A Multirate Loss Model for Quasi-Random Traffic under the Multiple Fractional Channel Reservation Policy

I. D. Moscholios

Dept. of Informatics & Telecommunications, University of Peloponnese, 221 00 Tripolis, Greece
E-mail: idm@uop.gr

***Abstract*–We propose a teletraffic loss model of a link that accommodates different service-classes whose calls have different bandwidth requirements and come from finite sources. This arrival process is known as quasi-random. New calls compete for the available link bandwidth under the Multiple Fractional Channel Reservation (MFCR) policy. The MFCR policy allows the reservation of real (not integer) number of channels in order to benefit calls of high channel (bandwidth) requirements. The proposed model does not have a product form solution for the steady state probabilities. However, we propose approximate but recursive formulas for the calculation of time and call congestion probabilities as well as link utilization. The accuracy of the proposed formulas is verified through simulation and found to be highly satisfactory.**

I. Introduction

Contemporary communication networks require QoS mechanisms in order to provide the necessary bandwidth needed by multirate service-classes. In the case of multirate call-level traffic in a single link, modeled as a loss system, which accommodates service-classes with different QoS requirements, such a QoS mechanism is a bandwidth sharing policy. The QoS assessment of service systems under a bandwidth sharing policy is accomplished through multirate teletraffic loss/queueing models [1].

The simplest bandwidth sharing policy is the Complete Sharing (CS) policy, where a new call is accepted in the system if the call's bandwidth is available. Otherwise, the call is blocked and lost without further affecting the system. The main teletraffic multirate loss model that adopts the CS policy is the classical Erlang Multirate Loss Model (EMLM) [2]-[3]. In the EMLM, the call arrival process is Poisson while calls have fixed bandwidth requirements and generally distributed service times. The fact that the link occupancy distribution and Call Blocking Probabilities (CBP) are calculated via the accurate and recursive Kaufman-Roberts formula ([2]-[3]) has led to numerous extensions of the EMLM proposed for the call-level analysis of wired (e.g., [4]-[17]), wireless (e.g., [18]-[29]), satellite (e.g., [30]-[31]) and optical networks (e.g., [32]-[34]).

The main drawback of the CS policy is that it cannot provide a certain QoS to calls of a service-class. In addition, it is unfair to service-classes of high bandwidth-per-call requirements since it results in higher CBP compared to CBP of service-classes with low bandwidth-per-call requirements. A policy whereby QoS can be guaranteed to new calls is the Bandwidth Reservation (BR) policy [1]. In the BR policy, an integer number of bandwidth units (b.u.) or channels is reserved to benefit calls of high bandwidth requirements. The BR policy can achieve CBP equalization among service-classes at the cost of substantially increasing the CBP of calls with lower bandwidth requirements (e.g., [6]-[8], [35]-[39]).

In this paper, we consider an extension of the BR policy, namely the Multiple Fractional Channel Reservation (MFCR) policy [19]. The MFCR policy extends the BR policy by allowing the reservation of real (not integer) number of channels (or b.u.). More precisely, in the MFCR policy, real number of channels, $t_{r,k}$, are reserved to benefit calls from all service-classes apart from service-class k calls. The reservation of real number of channels is achieved since $\lfloor t_{r,k} \rfloor + 1$ channels are reserved with probability $t_{r,k} - \lfloor t_{r,k} \rfloor$ while $\lfloor t_{r,k} \rfloor$ channels are reserved with probability $1-\left(t_{r,k} - \lfloor t_{r,k} \rfloor\right)$, where $\lfloor t_{r,k} \rfloor$ is the largest integer not exceeding $t_{r,k}$. In [19], the case of Poisson (random) traffic is considered. We name this model Random MFCR (R-MFCR). In the R-MFCR, there is no Product Form Solution (PFS) for the steady state distribution, due to the fact that local balance between adjacent states is destroyed. This leads to an approximate but recursive formula for the determination of the link occupancy distribution and consequently the CBP calculation [19].

We extend the R-MFCR model by assuming that calls of each service-class k come from finite sources. This arrival process is known in the literature as quasi-random and is smoother than the Poisson process [40], [41]. To this end, we propose the Quasi-Random MFCR model (QR-MFCR), which describes a multirate loss system of K different service-classes whose calls have fixed bandwidth requirements and an exponentially distributed service time. The proposed model does not have a product form solution due to the existence of the MFCR policy. However, we prove approximate but recursive formulas for the calculation of Time Congestion (TC) and Call Congestion (CC) probabilities as well as link utilization. The accuracy of the proposed formulas is verified through simulation and found to be highly satisfactory. Note that TC probabilities are determined by the proportion of time the system is congested and can be measured by an outside observer. CC probabilities refer to the probability that a new call is blocked and lost. TC and CC probabilities coincide when calls of all service-classes follow a Poisson process (PASTA property [40]). In that case we use the term CBP, instead of TC or CC probabilities.

This paper is organized as follows: In Section II, we review the R-MFCR model of [19]. In Section III, we propose the QR-MFCR model and provide approximate but recursive formulas for the calculation of the link occupancy distribution and consequently TC and CC probabilities as well as link utilization. In Section IV, we present analytical and simulation TC probabilities results for the proposed model (QR-MFCR) and analytical TC probabilities for the models of [2], [3] and [19]. We conclude in Section V.

II. The R-MFCR Model

Consider a single link of capacity C channels (or b.u.) that accommodates calls of K service-classes under the MFCR policy. A call of service class k (k =1,…,K) follows a Poisson process with arrival rate λ_k, requests b_k channels and has an MFCR parameter $t_{r,k}$ that expresses the real number of channels reserved to benefit calls of all other service-classes except from service-class k. The reservation of $t_{r,k}$ channels is achieved because $\lfloor t_{r,k} \rfloor + 1$ channels are reserved with probability $t_{r,k} - \lfloor t_{r,k} \rfloor$ while $\lfloor t_{r,k} \rfloor$ channels are reserved with probability $1-\left(t_{r,k} - \lfloor t_{r,k} \rfloor\right)$. As an example, calls of service-class k may have an MFCR parameter of $t_{r,k}$ = 2.4 channels. The reservation of 2.4 channels is achieved by assuming that $\lfloor 2.4 \rfloor + 1 = 3$ channels are reserved with probability $2.4 - \lfloor 2.4 \rfloor = 0.4$ while $\lfloor 2.4 \rfloor = 2$ channels are reserved with probability $1-\left(2.4 - \lfloor 2.4 \rfloor\right) = 0.6$.

Let j be the occupied link bandwidth (j = 0, 1…,C) when a new service-class k call arrives in the link. Then, we consider the following admission control cases: a) if the available link bandwidth (C – j) minus the MFCR parameter $\lfloor t_{r,k} \rfloor$ is higher than the required b_k channels i.e., if $C - j - \lfloor t_{r,k} \rfloor > b_k$, then the new call is accepted in the system, b) if $C - j - \lfloor t_{r,k} \rfloor = b_k$, then the new call is accepted in the system with probability $1-\left(t_{r,k} - \lfloor t_{r,k} \rfloor\right)$ and c) if $C - j - \lfloor t_{r,k} \rfloor < b_k$, then there is no available bandwidth and the new call is blocked and lost without further affecting the system. An accepted call remains in the system for an exponentially distributed service time with mean μ_k^{-1}.

The determination of the link occupancy distribution, $G(j)$, in the MFCR is based on the following approximate but recursive formula [19]:

$$G(j) = \begin{cases} 1 \; for \; j=0 \\ \dfrac{1}{j}\sum_{k=1}^{K} a_k(j-b_k) b_k G(j-b_k) \; for \; j=1,...,C \\ 0 \; otherwise \end{cases} \tag{1}$$

where:

$$a_k(j\text{-}b_k) = \begin{cases} a_k \; for \; j < C - \lfloor t_{r,k} \rfloor \\ \left(1-\left(t_{r,k} - \lfloor t_{r,k} \rfloor\right)\right) a_k \; for \; j = C - \lfloor t_{r,k} \rfloor \\ 0 \; for \; j > C - \lfloor t_{r,k} \rfloor \end{cases} \tag{2}$$

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

Having determined $G(j)$'s we calculate the CBP of service-class k calls, B_k, by the formula [19]:

$$B_k = \sum_{j=C-b_k-\lfloor t_{r,k} \rfloor+1}^{C} G^{-1} G(j) + \left(t_{r,k} - \lfloor t_{r,k} \rfloor\right) G^{-1} G\left(C - b_k - \lfloor t_{r,k} \rfloor\right) \tag{3}$$

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

In addition, we can determine the link utilization, U, via (4), or the average number of service-class k calls in state j, $y_k(j)$, via (5):

$$U = \sum_{j=1}^{C} j G^{-1} G(j) \tag{4}$$

$$y_k(j) = \begin{cases} \dfrac{a_k G(j-b_k)}{G(j)} \; for \; j < C - \lfloor t_{r,k} \rfloor \\ \dfrac{\left(1-\left(t_{r,k} - \lfloor t_{r,k} \rfloor\right)\right) a_k G(j-b_k)}{G(j)} \; for \; j = C - \lfloor t_{r,k} \rfloor \\ 0 \; for \; j > C - \lfloor t_{r,k} \rfloor \end{cases} \tag{5}$$

Note that (5) is the basis for the proof of (1) and implies that the average number of calls in state j, $y_k(j)$, is negligible in the part of the reservation space of service-class k denoted by the states: $j = C - \lfloor t_{r,k} \rfloor + 1, ..., C$.

In the case of the classical BR policy, where an integer number of channels, t_k, is reserved, the link occupancy distribution is determined by (1), the link utilization by (4) while (2), (3) and (5) take the form of (6), (7) and (8), respectively [35]:

$$a_k(j\text{-}b_k) = \begin{cases} a_k \; for \; j \le C - t_k \\ 0 \; for \; j > C - t_k \end{cases} \tag{6}$$

$$B_k = \sum_{j=C-b_k-t_k+1}^{C} G^{-1} G(j) \tag{7}$$

$$y_k(j) = \begin{cases} \dfrac{a_k G(j-b_k)}{G(j)} \; for \; j \le C - t_k \\ 0 \; for \; j > C - t_k \end{cases} \tag{8}$$

In the case of the CS policy (all BR parameters are set to zero), the link occupancy distribution is determined by the classical Kaufman-Roberts recursion (9), CBP by (10) and the values of $y_k(j)$ by (11), [2]-[3]:

$$G(j)=\begin{cases} 1 \; for \; j=0 \\ \frac{1}{j}\sum_{k=1}^{K} a_k b_k G(j-b_k) \; for \; j=1,\ldots,C \\ 0 \; otherwise \end{cases} \tag{9}$$

$$B_k = \sum_{j=C-b_k+1}^{C} G^{-1} G(j) \tag{10}$$

$$y_k(j)=\begin{cases} \frac{a_k G(j-b_k)}{G(j)} \; for \;\; j \le C \\ 0 \;\; for \;\; j > C \end{cases} \tag{11}$$

III. THE PROPOSED QR-MFCR MODEL

Consider a link of capacity C channels that accommodates K different service-classes. Calls of service class k (k =1,…,K) come from a finite source population N_k and compete for the available channels under the MFCR policy. The mean arrival rate of service-class k idle sources is $\lambda_k = (N_k - n_k)v_k$ where n_k is the number of in-service calls and v_k is the arrival rate per idle source. The offered traffic-load per idle source of service-class k is given by $a_{k,f} = v_k / \mu_k$ (in erl). This arrival process is known as a quasi-random process [40], [41]. If $N_k \to \infty$ for k = 1,…,K, and the total offered traffic-load remains constant, then the arrival process becomes Poisson.

Figure 1 shows the steady state transition rates of the QR-MFCR model. Based on Fig. 1, the global balance equation for state $\boldsymbol{n}=(n_1,n_2,\ldots,n_k,\ldots,n_K)$, expressed as *rate into state* $\boldsymbol{n}$ = *rate out of state* $\boldsymbol{n}$, is given by:

$$\sum_{k=1}^{K}(N_k-n_k+1)v_k(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-)+\sum_{k=1}^{K}(n_k+1)\mu_k P(\boldsymbol{n}_k^+)= \sum_{k=1}^{K}(N_k-n_k)v_k(\boldsymbol{n})P(\boldsymbol{n})+\sum_{k=1}^{K}n_k\mu_k P(\boldsymbol{n}) \tag{12}$$

where:

$$v_k(\boldsymbol{n})=\begin{cases} v_k \;\; for \;\; C-\boldsymbol{nb} > b_k + \lfloor t_{r,k} \rfloor \\ \left(1-\left(t_{r,k}-\lfloor t_{r,k} \rfloor\right)\right)v_k \;\; for \;\; C-\boldsymbol{nb} = b_k + \lfloor t_{r,k} \rfloor \\ 0 \;\; otherwise \end{cases} \tag{13}$$

$\boldsymbol{n}_k^+ = (n_1,\ldots,n_{k-1},n_k+1,n_{k+1},\ldots,n_K)$,

$\boldsymbol{n}_k^- = (n_1,\ldots,n_{k-1},n_k-1,n_{k+1},\ldots,n_K)$

and $P(\boldsymbol{n}), P(\boldsymbol{n}_k^-), P(\boldsymbol{n}_k^+)$ are the probability distributions of the corresponding states $\boldsymbol{n}, \boldsymbol{n}_k^-, \boldsymbol{n}_k^+$, respectively.

The proposed model does not have a PFS for the determination of the steady state probabilities $P(\boldsymbol{n})$ due to the fact that local balance can be destroyed between states $\boldsymbol{n}_k^-, \boldsymbol{n}$ or $\boldsymbol{n}, \boldsymbol{n}_k^+$. This means that $P(\boldsymbol{n})$'s (and consequently all performance measures) can be determined by solving the global balance equations, a realistic task only for small (i.e., tutorial) examples of links with small capacity and two or three service-classes.

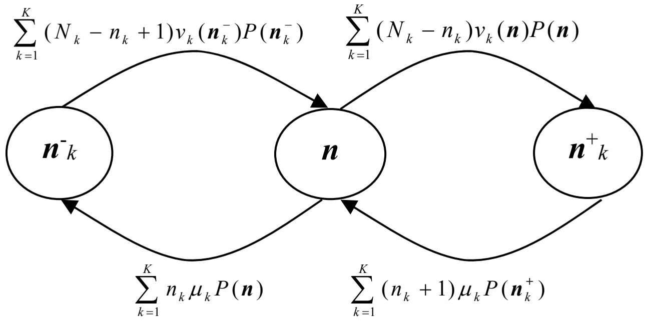

Figure 1. State transition diagram of the proposed QR/MFCR.

To circumvent this problem, we prove an approximate but recursive formula for the calculation of the link occupancy distribution, $G_f(j)$, of the proposed finite source model. By definition:

$$G_f(j) = \sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j} P(\boldsymbol{n}) \tag{14}$$

where $\boldsymbol{\Omega}_j$ is the set of states whereby exactly j b.u. are occupied by all in-service calls, i.e. $\boldsymbol{\Omega}_j = \{\boldsymbol{n}\in\boldsymbol{\Omega} : \boldsymbol{nb} = j\}$ and $\boldsymbol{\Omega}=\{\boldsymbol{n}: 0 \le \boldsymbol{nb} \le C, k=1,\ldots,K\}$.

Since $j=\boldsymbol{nb} = \sum_{k=1}^{K} n_k b_k$ we write (14) as follows:

$$jG_f(j) = \sum_{k=1}^{K} b_k \sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j} n_k P(\boldsymbol{n}) \tag{15}$$

To determine the $\sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j} n_k P(\boldsymbol{n})$ in (14), we assume (this is an approximation) that local balance exists between the adjacent states $\boldsymbol{n}_k^-, \boldsymbol{n}$ and has the form:

$$(N_k - n_k + 1)a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) = n_k P(\boldsymbol{n}) \tag{16}$$

where: $a_{k,f}(\boldsymbol{n}_k^-) = v_k(\boldsymbol{n}_k^-)/\mu_k$.

Summing both sides of (16) over $\boldsymbol{\Omega}_j$ we have:

$$\sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j}(N_k - n_k + 1)a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) = \sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j} n_k P(\boldsymbol{n}) \tag{17}$$

The left hand side of (17) can be written as:

$$\sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j}(N_k - n_k + 1)a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) = N_k \sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j} a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) - \sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j}(n_k - 1)a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) \tag{18}$$

Since $\sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j} a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) = a_{k,f}(j-b_k)G_f(j-b_k)$ the first term of the right hand side of (18) becomes:

$$N_k \sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j} a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) = N_k a_{k,f}(j-b_k)G_f(j-b_k) \tag{19}$$

where:

$$a_{k,f}(j\text{-}b_k)=\begin{cases}a_{k,f} \text{ for } j<C-\lfloor t_{r,k}\rfloor \\ \left(1-\left(t_{r,k}-\lfloor t_{r,k}\rfloor\right)\right)a_{k,f} \text{ for } j=C-\lfloor t_{r,k}\rfloor \\ 0 \text{ for } j>C-\lfloor t_{r,k}\rfloor\end{cases} \quad (20)$$

The second term of the right hand side of (18) is written as:

$$\sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j}(n_k-1)a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) = a_{k,f}(j-b_k)y_{k,f}(j-b_k)G_f(j-b_k) \quad (21)$$

where $y_{k,f}(j-b_k)$ is the average number of service-class k calls in state $j-b_k$.

Based on (19)-(21), (18) takes the form:

$$\sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j}(N_k-n_k+1)a_{k,f}(\boldsymbol{n}_k^-)P(\boldsymbol{n}_k^-) = a_{k,f}(j-b_k)\left(N_k-y_{k,f}(j-b_k)\right)G_f(j-b_k) \quad (22)$$

Equation (17) due to (22) is written as:

$$\left(N_k-y_{k,f}(j-b_k)\right)a_{k,f}(j-b_k)G_f(j-b_k) = \sum_{\boldsymbol{n}\in\boldsymbol{\Omega}_j}n_kP(\boldsymbol{n}) \quad (23)$$

Equation (15) due to (23) is written as:

$$jG_f(j)=\sum_{k=1}^{K}\left(N_k-y_{k,f}(j-b_k)\right)a_{k,f}(j-b_k)b_kG_f(j-b_k) \quad (24)$$

In (24), the values of $y_{k,f}(j-b_k)$ are not known. To determine them, we use a lemma of [5]. According to that lemma, two stochastic systems are equivalent and result in the same CBP, if they have: a) the same traffic description parameters $(K, N_k, a_{k,f})$ where k=1,…,K and b) exactly the same set of states.

Our purpose is therefore to find a new stochastic system, whereby we can calculate $y_{k,f}(j-b_k)$. The bandwidth (channel) requirements of calls and the capacity in the new stochastic system are chosen according to the following two criteria: 1) conditions (a) and (b) are valid and 2) each state has a unique occupancy j.

Now, state j is reached only via the previous state $j-b_k$.

Thus, $y_{k,f}(j-b_k)=n_k-1$.

Based on the above, (24) is given by:

$$G_f(j)=\begin{cases}1, & \text{for } j=0\\ \frac{1}{j}\sum_{k=1}^{K}(N_k-n_k+1)a_{k,f}(j-b_k)b_kG_f(j-b_k), & \text{for } j=1,\dots,C\\ 0, & \text{otherwise}\end{cases} \quad (25)$$

where $a_{k,f}(j\text{-}b_k)$ is given by (20).

The calculation of $G_f(j)$'s via (25) requires the value of n_k which is unknown. The determination of n_k's requires the state space determination of the equivalent system, a complex procedure especially for large capacity systems that accommodate many service-classes. Because of this we approximate n_k in state j, $n_k(j)$, as $y_k(j)$, when Poisson arrivals are considered, i.e., $n_k(j)\approx y_k(j)$. Thus, we determine $G_f(j)$'s via the formula:

$$G_f(j)=\begin{cases}1, & \text{for } j=0\\ \frac{1}{j}\sum_{k=1}^{K}(N_k-y_k(j-b_k))a_{k,f}(j-b_k)b_kG_f(j-b_k), & \text{for } j=1,\dots,C\\ 0, & \text{otherwise}\end{cases} \quad (26)$$

where the values of $y_k(j)$'s are given by (5).

Having determined $G_f(j)$'s we calculate the TC probabilities of service-class k calls, P_{b_k}, as follows:

$$P_{b_k}=\sum_{j=C-b_k-\lfloor t_{r,k}\rfloor+1}^{C}G^{-1}G_f(j) +\left(t_{r,k}-\lfloor t_{r,k}\rfloor\right)G^{-1}G_f\left(C-b_k-\lfloor t_{r,k}\rfloor\right) \quad (27)$$

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

CC probabilities of service-class k, B_k, can be determined via (27) where $G_f(j)$'s are calculated (via (26)) for a system with N_k - 1 traffic sources. As far as link utilization, U, is concerned, it can be calculated via (4).

IV. NUMERICAL EXAMPLES - EVALUATION

In this section, we present an application example and provide analytical and simulation TC probabilities results of the proposed QR-MFCR model and analytical TC probabilities results of the R-MFCR model of [19]. As a reference we also present analytical results in the case of Poisson arrivals and the CS policy [2]-[3] or the BR policy [35]. Simulation results are derived via the Simscript III simulation language [42] and are mean values of 7 runs. As far as the reliability ranges are concerned they are less than two order of magnitude, and therefore are not presented in the following figures. All simulation runs are based on the generation of four million calls per run. To account for a warm-up period, the first 5% of these generated calls are not considered in the CBP results.

As an application example, consider a link of capacity C = 60 channels, that accommodates calls of three service-classes, with the traffic characteristics of Table 1.

Table 1: Service-classes – Traffic characteristics

Service-class	Traffic-load for Poisson traffic (erl)	Bandwidth (channels)	MFCR parameter (channels)
1st	a_1 = 1.0	b_1 = 1	$t_{r,1}$ = 9.4
2nd	a_2 = 1.0	b_2 = 5	$t_{r,2}$ = 5.3
3rd	a_3 = 1.0	b_3 = 10	$t_{r,3}$ = 0

In the case of quasi-random traffic, we consider two sets of traffic sources: 1) N_1=N_2=N_3 = 10 sources and 2) N_1=N_2=N_3 = 30 sources. In both sets, the values of $a_{k,f}$ are determined by $a_{k,f}=a_k/N_k$ for k=1, 2, 3.

Concerning the MFCR parameter of the 1st service-class, the reservation of 9.4 channels is achieved by assuming that 10 channels are reserved with probability

0.4 while 9 channels are reserved with probability 0.6. Similarly, 5.3 channels for the 2nd service-class are reserved by assuming that 6 channels are reserved with probability 0.3 while 5 channels are reserved with probability 0.7.

In the x-axis of Figs 2-4 the offered traffic load of the 1st, 2nd and 3rd service-class increases in steps of 0.5, 0.2 and 0.1 erl, respectively. So, point 1 is: $(a_1, a_2, a_3) = (1.0, 1.0, 1.0)$ while point 8 is: $(\alpha_1, \alpha_2, \alpha_3) = (4.5, 2.4, 1.7)$.

In Figs. 2-4, we present analytical TC probabilities results of the QR-MFCR, the R-MFCR and the models of [2]-[3], [35] together with the QR-MFCR simulation results, for each service-class, respectively. All figures show that the analytical results of the QR-MFCR model: a) are close to the corresponding simulation results, a fact that validates the proposed formulas, b) are lower than those of the R-MFCR model, especially for $N_1=N_2=N_3$ = 10 sources, due to the finite number of traffic sources. In addition, Figs. 2-4, show that TC probabilities of the 3rd service-class are reduced due to the MFCR policy at the cost of substantially increasing the TC probabilities of the other two service-classes.

V. CONCLUSION

In this paper we propose a multirate loss model of quasi-random arriving calls which compete for the available link bandwidth under the MFCR policy. The analysis of the proposed model leads to approximate but recursive formulas for the calculation of the link occupancy distribution and consequently TC and CC probabilities as well as link utilization. Simulation results verify the accuracy of the proposed model.

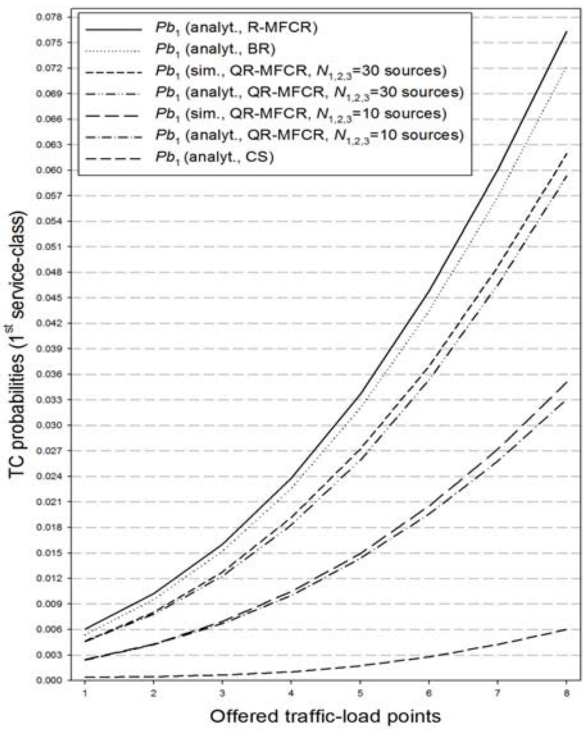

Figure 2. TC probabilities – 1st service-class.

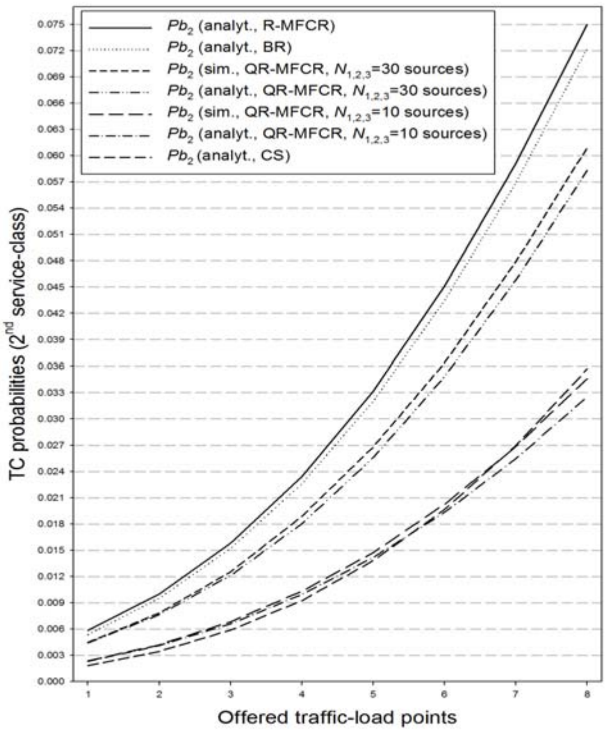

Figure 3. TC probabilities – 2nd service-class.

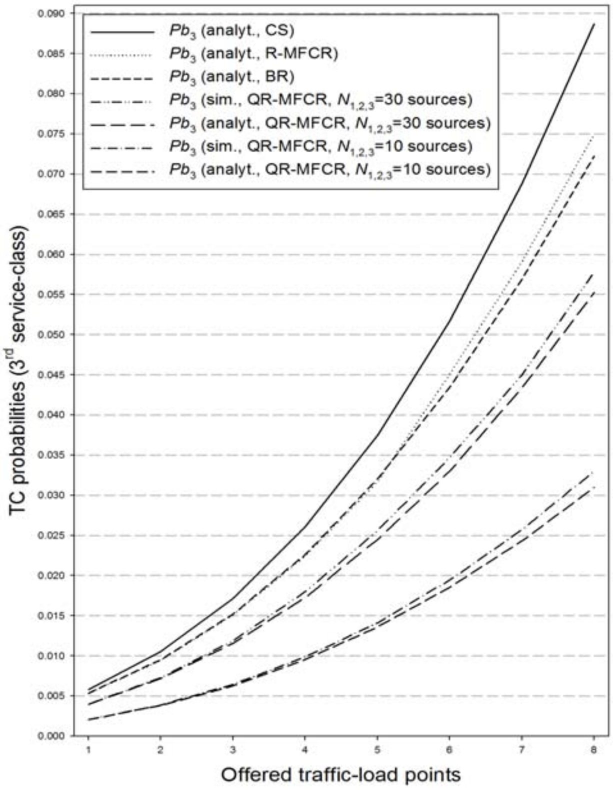

Figure 4. TC probabilities – 3rd service-class.

REFERENCES

1. M. Stasiak, M. Glabowski, A.Wisniewski, and P. Zwierzykowski, Modeling and Dimensioning of Mobile Networks, Wiley & Sons, 2011.
2. J. Kaufman, "Blocking in a shared resource environment", IEEE Trans. Commun. vol. 29, no. 10, pp. 1474-1481, October 1981.

3. J. Roberts, "A service system with heterogeneous user requirements", in: G. Pujolle (Ed.), Performance of Data Communications systems and their applications, North Holland, Amsterdam, pp.423-431, 1981.
4. J. Kaufman, "Blocking with retrials in a completely shared resource environment", Performance Evaluation, 15 (2), pp. 99-113, June 1992.
5. G. Stamatelos and J. Hayes, "Admission control techniques with application to broadband networks", Comput. Commun., 17 (9), pp. 663-673, 1994.
6. G. Stamatelos and V. Koukoulidis, "Reservation-Based Bandwidth Allocation in a Radio ATM Network", IEEE/ACM Trans. Netw., 5 (3), pp. 420-428, June 1997.
7. M. Stasiak and M. Glabowski, "A simple approximation of the link model with reservation by a one-dimensional Markov chain", Performance Evaluation, 41 (2-3), pp.195–208, July 2000.
8. M. Glabowski and M. Stasiak, "Point-to-point blocking probability in switching networks with reservation", Annals of Telecommunications, 57 (7-8), pp. 798-831, July-August 2002.
9. S. Rácz, B. Gerő, and G. Fodor, "Flow level performance analysis of a multi-service system supporting elastic and adaptive services", Performance Evaluation, 49 (1-4), Sept. 2002, pp. 451-469.
10. I. Moscholios, P. Nikolaropoulos and M. Logothetis, "Call level blocking of ON-OFF traffic sources with retrials under the complete sharing policy", Proc. of 18th ITC, Berlin, Germany, 31 August – 5 September 2003, pp. 811-820.
11. M. Glabowski and M. Stasiak, "Multi-rate model of the limited availability group with finite source population", Proc. 10th Asia-Pacific Conf. on Commun., Beijing, China, Sept. 2004.
12. I. Moscholios and M. Logothetis, "Engset Multirate State-Dependent Loss Models with QoS Guarantee", Int. Journal of Commun. Systems, 19 (1), pp. 67-93, Feb. 2006.
13. V. Vassilakis, I. Moscholios and M. Logothetis, "Call-level performance modelling of elastic and adaptive service-classes with finite population", IEICE Trans. Commun., vol. E91-B, no. 1, pp. 151-163, Jan. 2008.
14. Q. Huang, King-Tim Ko and V. Iversen, "Approximation of loss calculation for hierarchical networks with multiservice overflows", IEEE Trans. Commun., 56 (3), pp. 466-473, March 2008.
15. M. Stasiak, M. Sobieraj, J. Weissenberg and P. Zwierzykowski, "Analytical Model of the Single Threshold Mechanism with Hysteresis for Multi-service Networks", IEICE Transactions on Communications, vol. E95-B, no. 1, pp. 120-132, January 2012.
16. I. Moscholios, J. Vardakas, M. Logothetis and A. Boucouvalas, "Congestion probabilities in a Batched Poisson multirate loss model supporting elastic and adaptive traffic", Annals of Telecommunications, 68 (5), pp. 327-344, June 2013.
17. I. Moscholios, J. Vardakas, M. Logothetis and M. Koukias, "A Quasi-random Multirate Loss Model supporting Elastic and Adaptive Traffic under the Bandwidth Reservation Policy", Int. Journal on Advances in Networks and Services, 6 (3&4), pp. 163-174, December 2013.
18. V. Iversen, V. Benetis, N. Ha, S. Stepanov, "Evaluation of Multi-service CDMA Networks with Soft Blocking", Proc. of ITC Specialist Seminar, Antwerp, Belgium, pp. 223-227, August/September 2004.
19. F. Cruz-Pérez, J. Vázquez-Ávila and L. Ortigoza-Guerrero, "Recurrent formulas for the multiple fractional channel reservation strategy in multi-service mobile cellular networks", IEEE Commun. Letters, 8 (10), pp. 629-631, Oct. 2004.
20. I. Moscholios, M. Logothetis and M. Koukias, "A State-Dependent Multi-Rate Loss Model of Finite Sources with QoS Guarantee for Wireless Networks", Mediterranean Journal of Computers and Networks, 2 (1), pp. 10-20, Jan. 2006.
21. G. Fodor and M. Telek, "Bounding the Blocking Probabilities in Multirate CDMA Networks Supporting Elastic Services", IEEE/ACM Trans. Netw., 15 (4), pp. 944-956, Aug. 2007.
22. V. Vassilakis, G. Kallos, I. Moscholios and M. Logothetis, "Call-Level Analysis of W-CDMA Networks Supporting Elastic Services of Finite Population", IEEE ICC 2008, Beijing, China, 19-23 May 2008.
23. I. Widjaja and H. Roche, "Sizing X2 bandwidth for Inter-connected eNBs", Proc. IEEE VTC Fall, Anchorage, Alaska, USA, Sept. 2009.
24. M. Stasiak, P. Zwierzykowski, D. Parniewicz: Modelling of the WCDMA interface in the UMTS network with Soft Handoff Mechanism, GLOBECOM, Hawaii, Honolulu, Dec. 2009.
25. B. Renard, S. Elayoubi and A. Simonian, "A dimensioning method for the LTE X2 interface", Proc. IEEE WCNC, Shanghai, China, April 2012.
26. M. Stasiak, D. Parniewicz and P. Zwierzykowski, "Traffic Engineering for Multicast Connections in Multiservice Cellular Network", IEEE Transactions on Industrial Informatics, 9 (1), pp. 262 – 270, Feb. 2013.
27. I. Moscholios, G. Kallos, M. Katsiva, V. Vassilakis and M. Logothetis, "Call Blocking Probabilities in a W-CDMA cell with interference cancellation and bandwidth reservation", Proc. of IEICE ICTF, Poznan, Poland, 28-30 May 2014.
28. I. Moscholios, G. Kallos, V. Vassilakis and M. Logothetis, "Congestion Probabilities in CDMA-based networks supporting batched Poisson input traffic", Wireless Personal Communications, 79 (2), Nov. 2014, pp. 1163-1186.
29. V. Vassilakis, I. Moscholios, J. Vardakas and M. Logothetis, "Handoff Modeling in Cellular CDMA with Finite Sources and State-Dependent Bandwidth Requirements", Proc. of IEEE CAMAD 2014, Athens, Greece, Dec. 2014.
30. Z. Wang, P. Mathiopoulos, and R. Schober, "Performance Analysis and Improvement Methods for Channel Resource Management Strategies of LEO-MSS with Multiparty Traffic", IEEE Trans. Vehicular Tech., 57 (6), pp. 3832-3842, Nov. 2008.
31. Z. Wang, P. Mathiopoulos, and R. Schober, "Channel partitioning policies for multi-class traffic in LEO-MSS", IEEE Trans. Aerosp. Electron. Syst., 45 (4), pp. 1320 – 1334, Oct. 2009.
32. J. Vardakas, I. Moscholios, M. Logothetis and V. Stylianakis, "An Analytical Approach for Dynamic Wavelength Allocation in WDM-TDMA PONs Servicing ON-OFF Traffic", IEEE/OSA Journal of Optical Commun. Netw., 3 (4), pp. 347-358, April 2011.
33. Y. Deng and P. Prucnal, "Performance analysis of heterogeneous optical CDMA networks with bursty traffic and variable power control", IEEE/OSA Journal of Optical Commun. Netw., 3 (6), pp. 487-492, June 2011.
34. J. Vardakas, I. Moscholios, M. Logothetis, and V. Stylianakis, "Performance Analysis of OCDMA PONs Supporting Multi-Rate Bursty Traffic", IEEE Trans. Commun., 61 (8), pp. 3374-3384, August 2013.
35. J. Roberts, "Teletraffic models for the Telecom 1 Integrated Services Network", Proc. 10th ITC, paper 1.1-2, Montreal 1983.
36. I. Moscholios, M. Logothetis and G. Kokkinakis, "Connection Dependent Threshold Model: A Generalization of the Erlang Multiple Rate Loss Model", Performance Evaluation, 48 (1-4), pp. 177-200, May 2002.
37. M. Glabowski, A. Kaliszan and M. Stasiak, "Asymmetric convolution algorithm for blocking probability calculation in full-availability group with bandwidth reservation", IET Circuits, Devices & Systems, 2 (1), pp.87-94, Feb. 2008.
38. V. Vassilakis, I. Moscholios and M. Logothetis, "The Extended Connection-Dependent Threshold Model for Call-level Performance Analysis of Multi-rate Loss Systems under the Bandwidth Reservation Policy", Int. Journal of Communication Systems, 25 (7), pp. 849-873, July 2012.
39. I. Moscholios, M. Logothetis, J. Vardakas and A. Boucouvalas, "Performance metrics of a multirate resource sharing teletraffic model with finite sources under the threshold and bandwidth reservation policies", IET Networks, 4 (3), pp. 195-208, May 2015.
40. H. Akimaru and K. Kawashima, Teletraffic - Theory and Applications, 2nd edition, Springer, Berlin, 1999.
41. I. Moscholios, M. Logothetis and P. Nikolaropoulos, "Engset Multi-Rate State-Dependent Loss Models", Performance Evaluation, 59 (2-3), pp. 247-277, Feb. 2005.
42. Simscript III, http://www.simscript.com