Int. J. Electron. Commun. (AEÜ) 66 (2012) 1038–1041

Contents lists available at SciVerse ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.de/aeue

A new analytical model for the CQ switch throughput calculation under the bursty traffic

Igor Radusinovic[a], Milutin Radonjic[a,*], Anita Simurina[a], Ivo Maljevic[b], Zoran Veljovic[a]

[a] Faculty of Electrical Engineering, University of Montenegro, Podgorica, 81000, Montenegro
[b] Technology Strategy, TELUS Mobility, Toronto, Canada

ARTICLE INFO

Article history:
Received 10 June 2011
Received in revised form 23 May 2012
Accepted 24 May 2012

Keywords:
Crosspoint queued switch
Throughput
Bursty traffic

ABSTRACT

In this paper we propose a new analytical iterative method for the throughput calculation of the Crosspoint Queued (CQ) switch with a random scheduling algorithm under the bursty traffic model. This method is verified by comparing it with the simulation results, which shows a very good match. To the authors' knowledge, this is the first analytical method for the throughput calculation of such a switch for the bursty traffic model.

1. Introduction

The Crosspoint Queued (CQ) switch has recently been brought back into focus since it is possible to implement large buffers with the CQ fabric on the same chip, using modern technology [1]. It has been shown in [1] that the CQ switch can manage packets without permanently relying on the current states of the input and output linecards, or on the complex centralized scheduler. Therefore, the control communication between the linecards and the switching fabric, which can be a limiting factor to the transfer speed in distributed switching systems, is no longer necessary.

The CQ switch performances were analyzed in the previous research [1–3]. Closed form relations for the throughput and the average cell latency are presented in [1], but only for one-cell buffers and a uniform arrival traffic. The complexity of this approach makes it inappropriate for the longer buffers [2]. The iterative method for the throughput calculation of the CQ switch with various-length buffers, for uniform arrival traffic is presented in [2]. The simulation analysis of the throughput, the average cell latency, and the cell delay variation are performed for different input traffic, buffer lengths and scheduling algorithms [3].

Since the CQ switch is very attractive for implementation, and considering that the bursty traffic model closely resembles real Internet traffic, we propose a new analytical iterative method for the throughput calculation of the CQ switch with any number of ports or buffer lengths, where the bursty traffic is modeled as an Interrupted Bernoulli Process (IBP). The proposed method is a modification of one based on the CICQ switch performance analysis, originally presented in [4]. The analysis is based on the 3D Markov chain system modeling. This method has been verified by the simulation results.

This paper is organized as follows. The structure of the analyzed CQ switch and the input traffic model are given in Section 2. The analytical model for the throughput analysis is proposed in Section 3. The comparison between the analytical and simulation results is performed in Section 4.

2. Structure of the analyzed switch

The structure of the CQ switch, as illustrated in Fig. 1, is well known [1]. Each crosspoint buffer (XB_{ij}) contains packets that originated from an input i and are intended for an output j. At the beginning of each time slot, the scheduler chooses one of the non-empty crosspoint buffers from the common output line and forwards its head-of-the-line packet to an output linecard. In this paper, we analyze the switch with a random scheduling policy.

Following common practice, we assume that the incoming packets have a fixed size length (referred to as cells), which means that the segmentation and reassembly are accomplished outside the switch [5]. Time is divided into equal slots, where each slot's length corresponds to the requirement of transferring one cell.

The bursty traffic at each input is modeled by a well-known two-state ON–OFF Interrupted Bernoulli Process [3]. The IBP models large packets that are segmented into fix-sized cells, or a large number of successive packets that are a part of the same data transfer (video or voice segments, file transfer, etc.). Each of the inputs is

* Corresponding author. Tel.: +382 20 245839; fax: +382 20 245873.
E-mail address: m.radonjic@ieee.org (M. Radonjic).

1434-8411/$ – see front matter
http://dx.doi.org/10.1016/j.aeue.2012.05.009

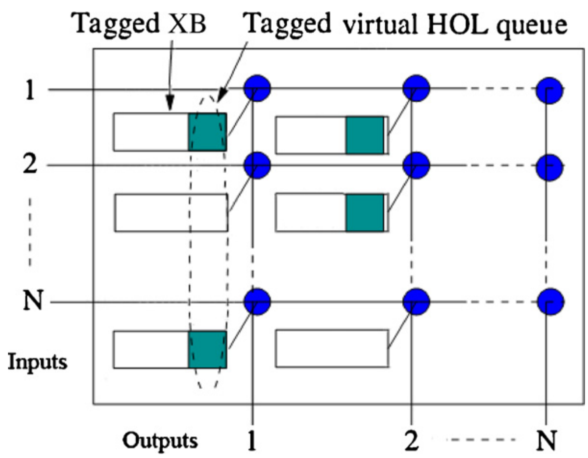

Fig. 1. The crosspoint queued switch architecture.

described by a two-state ON–OFF model where both busy and idle periods are geometrically distributed. Thus, the source generates cells in the ON (busy) state. In the OFF (idle) state, the source does not generate any traffic. The output port addresses are uniformly distributed, which is a feature of the traffic with many flows in the core switch. The cells of the same burst are intended for the same output (a model of the fragmented packet). If the input is in the ON state, it will remain in that state with probability α, and switches to the OFF state with probability $1-\alpha$. If the input is in the OFF state, it will remain in that state with probability β, while it switches to the ON state with probability $1-\beta$. These probabilities can be calculated by the following equations:

$$\alpha = 1 - 1/Bs \tag{1}$$

$$\beta = (1-p)/(1-p\alpha) \tag{2}$$

Bs is the average burst size and *p* is the offered input load. The arriving bursts are intended for one of the *N* possible outputs, so the incoming traffic can be in one of three states:

- State 1: There is no incoming cell on the observed input.
- State 2: There is an incoming cell on the observed input, which is not intended for the observed output.
- State 3: There is an incoming cell on the observed input which is intended for the observed output.

The finite state machine of the observed *XB's* incoming traffic is shown in Fig. 2, and the transition probabilities are given by (3).

$$\left[P_{ij}\right] = \begin{bmatrix} \beta & \left(1-\beta\right)(1-\gamma) & \left(1-\beta\right)\gamma \\ (1-\alpha)\beta & \alpha+(1-\alpha)\left(1-\beta\right)(1-\gamma) & (1-\alpha)\left(1-\beta\right)\gamma \\ (1-\alpha)\beta & (1-\alpha)\left(1-\beta\right)(1-\gamma) & \alpha+(1-\alpha)\left(1-\beta\right)\gamma \end{bmatrix} \tag{3}$$

where $\gamma = 1/N$.

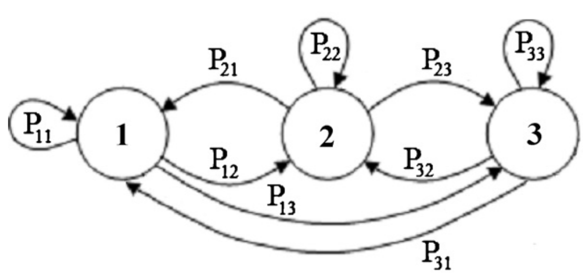

Fig. 2. Traffic source finite state machine.

3. Buffer state model

Our method for the throughput calculation is based on a virtual buffer model, which is a modification of the one presented in [4]. This virtual buffer model basically models two queues: the observed *XB* (each with length of *s*) and the corresponding virtual buffer (*VB*) which is composed of head-of-line (HOL) cells from a non-empty *XBs* from the observed output line (see Fig. 1). To simplify the model we made an approximation that all *XBs* from the observed output line have the same distribution. Also, we assumed that the processing in each time slot is conceptually divided into: the departure phase, in which packets leave the switch; and the arrival phase, in which packets arrive on the input lines of the switch and are stored in the corresponding crosspoint buffer, if it is not full. In this analysis the departure phase precedes the arrival phase. Besides the information of the observed *XB's* and *VB's* occupancies, it is necessary to take into account the state of the traffic source on the observed input. Therefore, the system is modeled by 3D Markov chain that considers the occupancy of the observed *XB* (labeled by *L*), the state of the traffic source on the observed input (labeled by *G*), and the observed *VB's* length (labeled by *W*). The state distribution vector, $\pi_{(l,g,w)}$, is defined as the probability that the observed *XB* at the end of the time slot has $L = l$ cells, the traffic source on the observed input is in the state $G = g$, and that the virtual buffer length is $W = w$, for $l \in [0, \cdots, s]$, $g \in [1, 2, 3]$, $w \in [0, \cdots, N]$. The corresponding transition matrix is given by (4).

Matrices that define the probabilities of moving to the states of lower, higher and the same order are denoted as A_{-1}, A_1 and A_0, respectively. Since the departure phase precedes the arrival phase, the case of previously full *XB* when the loss can occur (C_0), and the cases of previously empty *XB* when the arriving cell cannot leave the buffer (D_0, D_1), must be carefully considered.

$$T = \begin{bmatrix} D_0 & D_1 & 0 & 0 & \cdots & 0 \\ A_{-1} & A_0 & A_1 & 0 & \cdots & 0 \\ 0 & A_{-1} & A_0 & A_1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & A_{-1} & A_0 & A_1 \\ 0 & 0 & 0 & 0 & A_{-1} & C_0 \end{bmatrix} \tag{4}$$

The virtual buffer lengths at the end of previous and current time slots are W_l and W_c, respectively.

The probability of a new cell arriving at the observed *XB* which was empty at the end of the previous slot is given by:

$$\eta_{(W_l)} = \frac{\pi_{(0,1,W_l)}P_{13} + \pi_{(0,2,W_l)}P_{23} + \pi_{(0,3,W_l)}P_{33}}{\pi_{(0,1,W_l)} + \pi_{(0,2,W_l)} + \pi_{(0,3,W_l)}} \tag{5}$$

The probability that the observed non-empty XB contains only one cell at the end of the previous slot, while no new cells arrive in the current slot, is given by:

$$\psi_{(W_l)} = \frac{\sum_{k=1}^{3}\pi_{(1,k,W_l)}(1-P_{k3})}{\sum_{i=1}^{s}\pi_{(i,1,W_l)} + \pi_{(i,2,W_l)} + \pi_{(i,3,W_l)}} \tag{6}$$

Let $P_{F(W_l,W_c)}$ and $P_{B(W_l,W_c)}$ be the probabilities that a HOL cell of the observed *XB* is forwarded to the output or blocked, respectively, during the current time slot. Then, the following relation is derived:

$$P_{F(W_l,W_c)} = \\ = \frac{1}{W_l}\binom{N-W_l}{W_c-W_l}\eta_{(W_l)}{}^{W_c-W_l}(1-\eta_{(W_l)})^{N-W_c}, \quad 0 < W_l \le W_c \le N \tag{7}$$