Efficient Call-level Assessment of Multirate Loss Systems Including Cooperative Users

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***Abstract*– We consider a multirate loss system that accommodates Poisson arriving calls of many service-classes with cooperative and non-cooperative users. "Cooperative" users can retry to be connected in the system with a reduced bandwidth, when they are blocked with their initial peak-bandwidth requirement. This behavior increases the quality of service perceived by other users. Due to the existence of retrials, the system model does not have a product form solution for the steady state distribution. However, we propose an efficient calculation of system's occupancy distribution and Call Blocking Probabilities (CBP), while avoiding complex state space enumeration and processing. The proposed recursive formula is consistent and quite accurate, as it is shown through simulation. As a reference (for comparison), we use the conventional trunk reservation control for CBP equalization.**

I. INTRODUCTION

Performance modelling in modern communication networks necessitates those multirate loss or queueing models that result in recursive formulas. The latter are essential, since they reduce computational complexity and, therefore, can be invoked in efficient network planning and dimensioning procedures. Considering call-level traffic in a single link which accommodates different service-classes with different bandwidth requirements, a bandwidth sharing policy is needed to guarantee specific Quality of Service (QoS) needs for each service-class. Moreover, a fairer (equal, if possible) admission opportunity among calls belonging to broadband services with calls of narrowband services is required. Thus, the Complete Sharing (CS) policy ([1]) is abolished, and other policies are preferred, such as the Trunk (bandwidth) Reservation (TR) (see e.g., [2]-[18]) or the Threshold (TH) policy (see e.g., [19]-[23]), or their combination (see e.g., [24]-[26]).

In the CS policy, a new call is accepted in the system if the call's bandwidth is available. Otherwise, the call is blocked and lost. A drawback of the CS policy is that it cannot provide a certain QoS to calls of a service-class. Furthermore, the CS policy is unfair to service-classes of high bandwidth-per-call requirements since it results in higher Call Blocking Probabilities (CBP) compared to CBP of service-classes with low bandwidth-per-call requirements. The main multirate loss model that adopts the CS policy is the classical Erlang Multirate Loss Model (EMLM) [27]-[28]. In the EMLM, calls follow a Poisson process, have fixed bandwidth requirements and generally distributed service times. All calls are accommodated in a single link of fixed capacity. The link occupancy distribution can be recursively calculated in an accurate way via the classical Kaufman-Roberts formula [27]-[28].

A policy whereby QoS can be guaranteed to new calls is the TR policy. In the TR policy, an integer number of bandwidth units (b.u.) is reserved to benefit calls of high bandwidth requirements. The TR policy can achieve CBP equalization among service-classes at the cost of substantially increasing the CBP of calls with lower bandwidth requirements. The main multirate loss model that adopts the TR policy is the EMLM/TR [29]. Due to the TR policy, the EMLM/TR does not have a Product Form Solution (PFS) and therefore the link occupancy distribution can be recursively determined via an approximate formula that resembles the Kaufman-Roberts formula [29].

QoS guarantee can also be achieved by the TH policy. The latter does not allow in-service calls of each service-class to exceed a predefined threshold (different for each service-class). The interested reader may resort to [30] for the main reference in the EMLM/TH and a recursive formula for the accurate CBP determination. The importance of the TH policy in teletraffic engineering is twofold: i) It analyzes a multirate access tree network which accommodates calls of K service-classes. ii) It provides service-class differentiation in terms of CBP, revenue rates, etc.

Stimulated by [31]-[32], we consider a single link as a multirate loss system that accommodates Poisson arriving calls of K different service-classes (with different bandwidth requirements), under a new variant of the CS policy. Specifically, some service-classes are characterized "cooperative" and the rest "non-cooperative". Users from a cooperative service-class can retry with a certain probability to be connected in the system with reduced bandwidth, when blocked with their initial peak-bandwidth. This behavior increases the QoS perceived by other users [31]. The system model, initially described in [31]-[32] for only two service-classes (a "cooperative" and "non-cooperative" service-class) does not have a PFS for the steady state distribution due to the existence of retrials. Hence, to assess the call-level performance, enumeration and processing of the state space is required. This procedure is quite complex even for systems of moderate capacity and only two service-classes.

In this paper, we propose an approximate but recursive formula for the efficient calculation of the link occupancy distribution and, consequently, of CBP in a system with a realistic bandwidth capacity and K different service-classes. Evaluation of the proposed recursive formula is done by simulation and found to be highly satisfactory. The conventional TR control for CBP balancing among service-classes is used as a reference point for comparison.

This paper is organized as follows: In Section II, we review the system model of [31], [32]. In Section III, we present the analytical model and propose an approximate but recursive formula for the efficient calculation of the link occupancy distribution and consequently CBP. In Section IV, we present analytical and simulation CBP results for the model of [31], [32]. We conclude in Section V.

II. THE SYSTEM

Consider a single link of capacity C b.u. that accommodates calls of K service-classes. Let j be the occupied link bandwidth in b.u., i.e., $j = 0, 1,\ldots, C$. Let K_c and K_{nc} be the number of cooperative and non-cooperative service-classes, respectively, i.e., $K = K_c + K_{nc}$. Calls of service-class k (k=1,…,K) follow a Poisson process with arrival rate λ_k, have a peak-bandwidth requirement of b_k b.u. and an exponentially distributed service time with mean μ_k^{-1}. Without loss of generality let $b_1 \le b_2 \le \ldots \le b_K$. In addition, let $a_k = \lambda_k / \mu_k$ be the offered traffic-load (in erl) of service-class k (k=1,…,K).

A new non-cooperative service-class k call (k = 1,…,K_{nc}) is accepted in the link if there is available link bandwidth, i.e., if $j + b_k \le C$. Otherwise the call is blocked and lost without further affecting the system. On the other hand, a new cooperative service-class k call (k = 1,…,K_c) is accepted in the link with b_k b.u. if there exists available link bandwidth and j is below a threshold J_0 (common to all service-classes) at the time of arrival. Otherwise, if $j \ge J_0$ the blocked call retries with probability δ_k (dependent on the cooperative service-class k) to be connected in the link as a 1st "non-cooperative" service-class call by requiring b_1 b.u. With probability (1-δ_k) the blocked call departs from the system without further affecting it. The retry call is accepted in the link if $j + b_1 \le C$. Otherwise, the call is blocked and lost.

III. THE ANALYTICAL MODEL

The system does not have a PFS, due to the existence of retrials that destroy Local Balance (LB) between adjacent states (states that differ only by one call) [1]. However, we assume that LB does exist between adjacent states. This is a necessary approximation in order to derive a recursive formula for the calculation of the link occupancy distribution; of course, it is a source of error in our analysis. To simplify the derivation, we initially consider a link of C b.u. that accommodates two service-classes, and then generalize for K service-classes. The 1st service-class is non-cooperative with bandwidth per call requirement b_1 b.u., while the 2nd service-class is cooperative with bandwidth per call requirement b_2 b.u. If $j \ge J_0$, a 2nd service-class call is blocked and retries with probability δ_2 by requiring $b_1 < b_2$ b.u.

For calls of the 1st service-class we can write the following LB equation between the adjacent states $j - b_1$ and j:

$$\lambda_1 b_1 q(j - b_1) = y_1(j)\mu_1 q(j) \qquad j = 1,\ldots,C \quad (1)$$

where $q(j)$ is the link occupancy distribution and $y_1(j)$ is the average number of the 1st service-class calls assuming that the system is in state j.

For calls of the 2nd service-class we have the following two LB equations:

$$\lambda_2 b_2 q(j - b_2) = y_2(j)\mu_2 q(j) \qquad j - b_2 < J_0 \quad (2)$$

$$\delta_2 \lambda_2 b_1 q(j - b_1) = y_2'(j)\mu_1 q(j) \qquad j - b_1 \ge J_0 \quad (3)$$

where $y_2'(j)$ refers to the average number of 2nd service-class calls, in state j, accepted in the system with their retry bandwidth b_1.

Based on (1)-(3), we have the following system of equations:

$$a_1 b_1 q(j - b_1) + a_2 b_2 q(j - b_2) = (y_1(j) + y_2(j))q(j) \qquad j < J_0 + b_1 \quad (4)$$

$$a_1 b_1 q(j - b_1) + a_2 b_2 q(j - b_2) + \frac{\delta_2 \lambda_2}{\mu_1} b_1 q(j - b_1) = (y_1(j) + y_2(j) + y_2'(j))q(j) \qquad J_0 + b_1 \le j < J_0 + b_2 \quad (5)$$

$$a_1 b_1 q(j - b_1) + \frac{\delta_2 \lambda_2}{\mu_1} b_1 q(j - b_1) = (y_1(j) + y_2'(j))q(j) \qquad J_0 + b_2 \le j \le C \quad (6)$$

We now assume that: a) in (4), $y_2'(j)$ is negligible compared to $y_1(j) + y_2(j)$ when $j < J_0 + b_1$ and b) in (6), $y_2(j)$ is negligible compared to $y_1(j) + y_2'(j)$ when $J_0 + b_2 \le j \le C$. Based on these assumptions, which are the second source of error in our analysis, we can write (4)-(6) as follows:

$$a_1 b_1 q(j - b_1) + a_2 b_2 x_2(j) q(j - b_2) + \frac{\delta_2 \lambda_2}{\mu_1} b_1 x_2'(j) q(j - b_1) = j q(j) \qquad 1 \le j \le C \quad (7)$$

where: $x_2(j) = \begin{cases} 1, & if \ \ j < J_0 + b_2 \\ 0, & otherwise \end{cases}$ and

$x_2'(j) = \begin{cases} 1, & if \ \ J_0 + b_1 \le j \le C \\ 0, & otherwise \end{cases}$.

Based on (7), the recursive formula in the case of K different service-classes, takes the form, while considering probabilities δ_k (k=1,…,K_c):

$$\sum_{k=1}^{K_{nc}} a_k b_k q(j - b_k) + \sum_{k=1}^{K_c} a_k b_k x_k(j) q(j - b_k) + \sum_{k=1}^{K_c} \frac{\delta_k \lambda_k}{\mu_1} b_1 x_k'(j) q(j - b_1) = j q(j) \qquad 1 \le j \le C \quad (8)$$

where:

$x_k(j) = \begin{cases} 1, & if \ \ j < J_0 + b_k, \ k = 1,\ldots,K_c \\ 0, & otherwise \end{cases}$,

$x_k'(j) = \begin{cases} 1, & if \ \ J_0 + b_1 \le j \le C, \ k = 1,\ldots,K_c \\ 0, & otherwise \end{cases}$.

To derive (8), we assume that all retry calls ask for b_1 b.u. when they retry.

As far as the computational complexity of (8) is concerned, it is in the order of O(KC) which makes it suitable for network planning and dimensioning procedures.

Based on (8), we efficiently calculate the following performance measures:

a) the CBP of non-cooperative and cooperative service-class k, $B_{k,nc}$, (k=1,…,K_{nc}) and $B_{k,c}$, (k=1,…,K_c), respectively, requesting b_1 b.u. per call:

$$B_{k,nc} = \sum_{j=C-b_k+1}^{C} G^{-1} q(j) \quad (9)$$

$$B_{k,c} = \sum_{j=C-b_1+1}^{C} G^{-1} q(j) = B_{1,nc} \quad \forall k \quad (10)$$

b) the CBP of service-class k cooperative calls (k=1,…,K_c), $B^{'}_{k,c}$ with either their initial bandwidth requirement b_k or the retry bandwidth b_1:

$$B^{'}_{k,c} = \sum_{j=J_0}^{C-b_1} G^{-1}(1-\delta_k) q(j) + \sum_{j=C-b_1+1}^{C} G^{-1} q(j) \quad (11)$$

c) the link utilization, U, (in b.u.):

$$U = \sum_{j=1}^{C} G^{-1} j q(j) \quad (12)$$

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

IV. Numerical Examples - Evaluation

In this section, we present an application example and provide analytical and simulation CBP probabilities results of the considered model [31]-[32]. As a reference we also present analytical results in the case of the EMLM/TR [29]. Simulation results are derived via the Simscript III simulation language [33] and are mean values of 7 runs. In each run, two million calls are generated. Due to stabilization time, we exclude the blocking events of the first 5% of the generated calls. Confidence intervals of the results are found to be very small (less than two order of magnitude) and are not presented in the following figures (Figs. 1-2).

Consider a link of C = 100 b.u. that accommodates K = 3 service-classes. The 1st service-class is non-cooperative with b_1 = 1 b.u. per call requirement. The 2nd and 3rd service-classes are cooperative, with b_2 = 3 and b_3 = 5 b.u. per call, peak-bandwidth requirement, respectively, and common retry bandwidth of b_1 = 1 b.u. per call (when $j \geq J_0$); the corresponding retry probabilities for the 2nd and 3rd service-classes are δ_2 and δ_3. Assume also that, initially, $(a_1, a_2, a_3) = (70.0, 5.0, 1.0)$ *erl*.

We provide analytical and simulation CBP results for all service-classes, considering the following scenarios:

1) $\delta_2 = \delta_3 = 0.8$ and $J_0 = 85$,

2) $\delta_2 = \delta_3 = 0.6$ and $J_0 = 85$,

3) $\delta_2 = \delta_3 = 0.8$ and $J_0 = 75$ and

4) $\delta_2 = \delta_3 = 0.6$ and $J_0 = 75$.

In the x-axis of Figs. 1-2, the traffic loads α_1, α_2 and α_3 increase in steps of 2, 0.5 and 0.2 *erl*, respectively. So, Point 1 represents the offered traffic-load vector $(a_1, a_2, a_3) = (70.0, 5.0, 1.0)$ while Point 7 refers to the vector $(a_1, a_2, a_3) = (82.0, 8.0, 2.2)$.

In Fig. 1, we present the analytical and simulation CBP results of $B_{1,nc}$, $B_{2,c}$ and $B_{3,c}$. Since calls of the 1st service-class and retry calls of the 2nd and 3rd service-classes have the same bandwidth requirement, we obtain $B_{1,nc}=B_{2,c}=B_{3,c}$. Fig. 2 portrays the analytical and simulation CBP results of the 2nd and the 3rd service-classes with either their initial bandwidth requirement or the retry bandwidth. Based on (11) these probabilities coincide when the probability of retry is the same. According to Figs. 1-2, we deduce that: (i) the analytical CBP results obtained are quite close to the simulation results. This fact reveals the accuracy of the proposed formulas. (ii) Increasing δ_k (and assuming that J_0 is fixed) or increasing J_0 (and considering that δ_k is fixed), the total CBP of cooperative service-classes decrease (Fig. 2). This fact reveals the consistency of our formulas. The opposite effect appears for non-cooperative service-classes, or for the retry calls of cooperative service-classes (Fig. 1).

For comparison, we consider the EMLM/TR with corresponding TR parameters (in b.u.) for the three service-classes, t_1 = 4, t_2 = 2, t_3 = 0, so that $b_1 + t_1 = b_2 + t_2 = b_3 + t_3$, in order to meet a fair call admission, i.e., CBP equalization. Note that the TR parameters of a service-class k express the reserved b.u. used to benefit calls of all service-classes apart from service-class k. The resultant equalized CBP are 0.060 for point 1, and 0.218 for point 7. Respectively, the present model results in 0.019 and 0.096, by setting J_0 = 95 (the highest) and δ_2=δ_3=1. For δ_2=δ_3=0.6, we get $B_{1,nc}$ = 0.065, $B_{2,c}$ = $B_{3,c}$ = 0.082 for point 1, and $B_{1,nc}$ = 0.185, $B_{2,c}$ = $B_{3,c}$=0.270 for point 7. These results show that the TR policy cannot capture the behaviour of the present model.

An open study is the determination of optimal values of J_0 and δ_k, while the interested reader may resort to [31], [32] for the case of K = 2 service-classes.

V. Conclusion

In this paper we propose a recursive formula for the calculation of the link occupancy distribution in a single link multirate loss system that accommodates Poisson arriving calls of many service-classes with cooperative and non-cooperative users. "Cooperative" users can retry to be connected in the system with a reduced bandwidth, when they are blocked with their initial peak-bandwidth requirement. This behavior increases the quality of service perceived by other users. On the other hand "non-cooperative" users are blocked and lost when their required bandwidth is not available. The proposed recursive formula: i) facilitates the call-level performance assessment and ii) is quite accurate, as it is shown through simulation. As a future work we intend to extend the model in the case of quasi-random traffic (smoother than Poisson traffic which is generated by a finite number of traffic sources) and study the optimal values of the threshold and the retry probabilities.

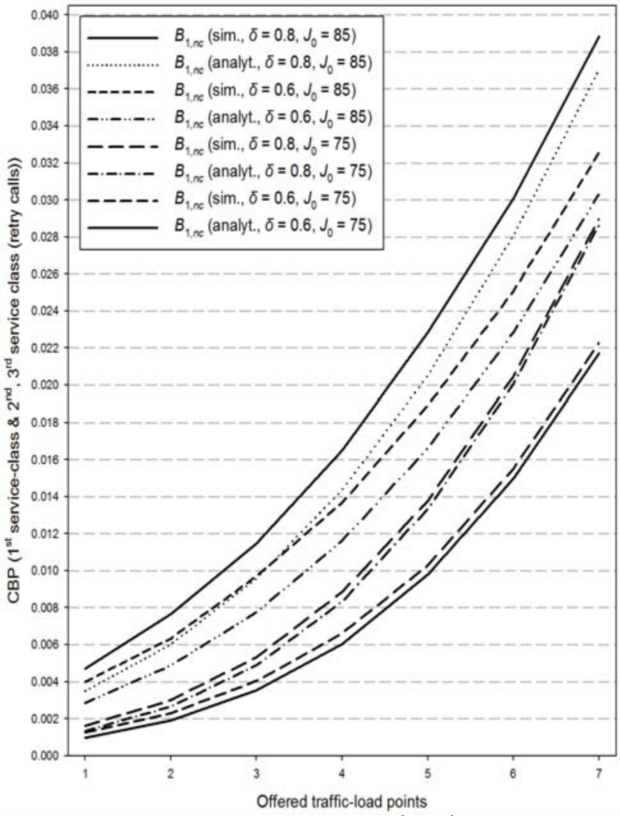

Figure 1. CBP of all service-classes (2nd & 3rd with retries).

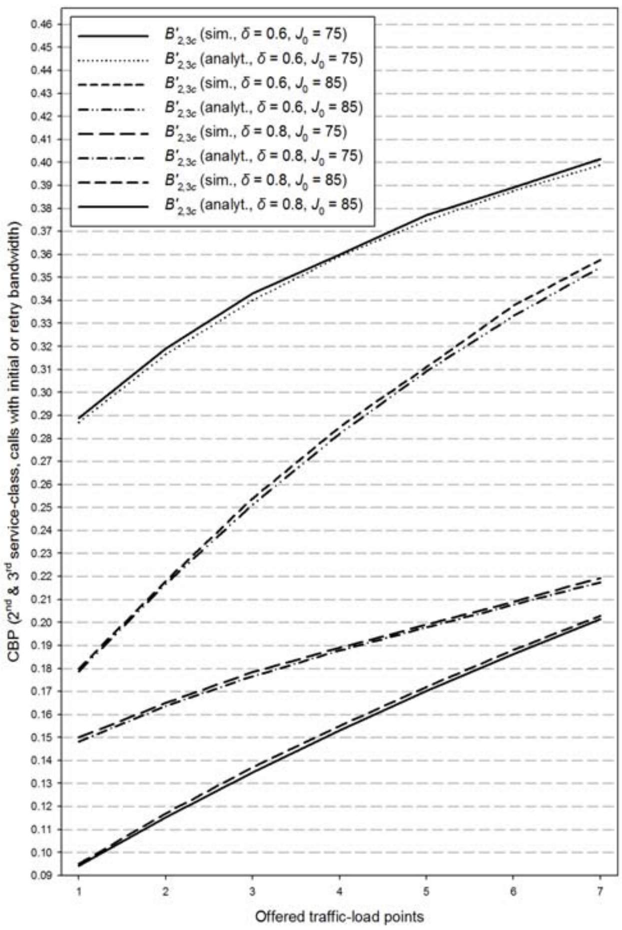

Figure 2. Total CBP of 2nd & 3rd service-class.

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