retry).

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In this paper, we study the effect of the Bandwidth Reservation (BR) policy in the EA-SRM and EA-MRM. The BR policy is used in order to achieve CBP equalization among different service-classes, or guarantee a certain QoS for each service-class. Although the proposed models do not have a PFS, we propose approximate but recursive formulas for the calculation of the link occupancy distribution, and consequently, CBP and link utilization. Simulation results validate the proposed models and show very good accuracy.

This paper is organized as follows. In Section II, we review the EA-SRM and the EA-MRM. In Section III, we present the proposed models under the BR policy and provide formulas for the approximate calculation of the link occupancy distribution, CBP and link utilization. In Section IV, we present analytical and simulation results in order to evaluate the models' accuracy. We conclude in Section V.

## II. Review of The EA-SRM And EA-MRM

### A. *Review of the EA-SRM*

Consider a link of capacity $C$ b.u. that accommodates $K$ service-classes. Let $K_e$ and $K_a$ be the set of elastic and adaptive service-classes ($K_e+K_a=K$), respectively. Let also $T > C$ be the limit (in b.u.) that determines the maximum permitted bandwidth compression among calls. Service-class $k$ calls ($k = 1,\dots, K$) follow a Poisson process with rate $\lambda_k$, request $b_k$ b.u. (peak-bandwidth requirement) and have an exponentially distributed service time with mean $\mu_k^{-1}$.

Let $j$ be the occupied link bandwidth, $j=0,1,\dots,T$, when a service-class $k$ call arrives in the link. Now, we consider the following cases: a) If $j+b_k \le C$, the call is accepted in the link with $b_k$ b.u. b) If $j+b_k > C$, then the call is blocked with $b_k$ and retries immediately to be connected in the link with $b_{kr} < b_k$. Now if: b1) $j + b_{kr} \le C$ the retry call is accepted in the system with $b_{kr}$ and $\mu_{kr}^{-1} > \mu_k^{-1}$, so that $b_{kr}\mu_{kr}^{-1} = b_k\mu_k^{-1}$, b2) $j + b_{kr} > T$ the retry call is blocked and lost and b3) $C < j + b_{kr} \le T$ the retry call is accepted in the system by compressing its bandwidth requirement $b_{kr}$ together with the bandwidth of all in-service calls of all service-classes. In that case, the compressed bandwidth of the retry call becomes $b_{kr}^{'} = rb_{kr} = \frac{C}{j+b_{kr}} b_{kr}$ where $r$ is the compression factor, common to all service-classes. Similarly, all in-service calls, which have been accepted in the link with $b_k$ (or $b_{kr}$), compress their bandwidth to $b_k^{'} = rb_k$ (or $b_{kr}^{'} = rb_{kr}$) for $k = 1,\dots,K$. After the compression of all calls the link state is $j = C$. The minimum value that the compression factor can take is given by $r_{\min} = C/T$.

When a service-class $k$ call, with bandwidth $b_k^{'}$ (or $b_{kr}^{'}$), departs from the system, the remaining in-service calls of each service-class $i$ ($i=1,\dots,K$), expand their bandwidth in proportion to their initially assigned bandwidth $b_i$ (or $b_{ir}$). After bandwidth compression/expansion, all elastic service-class $k$ calls ($k =1,\dots,K_e$) increase/decrease their service time so that the product *service time* by *bandwidth* remains constant. Adaptive service-class calls do not alter their service time.

The existence of retrials and the bandwidth compression mechanism destroys reversibility in the model and therefore no PFS exists. However, in [17] an approximate recursive formula is proposed for the calculation of the un-normalized values of the link occupancy distribution, $G(j)$:

$$G(j)=\left\langle \begin{array}{c} 1 \ for \ j=0 \\ \frac{1}{j}\left[\sum_{k\in K_a} a_k b_k \gamma_k(j) G(j-b_k) + \sum_{k\in K_a} a_{kr} b_{kr} \gamma_{kr}(j) G(j-b_{kr})\right] + \\ \frac{1}{min(C,j)}\left[\sum_{k\in K_e} a_k b_k \gamma_k(j) G(j-b_k) + \sum_{k\in K_e} a_{kr} b_{kr} \gamma_{kr}(j) G(j-b_{kr})\right] for \ j=1,\dots,T \\ 0 \ otherwise \end{array} \right\rangle \quad (1)$$

where: $\alpha_k=\lambda_k \mu_k^{-1}$ is the offered traffic-load (in erl) of service-class $k$ calls, $\alpha_{kr}=\lambda_k \mu_{kr}^{-1}$, $\gamma_k(j)=\begin{cases} 1 \ for \ 1 \le j \le C \ and \ b_{kr}>0 \\ 1 \ for \ 1 \le j \le T \ and \ b_{kr}=0 \\ 0 \ otherwise \end{cases}$ and $\gamma_{kr}(j)=\begin{cases} 1 \ for \ C-b_k+b_{kr} < j \le T \\ 0 \ otherwise \end{cases}$.

The proof of (1) is based on: 1) the application of local balance between adjacent states, which exists only in PFS models, 2) an approximation, expressed by $\gamma_{kr}(j)$ in (1), which assumes that the occupied link bandwidth from retry calls of service-class $k$ is negligible when $j \le C-(b_k-b_{kr})$ and 3) an approximation that refers only to those service-class $k$ calls whose $b_{kr} > 0$; it is expressed by $\gamma_k(j)$ in (1) and assumes that the occupied link bandwidth from service-class $k$ calls accepted in the system with $b_k$ b.u. is negligible when $j > C$.

Having determined $G(j)$'s we can calculate CBP and link utilization. The final CBP of a retry service-class $k$ call, $B_{kr}$, is given by:

$$B_{kr} = \sum_{j=T-b_{kr}+1}^{T} G^{-1} G(j) \quad (2)$$

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

The link utilization, $U$, is calculated according to the formula:

$$U = \sum_{j=1}^{C} jG^{-1}G(j) + \sum_{j=C+1}^{T} CG^{-1}G(j) \quad (3)$$

### B. *Review of the EA-MRM*

In the Elastic-Adaptive Multi-Retry loss Model (EA-MRM), a service-class $k$ call that is not accepted in the system with its peak-bandwidth requirement, $b_k$, may have many retry parameters $(b_{kr_l}, \mu_{kr_l}^{-1})$ for $l=1,\dots,s(k)$, with

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$b_{kr_{s(k)}} < ... < b_k$ and $\mu_{kr_{s(k)}}^{-1} > ... > \mu_k^{-1}$. Similar to the EA-SRM, the EA-MRM does not have a PFS and therefore the calculation of $G(j)$'s is based on an approximate but recursive formula:

$$G(j)=\begin{cases} 1 \ for \ j=0 \\ \frac{1}{j}\left[\sum_{k\in K_a} a_k b_k \gamma_k(j) G(j-b_k) + \sum_{k\in K_a}\sum_{s=1}^{s(k)} a_{kr_s} b_{kr_s} \gamma_{kr_s}(j) G(j-b_{kr_s})\right] + \\ \frac{1}{min(C,j)}\left[\sum_{k\in K_e} a_k b_k \gamma_k(j) G(j-b_k) + \sum_{k\in K_e}\sum_{s=1}^{s(k)} a_{kr_s} b_{kr_s} \gamma_{kr_s}(j) G(j-b_{kr_s})\right] \ for \ j=1,...,T \\ 0 \ otherwise \end{cases} \quad (4)$$

where: $\alpha_{kr}=\lambda_k \mu_{kr}^{-1}$ and $\gamma_k(j)=\begin{cases} 1 \ \ for \ \ 1\le j \le C \ \ and \ \ b_{kr_s}>0 \\ 1 \ \ for \ \ 1\le j\le T \ \ and \ \ b_{kr_s}=0 \\ 0 \ \ otherwise \end{cases}$

$$\gamma_{kr_s}(j)=\begin{cases} 1 \ \ for \ \ C-b_{kr_{s-1}}+b_{kr_s} < j \le C \ \ and \ s \ne s(k) \\ 1 \ \ for \ \ C-b_{kr_{s-1}}+b_{kr_s} < j \le T \ \ and \ s = s(k) \\ 0 \ \ otherwise \end{cases}.$$

If only elastic service-classes are accommodated by the link, then (4) takes the form [19]:

$$G(j)=\begin{cases} 1 \ for \ j=0 \\ \frac{1}{min(C,j)}\left[\sum_{k\in K_e} a_k b_k \gamma_k(j) G(j-b_k) + \sum_{k\in K_e}\sum_{s=1}^{s(k)} a_{kr_s} b_{kr_s} \gamma_{kr_s}(j) G(j-b_{kr_s})\right] \ for \ j=1,...,T \\ 0 \ otherwise \end{cases} \quad (5)$$

If the link accommodates elastic and adaptive service-classes whose blocked calls are not allowed to retry, then (4) takes the form [20]:

$$G(j)=\begin{cases} 1 & \text{for } j=0 \\ \frac{1}{min(j,C)}\sum_{k\in K_e}\alpha_k b_k G(j-b_k)+\frac{1}{j}\sum_{k\in K_a}\alpha_k b_k G(j-b_k) & \text{for } j=1,...,T \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

where $\alpha_k = \lambda_k \mu_k^{-1}$ is the offered traffic-load (in erl) of service-class $k$ calls.

If calls of all service-classes are not allowed to compress their bandwidth during their service time, then the MRM results and (4) takes the form [16]:

$$G(j)=\begin{cases} 1 \ for \ j=0 \\ \frac{1}{j}\left[\sum_{k\in K} a_k b_k G(j-b_k) + \sum_{k\in K}\sum_{s=1}^{s(k)} a_{kr_s} b_{kr_s} \gamma_{kr_s}(j) G(j-b_{kr_s})\right] \ for \ j=1,...,C \\ 0 \ otherwise \end{cases} \quad (7)$$

where: $\alpha_{kr}=\lambda_k \mu_{kr}^{-1}$ and $\gamma_{kr_s}(j)=\begin{cases} 1 \ \ for \ \ C-b_{kr_{s-1}}+b_{kr_s} < j \le C \\ 0 \ \ otherwise \end{cases}$.

The CBP of a retry service-class $k$ call with its last bandwidth requirement, $B_{kr_{s(k)}}$, is given by:

$$B_{kr_{s(k)}} = \sum_{j=T-b_{kr_{s(k)}}+1}^{T} G^{-1}G(j) \quad (8)$$

The calculation of the link utilization in the EA-MRM is based on (3) where the values of $G(j)$'s are determined by (4).

## III. THE PROPOSED EA-SRM & EA-MRM UNDER THE BR POLICY

The application of the BR policy in the EA-SRM and EA-MRM follows the analysis of Roberts in [21], who proposed an approximate but recursive formula for the calculation of $G(j)$'s in the EMLM under the BR policy.

The calculation of the un-normalized values of $G(j)$'s in the EA-SRM under the BR policy (EA-SRM/BR) is based on the following recursive formula:

$$G(j)=\begin{cases} 1 \ for \ j=0 \\ \frac{1}{j}\sum_{k\in K_a} a_k D_k(j-b_k)\gamma_k(j) G(j-b_k) + \\ \frac{1}{j}\sum_{k\in K_a} a_{kr} D_{kr}(j-b_{kr})\gamma_{kr}(j) G(j-b_{kr}) + \\ \frac{1}{min(C,j)}\sum_{k\in K_e} a_k D_k(j-b_k)\gamma_k(j) G(j-b_k) + \\ \frac{1}{min(C,j)}\sum_{k\in K_e} a_{kr} D_{kr}(j-b_{kr})\gamma_{kr}(j) G(j-b_{kr}) \ for \ j=1,...,T \\ 0 \ otherwise \end{cases} \quad (9)$$

where:

$D_k(j-b_k)=\begin{cases} b_k \ \ for \ \ j\le T-t(k) \\ 0 \ for \ \ j>T-t(k) \end{cases}$, $D_{kr}(j-b_{kr})=\begin{cases} b_{kr} \ \ for \ \ j\le T-t(k) \\ 0 \ for \ \ j>T-t(k) \end{cases}$

and $t(k)$ is the reserved bandwidth (BR parameter) in favor of calls other than service-class $k$ calls.

The calculation of the un-normalized values of $G(j)$'s in the EA-MRM under the BR policy (EA-MRM/BR) is based on the following recursive formula:

$$G(j)=\begin{cases} 1 \ for \ j=0 \\ \frac{1}{j}\sum_{k\in K_a} a_k D_k(j-b_k)\gamma_k(j) G(j-b_k) + \\ \frac{1}{j}\sum_{k\in K_a}\sum_{s=1}^{s(k)} a_{kr_s} D_{kr_s}(j-b_{kr_s})\gamma_{kr_s}(j) G(j-b_{kr_s}) + \\ \frac{1}{min(C,j)}\sum_{k\in K_e} a_k D_k(j-b_k)\gamma_k(j) G(j-b_k) + \\ \frac{1}{min(C,j)}\sum_{k\in K_e}\sum_{s=1}^{s(k)} a_{kr_s} D_{kr_s}(j-b_{kr_s})\gamma_{kr_s}(j) G(j-b_{kr_s}) \ for \ j=1,...,T \\ 0 \ otherwise \end{cases} \quad (10)$$

where:

$$D_k(j-b_k)=\begin{cases} b_k \ \ for \ \ j\le T-t(k) \\ 0 \ for \ \ j>T-t(k) \end{cases}, D_{kr_s}(j-b_{kr_s})=\begin{cases} b_{kr_s} \ \ for \ \ j\le T-t(k) \\ 0 \ for \ \ j>T-t(k) \end{cases}.$$

The recursive formulas (9), (10) are based on the assumption that the population of service-class $k$ calls is negligible in states $j>T-t(k)$. This assumption is incorporated in (9), (10) by the variables $D_k(j-b_k)$, $D_{kr}(j-b_{kr})$ and

$D_{kr_s}(j-b_{kr_s})$. The BR policy is used to attain CBP equalization among calls of different service-classes that share a link by a proper selection of the BR parameters. If, for example, CBP equalization is required between two service-classes whose calls require $b_1$=1 and $b_2$=5 b.u., respectively, then $t(1)$ = 4 b.u and $t(2)$ = 0 b.u. so that $b_1 + t(1) = b_2 + t(2)$. Note that $t(1)$ = 4 b.u means that 4 b.u. are reserved to benefit calls of the 2nd service-class.

If only elastic service-classes are accommodated by the link, then (10) takes the form:

$$G(j)=\left\langle \begin{array}{c} 1 \; for \; j=0 \\ \frac{1}{min(C,j)}\sum_{k\in K_e} a_k D_k(j-b_k)\gamma_k(j)G(j-b_k)+ \\ \frac{1}{min(C,j)}\sum_{k\in K_e}\sum_{s=1}^{s(k)} a_{kr_s} D_{kr_s}(j-b_{kr_s})\gamma_{kr_s}(j)G(j-b_{kr_s}) \; for \; j=1,\dots,T \\ 0 \; otherwise \end{array} \right\rangle \quad (11)$$

If the link accommodates elastic and adaptive service-classes whose blocked calls are not allowed to retry, then (10) takes the form [22]:

$$G(j)=\left\langle \begin{array}{c} 1 \; for \; j=0 \\ \frac{1}{j}\sum_{k\in K_a} a_k D_k(j-b_k)G(j-b_k)+ \\ \frac{1}{min(C,j)}\sum_{k\in K_e} a_k D_k(j-b_k)G(j-b_k) \; for \; j=1,\dots,T \\ 0 \; otherwise \end{array} \right\rangle \quad (12)$$

If calls of all service-classes may retry but are not allowed to compress their bandwidth during their service time, then the MRM under the BR policy results (MRM/BR) and (10) takes the form [23]:

$$G(j)=\left\langle \begin{array}{c} 1 \; for \; j=0 \\ \frac{1}{j}\sum_{k\in K} a_k D_k(j-b_k)G(j-b_k)+ \\ \frac{1}{j}\sum_{k\in K}\sum_{s=1}^{s(k)} a_{kr_s} D_{kr_s}(j-b_{kr_s})\gamma_{kr_s}(j)G(j-b_{kr_s}) \; for \; j=1,\dots,C \\ 0 \; otherwise \end{array} \right\rangle \quad (13)$$

In the EA-SRM/BR, the CBP of a retry service-class $k$ call with its last bandwidth requirement, $B_{kr}$, is given by:

$$B_{kr} = \sum_{j=T-b_{kr}-t(k)+1}^{T} G^{-1}G(j) \quad (14)$$

In the EA-MRM/BR, the CBP of a retry service-class $k$ call with its last bandwidth requirement, $B_{kr_{s(k)}}$, is given by:

$$B_{kr_{s(k)}} = \sum_{j=T-b_{kr_{s(k)}}-t(k)+1}^{T} G^{-1}G(j) \quad (15)$$

The calculation of the link utilization in the EA-SRM/BR and EA-MRM/BR is based on (3) where the values of $G(j)$'s are determined by (9), (10), respectively.

## IV. Application Example - Evaluation

We present an application example in order to compare the analytical CBP and link utilization results of the EA-MRM/BR with those obtained by simulation. To show the necessity of the proposed model we also present the analytical results of the MRM, MRM/BR and EA-MRM. Simulation results are mean values of 7 runs. In all figures of this section we present only mean values, since the reliability ranges of the measurements (assuming 95% confidence interval) are very small. The simulation language used is Simscript II.5 [24].

Consider a link of capacity $C$ = 80 b.u. that accommodates Poisson arriving calls from three different service-classes. Calls of the 1st and 2nd service-class are adaptive and are not allowed to retry while calls of the 3rd service-class are elastic and may retry two times. Their bandwidth requirements are: $b_1$=1 b.u., $b_2$=2 b.u. and $b_3$=6 b.u., respectively. The reduced bandwidth of the 3rd service-class calls for two retrials is: $b_{3_{r1}}$ =5 b.u. and $b_{3_{r2}}$ =4 b.u. To equalize the final CBP of all service-classes we choose the BR parameters $t(1)$=3, $t(2)$=2, $t(3)$=0, since: $b_1 + t(1) = b_2 + t(2) = b_{3_{r2}} + t(3)$. The call holding time is exponentially distributed with mean value: $\mu_1^{-1}=\mu_2^{-1}=\mu_3^{-1}=1$.

The initial values of the offered traffic-load are: $\alpha_1$=20 erl, $\alpha_2$=6 erl and $\alpha_3$=2 erl. For the retrials of the 3rd service-class we assume that: $\alpha_3 b_3 = a_{3_{r1}} b_{3_{r1}} = a_{3_{r2}} b_{3_{r2}}$. In the x-axis of all figures, we keep constant the value of $\alpha_3$=2 erl, while $\alpha_1$, $\alpha_2$ increase in steps of 1.0 and 0.5 erl, respectively. The last values are: $\alpha_1$=28 erl, $\alpha_2$=10 erl. Three values of $T$ are examined: a) $T = C$ =80 b.u., where no bandwidth compression takes place and the EA-MRM/BR gives the same CBP and link utilization results with the MRM/BR, b) $T$ =82 b.u. where $r_{min} = C/T$ =80/82 and c) $T$ =84 b.u. where $r_{min} = C/T$ =80/84. In Figs. 1-3, we present the analytical and simulation CBP results of the 1st, 2nd and 3rd service-class (CBP of calls with $b_{3_{r2}}$), respectively, for all values of $T$. In Fig. 4, we present the corresponding link utilization results. All figures show that the analytical results obtained by the EA-MRM/BR are of absolutely satisfactory accuracy, compared to simulation and that the MRM/BR fails to approximate the behaviour of EA-MRM/BR. This is expected since in the MRM/BR the bandwidth compression/expansion mechanism is not incorporated. Similarly, the results obtained by the MRM and the EA-MRM fail to approximate the behaviour of the EA-MRM/BR since the BR policy is not applied in these models. Furthermore, Figs. 1-3 show that the existence of the bandwidth compression/expansion mechanism in the EA-MRM/BR reduces CBP even for small values of $T$. This CBP decrease results in the increase of link utilization in the EA-MRM/BR compared to the MRM/BR (Fig. 4).

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## V. CONCLUSION

We propose multirate loss models for a link that accommodates elastic and adaptive calls, under the bandwidth reservation policy. Calls of all service-classes arrive in the link according to a Poisson process and have an initial peak-bandwidth requirement. If this bandwidth requirement is not available then calls are blocked and may immediately retry to be connected in the system one (EA-SRM/BR) or more times (EA-MRM/BR). If a retry call is blocked with its last bandwidth, it can still be accepted in the system by compressing its last bandwidth together with the bandwidth of all in-service calls of all service-classes. We propose approximate but recursive formulas for the efficient CBP calculation. Simulation CBP and link utilization results verify the corresponding analytical results.

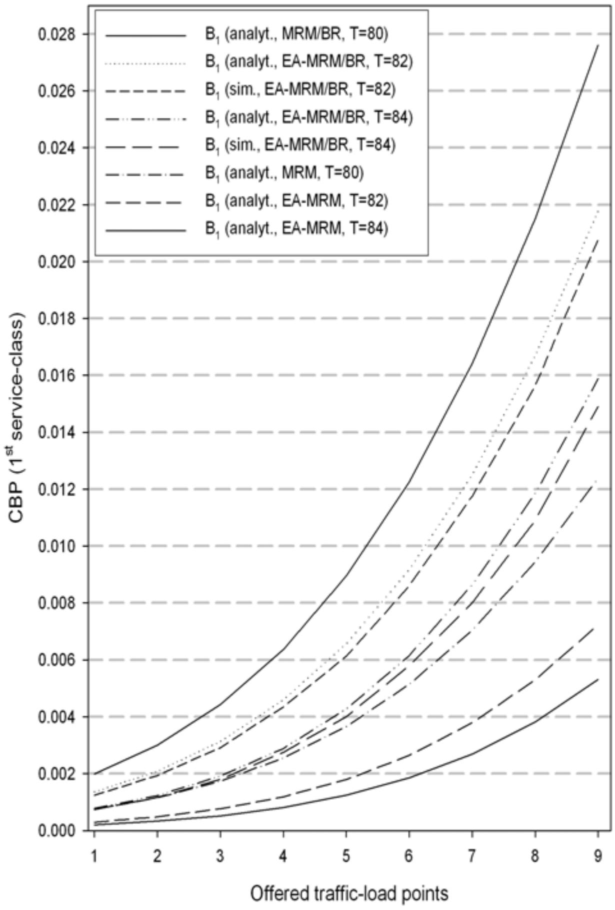


Figure 1. CBP (1st service-class, adaptive).

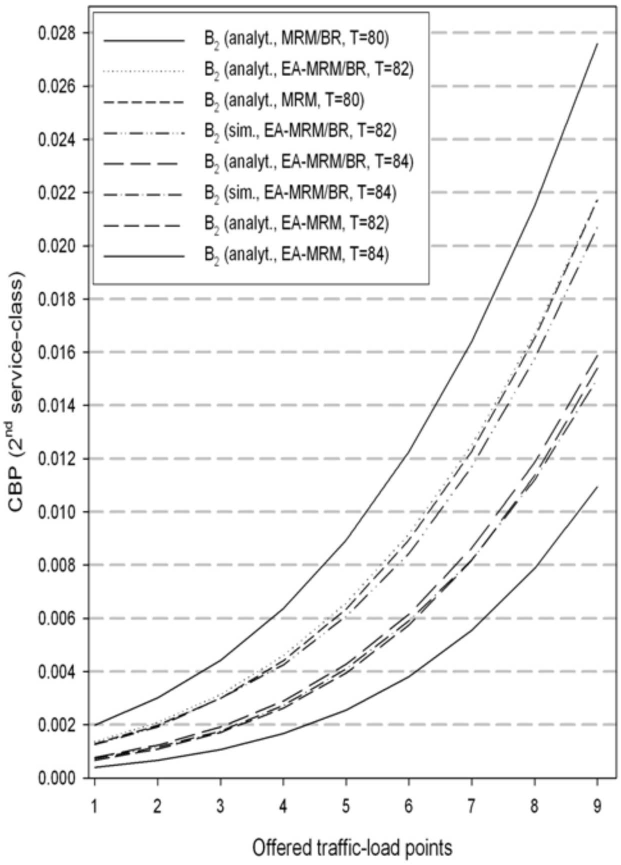


Figure 2. CBP (2nd service-class, adaptive).

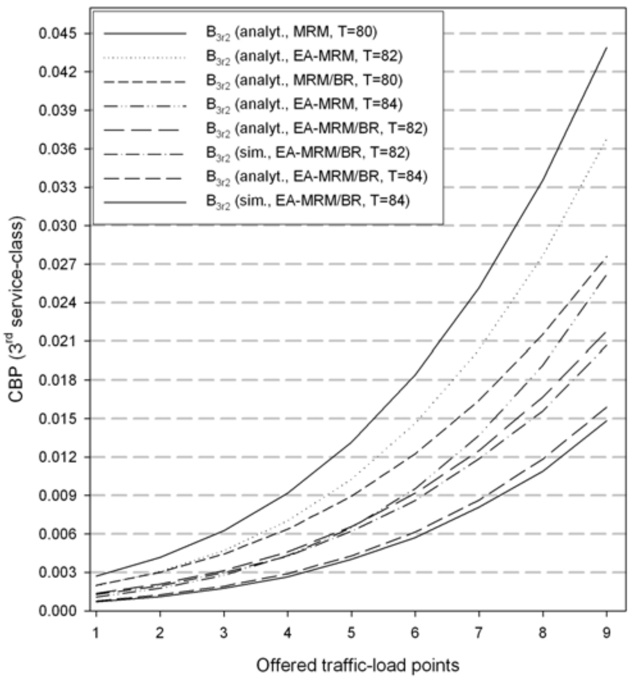


Figure 3. CBP of retry calls with $b_{3r2}$ (3rd service-class, elastic).

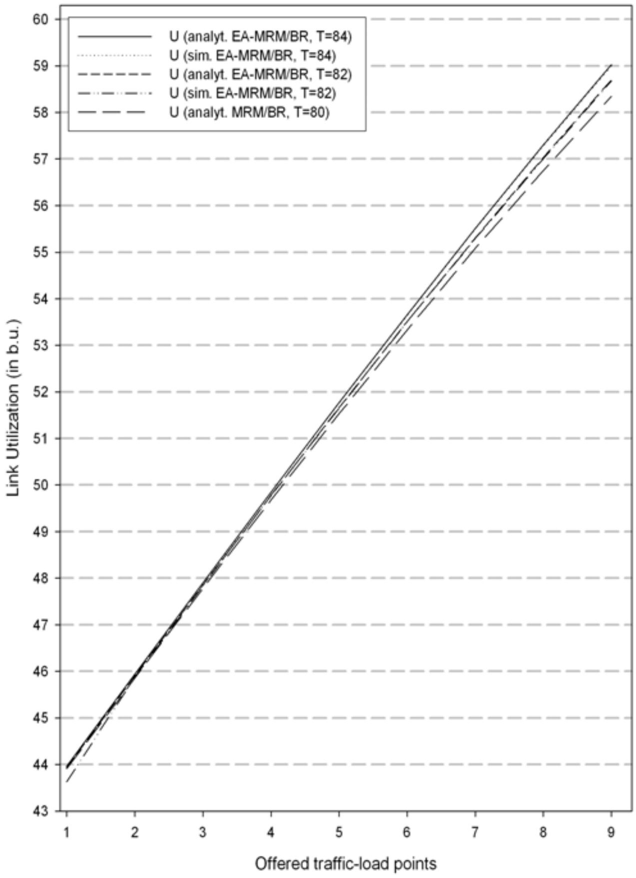


Figure 4. Link utilization (in b.u.).

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