The MM $\sum_{k=1}^{K}$ $\mathrm{CPP_k}$/GE/c/L G-Queue and its Application to the Analysis of the Load Balancing in MPLS Networks

Ram Chakka
Department of Computer Science,
Norfolk State University,
700 Park Avenue, Norfolk, VA 23504, USA.
Email: ramchakka@yahoo.com

Tien Van Do
Department of Telecommunications,
Budapest University of Technology and Economics
H-1111, Magyar tudósok körútja 2., Budapest, Hungary
Email: do@hit.bme.hu

1. The MM $\sum_{k=1}^{K} \mathrm{CPP_k}$/GE/c/L G-Queue

It is well known that the traffic in today's telecommunication systems often exhibits burstiness i.e. batches of transmission units (e.g. packets) arrive together with correlation among the interarrival times [12]. Several models have been proposed to model such arrival-service processes, queues and networks. These include the compound Poisson process (CPP) in which the interarrival times have generalised exponential (GE) probability distribution [8], the Markov modulated Poisson process (MMPP) and the self-similar traffic models such as the Fractional Brownian Motion (FBM) [11]. The CPP and the $\sum_{k=1}^{K} CPP_k$ traffic models often give a good representation of the burstiness (batch size distribution) of the traffic from one or more sources [7], but not the auto-correlations of the interarrival time observed in real traffic. Conversely, the MMPP models can capture the auto-correlations but not the burstiness [9, 14]. The self-similar traffic models such as the FBM can represent both burstiness as well as auto-correlations, but they are analytically intractable in a queueing context. Often, the traffic to a node is the superposition of traffic from a number of sources, complicating the system analysis further.

The MM CPP/GE/c/L G-queue has been capable of accommodating large batch sizes of arrivals and services with an efficient solution in the Markovian framework [2]. However it suffers from the restriction on the batch size distribution (i.e. geometric batch size distribution). In order to overcome that restriction, to make the model vastly flexible and also to accommodate the superposition of multiple arrival streams, a new traffic/queueing model, the Markov modulated $\sum_{k=1}^{K} CPP_k$/GE/c/L G-queue is introduced [4]. This is a homogeneous multi-server queue with c servers, GE service times and with the superposition of K independent positive and an independent negative[1] customer arrival streams each of which is a CPP, i.e. a Poisson point process with batch arrivals of geometrically distributed batch size. In other words, interarrival times of each of these $K+1$ arrival streams individually are also independent GE random variables. Also, all the $K+2$ GE distributions (K positive and 1 negative customer interarrival times and the service time) are jointly modulated by a continuous time Markov phase process (CTMP), also termed as the modulating process.

It is established in [4], the Makov modulated $\sum_{k=1}^{K} CPP_k$/GE/c/L G-queue is mathematically tractable with efficient analytical solution for the steady state probabilities. This was done by transforming the balance equations to a computable form (the QBD-M type) and then solving the resulting equations using the spectral expansion method [1, 2]. Those non-trivial transformations used are indeed mathematically equivalent to the SSS (successive, simultaneous, weighted subtractions of the balance equations) method used in [2], as applied to this more generalised queue.

Thus, the new MM $\sum_{k=1}^{K} CPP_k$/GE/c/L G-queue and its extensions [4, 5] can capture a large class of traffic, queueing models applicable to todays Internet, in a Markovian framework. Already several studies exist to fit the Internet traffic (voice traffic, multimedia traffic) to the MMPP processes which are the special cases of the new arrival process, the MM $\sum_{k=1}^{K} CPP_k$ [14, 15].

2 Applications

MPLS (Multiprotocol Label Switching) is the recent development of IETF in response to the explosive growth of the Internet [13]. One of the aims of the MPLS development is to expand the granularity of administrative traffic control

[1] Negative customers remove (positive) customers in the queue and have been used to model random neural networks, task termination in speculative parallelism, faulty components in manufacturing systems and server breakdowns [6].

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(i.e.: Traffic Engineering). MPLS assigns labels at ingress routers based upon the destination IP address of incoming packets. Thereafter, labels are simply swapped instead of interrogating IP headers at each hop, significantly increasing packet forwarding efficiency, which results in tremendous gains in traffic forwarding speed.

Efficient operation of multipath routing is considered as one of the important aspects in MPLS traffic engineering. Multipath routing has an advantage over traffic routing based on single shortest paths because single path routing may lead to unbalanced traffic situations and degraded QoS (Quality of Service) in some cases (even if the network is not so overloaded). In MPLS networks multiple LSPs (label switched path) can be established between MPLS ingress and egress nodes to enhance the network performance and QoS (Quality of Service) for subscribers.

In packet switched networks (e.g.: Internet), multipath routing has an advantage over the traffic routing based on a single shortest path because the single path routing can lead to unbalanced traffic situations and degraded QoS (Quality of Service).There exist some solutions ([10]) for the distribution of traffic among multiple paths in IP networks. However, the advantage of multipath routing is not fully exploited in IP networks due to the limited capability of routing mechanisms (like OSPF) and the limited traffic control capability in IP networks. Recently, IETF has started the work on MPLS (Multiprotocol Label Switching) providing label swapping mechanism with an automatic and explicit routing capability [13]. In MPLS networks multiple LSPs (label switched path) can be easily established between MPLS ingress and egress nodes to enhance the network performance and QoS (Quality of Service) for subscribers.

In [3] we model the arrival of packets to the ingress router as the MM $\sum_{k=1}^{K} CPP_k$ process, multipaths as multi-servers (homogeneous or heterogeneous, as appropriate) with GE service times, the maximum number of active LSP's as c and the capacity of the ingress node as L, respectively.The uses of the negative customer stream (represented by G-) are several, e.g. for flow control studies, to model breakdowns of the LSPs, to represent packet losses caused by the arrival of corrupted cells. These are discussed in [3, 5] in a greater detail. The breakdowns of LSPs are also modelled by increasing the number of operative states of the resulting QBD-M process [3]. Thus the MM $\sum_{k=1}^{K} CPP_k$/GE/c/L G-queue and its extensions [4, 5] can be used to model the ingress router and for efficient computation of the performance measures (such as the average queue sizes, average number of active paths) of the ingress nodes operating multipath routing in MPLS networks.

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