Performance of Multi-Class Scheduling Technique with Dual Threshold under Non-Uniform Traffic

A. A. A. Rahman
System Technology Unit
Telekom Research & Development (TMRND)
Cyberjaya, Selangor, Malaysia
abd_aziz@tmrnd.com.my

K. Seman
Faculty of Science & Technology
Universiti Sains Islam Malaysia (USIM)
Nilai, Negeri Sembilan, Malaysia
drkzaman@usim.edu.my

K. Saadan
Faculty of Science & Technology
Universiti Sains Islam Malaysia (USIM)
Nilai, Negeri Sembilan, Malaysia
kamarudin@usim.edu.my

A. Azman
Faculty of Science Computer & IT
Universiti Putera Malaysia (UPM)
Serdang, Selangor, Malaysia
azreen@fsktm.upm.edu.my

***Abstract*—Network with many types of traffic such as video conferencing, audio and data transfer requires specific Quality of Services (QoS) to maintain their performance. It is crucial for the switch design to guarantee QoS for all applications. In this paper, a new way of handling multi-class traffic is presented. The analysis is done on N x N switch with two priority traffic classes with dual threshold setting, which will give a better control on priority setting for both classes. The performance of this switch under uniform traffic is presented in [1]. However, real switch application operates under non-uniform traffic condition. The analysis in this paper is done under two different kind of non-uniform traffic patterns, a hot-spot pattern and a Community-of-Interest (COI) pattern. The proposed method is simulated to show that the delay performance of the switch under non-uniform traffic patterns can be improved.**

Keywords- multi-class; non-uniform traffic; scheduling

I. INTRODUCTION

The role of communication is rapidly growing in today's world. With the advent of the internet and the subsequent proliferation of internet technologies, multimedia applications have been given a whole new lease of life.

With more such as businesses and educations, are relying on high speed network, it is expected that high speed network can provide a guaranteed quality of services (QoS). This requirement has lead to the design of high speed switches and routers with high aggregate bandwidth.

Previous analysis on fast packet switches with input queues provides approximation techniques for the switches operating with only a single priority class [2]. In a single priority class, all cells are served equally without any consideration to high priority cells and low priority cells. In this situation, high priority cells will suffer a long delay in queue. This will contribute to poor application performance. To overcome this problem, a multi-class switch has been introduced to cater the need of various applications with different QoS requirement in the network. One of the best methods to satisfying these requirements is the use of a fast packet switching technology based on priority [1], [3], [4].

In most multi-class switches, high priority class will be served first compared to the low priority class [5]. This situation has lead to the starvation problem in low priority class. To reduce the starvation problem, a threshold setting is introduced in the scheduling phase. The threshold setting will increase the probability of serving for the low priority class. In other words, the low priority class can still be served even in the presence of high priority class. In this research, dual threshold setting is proposed to eliminate the starvation problem as well as to maintain the QoS requirements. The proposed scheduling technique is then applied to multi-class switch architecture to ensure the total delay for every class can be optimized.

Under uniform traffic, the cells are distributed equally to over all the output ports. Meanwhile, under non-uniform traffic, the cells are unevenly distributed to the output ports. There have been various studies on non-uniform traffic patterns [6]-[11]. The patterns used in this paper are the hot-spot traffic [6], [7] which consists of single output port and the community-of-interest (COI) traffic [8], [9], which consist a group of output ports.

This paper attempts to analyze the performance of input queue multi-class priority switch under non-uniform traffic, while taking into account the influence of different classes of services when the threshold is introduced. At the same time, the switch operation will be illustrated in term of high and low priority traffic loads with separate queues. The switch performance is then analyzed in term of average delay for high priority class and low priority class with the presence of dual thresholds under non-uniform traffic.

This paper is organized as follows. In section 2, the system description and the model proposed are discussed briefly. Section 3 will present the analysis of the proposed scheduling technique and multi-class switch architecture in term of total mean delay. Section 4 is devoted for simulation results with different probability values of threshold serving class, P_{TSC0} and the number of queue cell, N_b. Finally, section 5 provides a brief conclusion.

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II. SYSTEM DESCRIPTION AND MODELING

A. System Description

The proposed multi-class switch architecture with N ports serving C classes of traffics is shown in Figure 1. The delay requirement for class *j* cells is define by D_j with $j = 0, 1, 2\ldots$ C-1 with $D_0 > D_1 > D_2 > \ldots\ldots > D_{C-1}$. In simple words, delay requirement for Class 1 is more stringent than Class 0 for the system shown in Figure 1. Thus, cells that queue in Class 0 have the lowest priority and cells that queue in Class C-1 have the highest priority. These delay requirements is set based on QoS requirement for different type of applications.

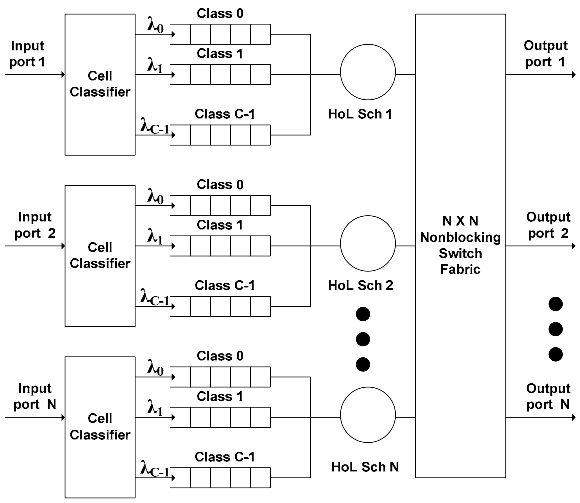

Figure 1. Multi-class switch architecture.

Time slot is used to represent the time of one cell arrival at input port or cell departure at output port. The period of time slot T_s, with s = 0, 1, 2, … is set to be equal to time to process a single cell when the server is idle.

The cell is arriving at each input in every time slot according to independent Bernoulli distributions. The cell is classified based on its delay requirement. In this architecture the class of the cell is located in the header. An arrival cells for Class j (λ_j) is queue in infinite First-In-First-Out (FIFO) buffer while waiting to be served.

At each time slot, the switch attempts to serve the cells at Head of Line (HoL) of each input queue. In the case when there are cells from different classes are waiting at HoL, the HoL scheduler (HoL Sch) will select the cell with high priority to be served. The lose cells in the contention must wait in queue. The numbers of queue cells will increase when there are new incoming cells to the queue.

The threshold setting is introduced in order to give some privileges to cells in the lower priority class. The threshold parameter used in this architecture are the number of queue cell, N_{bj} and the probability on threshold serving the low priority cell, P_{TSCj}; j = 0, 1, 2, …., C-1. N_{bj} parameter is chosen because of the limited buffer size available in practical design. The need to adjust the N_{bj} parameter is necessary to reduce the packet loss due to buffer full. This parameter is adjusted based on the size of buffer used to stored cells in Class j. P_{TSCj} is the probability to serve the Class j when the N_{bj} parameter threshold is met. The P_{TSCj} parameter is chosen in order to control the variation of delay between high priority and low priority cell based on the high priority QoS requirements. This is necessary in order to achieve better performance for Class j cells. In case where both threshold value are met, the switch will select the cell from class which the threshold is trigger even in the presence of higher priority cells.

B. Simulation Model

A simulation model is developed to simulate the performance of the proposed switch under dual thresholds setting. In this simulation, the architecture used is 16 x 16 switches with two classes for every input port. Class 0 is used to classify the low priority buffer for non-real-time data. At the same time, Class 1 will represent high priority buffer for real-time data.

Figure 2 shows the switch architecture for input queue multi-class switch with separate buffer for each class. Arrival cells are stored in different FIFO based on their classes. The HoL scheduler will choose one cell from HoL FIFO classes at every port to be forwarded to switch fabric. The cells will contend with each other to gain access for departure.

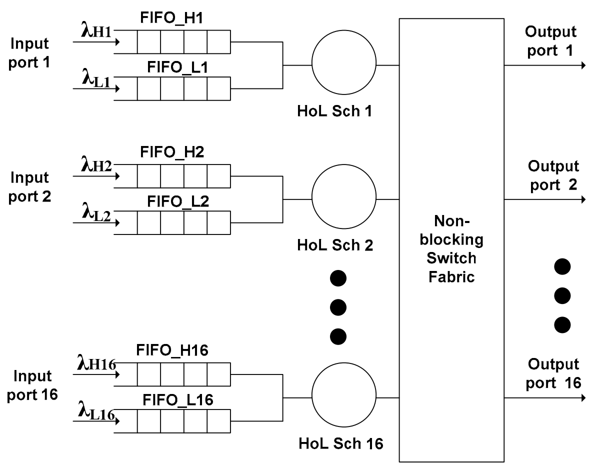

Figure 2. Switch architecture for input buffer multi-cladd switch.

The proposed switch operates in time slotted transmission to process each cells. Each time slot consists of three phases which are arrival, scheduler and departure.

The number of maximum cells, P_{max} which is generated in one time slot is depending on the traffic load, ρ and number of port, N, used. The relationship is shown in (1). The traffic load (λ) is the total of λH_i and λL_i.

$$\lambda = \lambda_H + \lambda_L \qquad (1)$$

```
IF (Hot-Spot Traffic)
  FOR (port = 1 to N) DO
  {
   IF (random number < traffic load) THEN
      Destination address = Hot-spot port
   ELSE
      No destination address;
   ENDIF
  }

ELSE IF (COI traffic)
  FOR (port = 1 to N) DO
  {
   IF (random number < traffic load) THEN
      Destination address = random number * COI port;
   ELSE
      No destination address;
   ENDIF
  }
```

Figure 3. Address packet generation in arrival process.

The cells are generated randomly to all destination port. Figure 3 shows the address packet generation in arrival process for hot-spot pattern and COI pattern.

Each generated cell is classified either to high priority class or low priority class based on the traffic type. Then, the cell is sent to FIFO while waiting to be served. The Class 1 cell is sent to FIFO_H1 and the Class 0 cell is sent to FIFO_L1. The HoL for Class 1 and Class 0 must wait until it is served. In general, the HoL scheduler will choose the cell in Class 1 since it has high priority cells. In the case when both threshold values are achieved, the HoL scheduler will choose the Class 0 cells even in the presence of Class 1 cells.

The pseudo code for input buffer with HoL output scheduling is shown in Figure 4. When HoL for Class 1 is not empty and the threshold value setting is applicable for both parameters, the HoL output will choose HoL packet from Class 0 instead of Class 1.

```
IF (HoL Class 1 not empty)
          IF (N_b > T_N) && (P_TSC0 >T_P)
HoL_out = HoL Class 0;
          ELSE
             HoL_out = HoL Class 1;
ELSE
          HoL_ out = HoL Class 0;
```

Figure 4. Pseudo code for HoL scheduler.

After HoL is selected, it will compete with other cells from other input port. The scheduler is using round robin policy with priority to select the cell in HoL for departure.

In departure phase, delays for Class 1 and Class 0 cells are calculated to measure the switch performance.

C. Non-Uniform Traffic

In non-uniform traffic, the traffic loads are not equally distributed to all port. There is large number of non-uniform traffic pattern, depending on the switch size.

In this paper, two types of non-uniform traffic patterns are used to analyze the performance of the switch.

1) Hot-spot traffic pattern

In this scenario, all the arrival cells are destined to one destination port only [6]-[7] as shown in Figure 5.

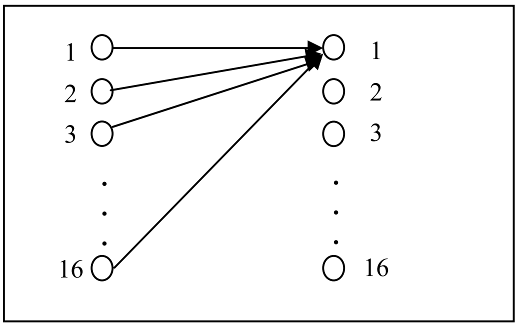

Figure 5. The hot-spot traffic pattern.

The total of departure rate, Y with input port i at hot-spot port (output port 1) is equal to 1 as express in (2). This traffic pattern will create enormous delay at the hot-spot location.

$$\sum_{i=1}^{N} Y_{i,1} = 1 \qquad (2)$$

2) Community-of-interest (COI) traffic pattern

In this scenario, all the arrival cells are destined to a group of ports in the switch [8]-[9]. In this case, the COI size is limited to 4 output ports and all the input cells are destined to this COI as shown in Figure 6.

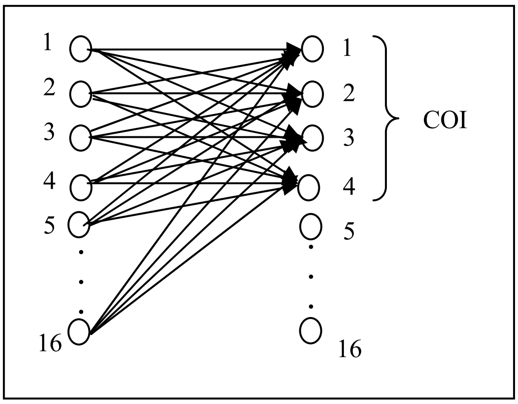

Figure 6. The COI traffic pattern.

The total departure rate, Y with input port i and output port j at COI location (output port 1 to 4) is equal to 1 as express in (3).

$$\sum_{i=1}^{N}\left(\sum_{j=1}^{4} Y_{i,j}\right)=1 \qquad (3)$$

III. ANALYSIS

In order to evaluate the performance of the proposed switch architecture, some analysis is done on the total mean delay with different threshold setting. The delay is calculated based on the assumption that those arrival cells in a slot are independent and identically distributed Bernoulli processes.

In hardware analysis, this total delay for each cell, D can be defined as time for one cell being process in the system from arrival to departure. This is shown in (4) with T_{in} is the arrival time of cell and T_{out} is the cell departure time.

$$D = T_{out} - T_{in} \qquad (4)$$

Then, the mean delay for single port Class C priority, D_{PC} can be calculated as expressed in (5) with L_c is the total number of cells for Class C priority.

By using data from (5), the total mean delay for the whole system with N number of node, E(D) can be calculated as in (6).

$$D_{PC} = \frac{\sum_{i=1}^{L_c}(D_i)}{L_c} \qquad (5)$$

$$E(D) = \frac{\sum_{i=1}^{N}(D_{PC})}{N} \qquad (6)$$

The threshold setting for both parameters will influence the delay performance of the system. Probability on threshold serving low priority cell (P_{TSC0}) can be defined as the amount of delay allowed for the low priority cell which is based on the delay requirement. The number of queue cell (N_b) can be defined as the minimum traffic load that needs to be adjusted.

The probability of threshold serving class can be calculated as expressed in (7) with P_{TSC0} is the probability of threshold serving Class 0, T_P is the threshold value in integer and R is the size of a random number generator.

$$P_{TSC0} = \frac{T_P}{2^R} \qquad (7)$$

The threshold value, T_P must be larger than $2^R/2$ to ensure the serving probability for Class 1 is better than Class 0.

IV. RESULTS

Hardware design using verilog code is develop to evaluate the performance of the proposed architecture. The hardware simulation result is used to obtain the total delay for each cell in (4). Later, the result is used by the Matlab code to calculate the total mean delay in (6) in order to show the performance of the switch.

The simulations are done in two kind of traffics; hot-spot and COI traffic model.

The analysis is done in Hot-spot traffic for both Class 1 and Class 0 cells under fixed N_b with vary P_{TSC0} and fixed P_{TSC0} with vary N_b in order to observe the threshold effect on the system in term of the total mean delay.

In Figure 7, a simulation graph for the total mean delay is plotted for Class 1 and Class 0 with the probability of serving Class 0, P_{TSC0} is fixed at 60%. From the graph, it can be seen that changes start to occur at load equal to 0.1 for the number of queue cells, N_b equal to 150 and at 0.3 for N_b equal to 750.

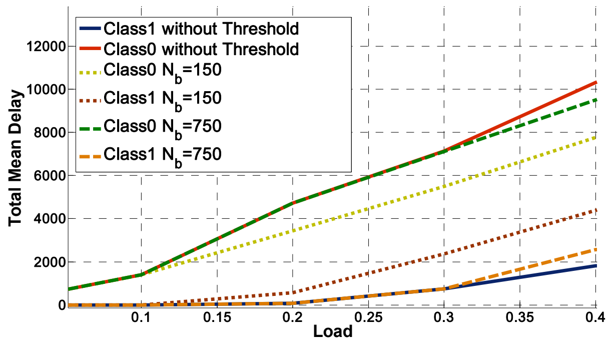

Figure 7. Total mean delay for Class 1 and Class 0 with P_{TSC0} fixed at 60% under hot-spot traffic.

In Figure 8, simulation graph for the total means delay is plotted for Class 1 and Class 0 with the number of queue cell N_b is 300. From the graph, it can be seen that a bigger variation delay starts at load equal to 0.2.

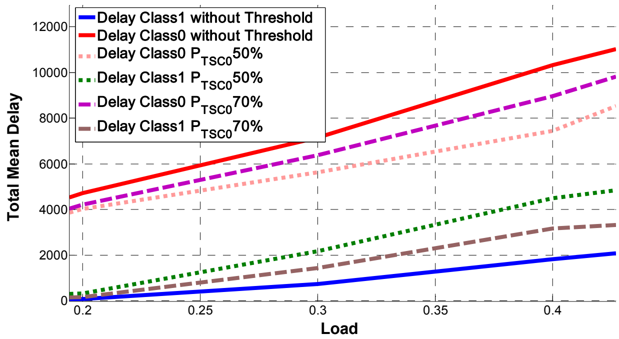

Figure 8. Total mean delay for Class 1 and Class 0 with N_B fixed at 300 under hot-spot traffic.

The analysis in COI traffic is done to observe the threshold effect on the system under different non-uniform traffic model.

In Figure 9, a simulation graph for the total mean delay is plotted for Class 1 and Class 0 with the probability of serving Class 0, P_{TSC0} is fixed at 60%. From the graph, it can be seen that changes start to occur at load equal to 0.2 for the number of queue cells, N_b equal to 150 and at 0.3 for N_b equal to 300.

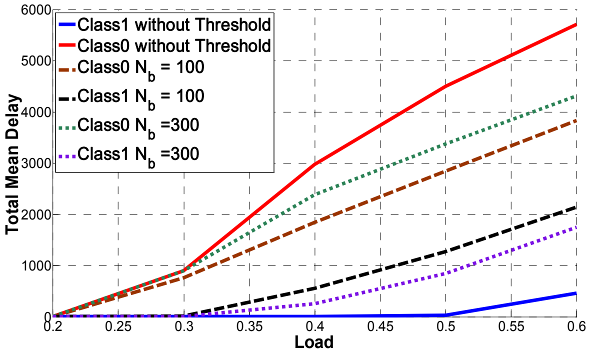

Figure 9. Total mean delay for Class 1 and Class 0 with P_{TSC0} fixed at 300 under COI traffic.

In Figure 10, simulation graph for the total mean delay is plotted for Class 1 and Class 0 with the number of queue cell N_b is 300. From the graph, it can be seen that a bigger variation delay starts at load equal to 0.3.

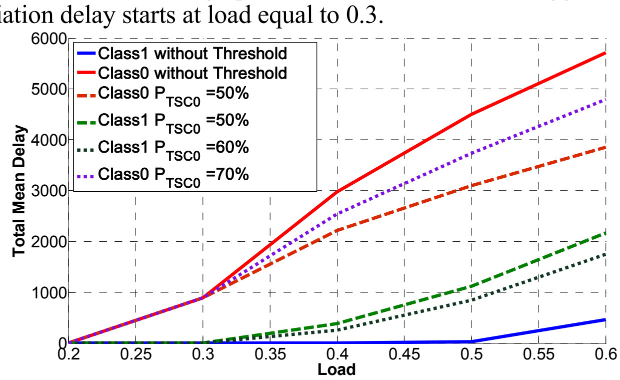

Figure 10. Total mean delay for Class 1 and Class 0 with N_B fixed at 300 under COI traffic.

Figure 11 shows the delay performance on Class 0 total mean delay under uniform and non-uniform traffic condition. It can be seen that usage of threshold has improved the total mean delay of the non-uniform traffics for both traffic patterns.

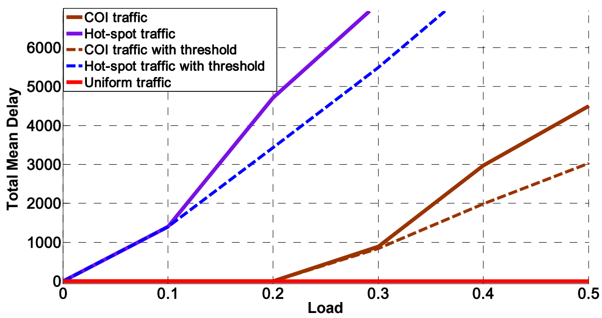

Figure 11. Total mean delay for Class 0 under different traffic characteristics.

V. CONCLUSION

The simulation results have shown that dual threshold setting has reduced the total mean delay for the low priority cell (Class 0) and at the same time minimized the delay increment for the high priority cell (Class 1) under non-uniform traffic. The number of queued cell (N_b) defines the minimum traffic load that need to be adjusted. The value of N_b is different depending on the type of traffic.

Probability on threshold serving low priority cell (P_{TSC0}) value defines the amount of delay allowed for the low priority cells which is based on the delay requirement of the high priority cells. The P_{TSC0} parameter will increase the serving probability for Class 0 cells. By combining both parameters, the threshold setting can define the traffic load to start serving low priority cell and the permitted variation delay.

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