Enhanced Dynamic Bandwidth Allocation Proportional to Queue Length with Threshold Value for VBR Traffic

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Abstract: *In Asynchronous Transfer Mode (ATM) network, Variable Bit Rate (VBR) service category has been defined to support any application for which the end-system can benefit from statistical multiplexing, by sending information at a variable rate, and can tolerate or recover from a potentially small random loss ratio. Due to its burst characteristic, bandwidth allocation strategy is necessary in order to share the network resources with other traffics fairly. The implementation of proposed approaches; heuristic, Unused Buffer Reallocation (UnBR) and Higher-priority Queue Sharing (HQS), in bandwidth strategy perform better improvement if compare to the proposed strategy. In addition, we observed that a bandwidth strategy did not always perform well, hence, suitable strategies should be chosen depending on the different conditions in order to fulfill its network demand.*

Keywords: *Bandwidth allocation, VBR, heuristic approach.*

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1. Introduction

Asynchronous Transfer Mode (ATM) is a high speed networking technology that provides seamless connectivity and low cost to user with Quality of Service (QoS) guarantee. Due to its reliability and various service categories; the requirements of all types of applications either delay or packet loss sensitive or insensitive, this high-speed technology is being widely deployed nowadays especially in the campus and carrier backbones. Variable Bit Rate (VBR) is one of the ATM services categories; it transmits the data, which has burst characteristic. There are two types of VBR, real time and non-real time. Real-time VBR may be very appropriate to some classes of multimedia communications. In the other hand, non-real time VBR can be used for data transfer and response-time critical transaction processing applications. The requirement of the real time or non-real time VBR in term of cell loss and delay are specified in Table 1, adopted from [1].

Due to the bursty behavior of VBR traffic in ATM network, a controller, such as bandwidth allocation is needed to utilize the ATM bandwidth in order to meet the QoS requirements. Three approaches, heuristic, Unused Buffer Reallocation (UnBR) and Higher-priority Queue Sharing (HQS), in bandwidth strategy over VBR service have been proposed. The algorithms are developed to enhance the bandwidth capability by correlating the bandwidth and the queue length thus improving the network performance.

Table 1. VBR QoS classes.

QoS Classes \ Requirements		Cell Delay	Cell Loss	Priority
rt - VBR	Class - 1	Very Low	Very Low	Top
	Class - 2	Low	Moderate	High
nrt - VBR	Class - 3	Moderate	Moderate	Medium
	Class - 4	Relatively Large	Very Low	Low

The performance metrics in this study are defined as Cell Loss Ratio (CLR), average cell delay (seconds) and average queue length (cells). These are the parameters measured in [7] and all these performance parameters are shown in this study instead of just CLR plotted in [7]. Cell loss occurs when a new cell arrives at a particular queue that exceeds the maximum of buffer size. Since the buffer is full, the new arrival cell will be dropped and caused cell loss. Cell delay is the waiting time of an ATM cell in the buffer to switch through the link or the waiting time of a cell after residents in buffer until transmission. The waiting time is measured in second. Besides, average queue length is defined as number of cells that occupies in the buffer during a cycle.

Our proposed approaches in bandwidth strategy perform better improvement than the strategy proposed in [3]. In general, it can be observed that there is a correlation between queue length and bandwidth allocation. Compared to the bandwidth strategies in [3], the bandwidth strategy with the approaches that have been proposed in this research produces improved results. The organization of this paper is as follows. Section 2 gives the overview of queue length based bandwidth strategies and the implementation of approaches. Section 3 presents the simulation development model. Section 4 elaborates the experiment results and discussion. The paper is concluded in section 5.

2. Bandwidth Allocation Strategies

Basically, bandwidth allocation procedure uses either a static or dynamic allocation strategy. In static allocation, a reference model is used to determine the bandwidth allocation. Therefore, static allocation does not modify the allocated bandwidth when traffic conditions change. In dynamic allocation, actual traffic conditions are monitored, and bandwidth is reallocated based on the changing conditions. Thus, with dynamic allocation the allocated bandwidth may be modified and/or reallocated if current conditions are changed.

Since in static allocation the bandwidth is determined based on a fixed reference model, the determination is usually simple and can be performed offline. If the reference model is valid, the resulting bandwidth allocation should be accurate and effective. On the other hand, the static allocation strategy is inaccurate and ineffective when the reference model is invalid because it does not have functions for monitoring the traffic and modifying the allocated bandwidth as needed. Hence, this strategy does not enable the system to adapt to changing situations. Dynamic allocation was proposed to overcome the deficiencies of static allocation. Dynamic allocation adapts to the actual situation and dynamically modifies the allocated bandwidth accordingly. It thus needs more advanced functions to monitor the current situation, determine the required bandwidth, allocate the bandwidth, and modify the bandwidth. Dynamic allocation is particularly effective when valid accurate reference models are unavailable.

2.1. Queue Length Based Bandwidth Allocation Strategies

The queue length based bandwidth allocation strategy uses the queue length in the buffer as an indicator of the bandwidth allocation‘s requirement in determining the amount of bandwidth to be assigned [7]. Generally, the bandwidth calculated in this strategy is:

$$Bandwidth = \frac{Queue\,length}{Total\,queue\,length * Cycle\,length}$$

In [7], a bandwidth strategy proportional to queue length before transmission was proposed. This strategy measures the queue length at certain point and probably will cause long queue in the highest priority buffer, shorter in second priority buffer and the shortest in the lowest priority buffer. This is caused by the different number of slots since the Dynamic Time Slice (DTS) server visited in every cycle. As the result, the queue measurement before the server started serving for each buffer is introduced to overcome the problem, named as bandwidth allocated proportional to expected queue length. As name implied, this strategy allocates bandwidth for next cycle proportional to the queue length and measures the queue length three times (one time for each buffer) after the server has visited it. Besides the algorithm will predict the number of cells that will visit the next cycle based on the numbers of cell generated in the pervious cycle. The bandwidth is assigned as follows:

$$Bandwidth = \frac{Queue\,length + Expected\,queue\,length}{\sum(Total\,queue + Total\,expected\,queue)}$$

Enhancement of the bandwidth allocated proportional to expected queue length was proposed in [3]. A threshold value controller is added to the strategy in order to utilize the network resources (bandwidth & buffer) effectively. The controller is based on the queue length of traffic. When the queue length exceeds the 90% of buffer size, the threshold controller will be activated. Consequently, the bandwidth assigned will be recalculated and reallocated. The 10% bandwidth of the non congested traffic will be deducted and assign to the congested traffic (queue length exceeds 90% of buffer size). The main aim for this strategy is to avoid the bandwidth allocated to non-congested queue is far more than adequate, subsequently improve the network performances. For example, VBR video buffer is congested and exceeded the threshold value and bandwidth allocated to VBR video/data buffer, VBR video buffer and connectionless data are 100, 80 and 20 slots respectively. Thus, by recalculating the bandwidth, bandwidth allocated to VBR video/data is 72 slots (0.9 * 80), connectionless data is 18 (0.9 * 20) and the VBR video is 110 slots (100 + 8 + 2). This scheme shows better performance in term of cell loss ratio.

2.2. Integration of Approaches

Three approaches are proposed in this study, they are heuristic, Unused Buffer Reallocation (UnBR) and Higher-priority Queue Sharing (HQS). These approaches are integrated with the bandwidth allocated proportional to expected queue length with threshold value in [3].

2.2.1. Heuristic Approach

Heuristic approach elaborates Dual Leaky Bucket (DLB). This approach is applied at Call Admission Control (CAC) in ATM Networks [6]. The system architecture is illustrated in Figure 1. For every incoming source, the cell generated will be assigned to its dedicated DLB before it has been transmitted out to a FIFO multiplexer. In this study, the DLB is used in the switch's queuing system and only applied to the top priority traffic, which is VBR video/data. For other VBR traffic types, their queuing systems are maintained as the single leaky bucket with FIFO discipline. Figure 2 depicts the implementation of DLB in ATM switch that is proposed in this research.

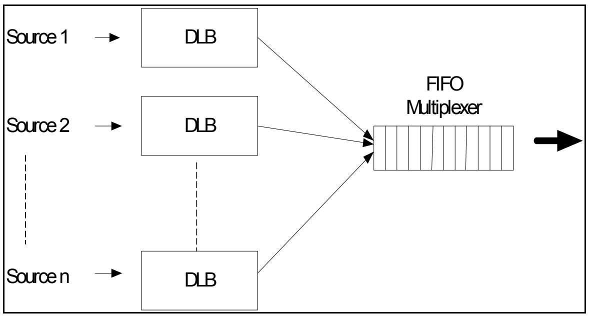


Figure 1. CAC system model with heuristic approach (adopted from [6]).

Assume there are two buffers inside the DLB, they are primary and secondary buffers. In non-congestion situation, the secondary will not be in used. When occurrence of network congests, in order to reduce the CLR, the secondary buffer will operate as temporary buffer storage for the cells when the primary buffer is full. Once a cell is queued in the secondary buffer, the followings cells will be also inserted into secondary buffer instead of primary buffer to retain the FIFO discipline. Then cells are copied to the primary buffer when there are vacancies in primary buffer before they transmitted to minimize the system overhead, cells in secondary buffer will be copied into primary buffer based on three criteria. The first criteria is at the inter cycle period. It is defined as the time when a cycle finished and before entering to next cycle. Second, once the secondary buffer is full. Third, there is no cell to be transmitted in primary buffer. If both primary and secondary buffer full, cell loss occurs. Before copying the cells from secondary to primary buffer, the system will check the queue length of primary buffer to determine the number of cells to be copied.

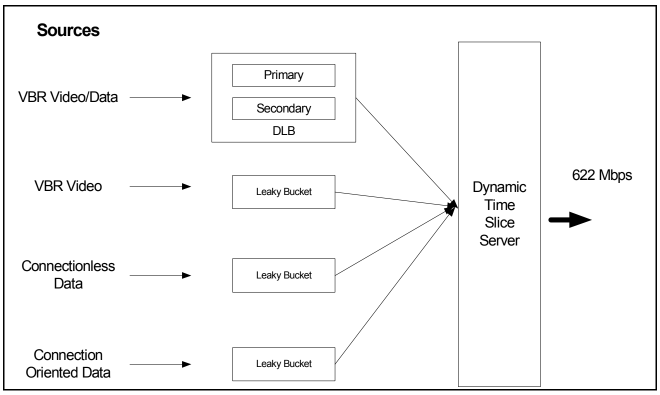


Figure 2. DLB in ATM switch.

2.2.2. UnBR Approach

This approach applies the conservation law by Kleinrock in managing the buffer size and bandwidth. Bandwidth and the buffer have been correlated by using the conservation law as shown below:

$$\sum_{i=1}^{N} c_i b_i = \text{constant}$$

Where c_i and b_i are bandwidth and buffer size, respectively.

In this approach, it is only applies for the two highest priority queue, which are VBR video/data and VBR video. In this case, any one of VBR traffic gained more bandwidth from others; its unused buffer should be merged with other traffic's unused buffer. Reallocation of these unused buffers would be done according to a ratio. If VBR video/data in congestion and requires more bandwidth from DTS, the DTS will assignthe bandwidth it needed and at the same time reallocates the unused buffer size based on the bandwidth inverse ratio between VBR video/data and VBR video. For instance, the bandwidth for VBR video/data and VBR video are in 3:1 ratio, so the unused buffer will be reallocated based on the ratio 1:3. The unused buffer indicates the remaining buffers after deducted from queue length and predicted arrival cells for next cycle. Some controllers have been added to ensure the queue length or the unused buffer allocation unit does not become more than the buffer size. The algorithm for the UnBR approach is elaborated as following:

```
1. Calculate the previous average incoming rate to
      predict the arrival cell for this cycle.
2. Get the ratio of
   c1 : c2
   c1 =  bandwidth class 1 and c2 = bandwidth class 2
3. If (estimate_arrival cells - assigned_bandwidth > 0)
      buffer_length = queue_length +
      (estimate_arrival cells  assigned_bandwidth);
  Else {
        If ((buffer_length – assigned_bandwidth -
           estimate_arrival cells)>queue_length)
           buffer_length -= (asiigned_bandwidth -
           estimate_arrival cells);
        Else
           buffer_length = queue_length;
       }
4. If (Buffer_length1 + Buffer_length2 > total size of 2
    buffer) //too much buffer  allocate
  {
    If (queue_length1+queue_length2 >=  total size of
       2 buffer) //no unused buffer
       buffer_length = queue_length;
    Else {
          extra_queue = buffer_length1 +
             buffer_length2 -
             total size of 2 buffer;
```

```
        extra queue1 = buffer_length1 -
           queue_length1;
        extra queue2 = buffer_length2 -
           queue_lenght2;
        rate = c1 / c2;
        If (rate < 1) {
            rate = 1.0/rate;
            If ((extra queue / (rate + 1) < extra
               queue1)
                buffer_length1 -= (extra queue /
                (rate+1));
            Else
              buffer_length1 -= extra queue1;
                    }
        Else {
              If ((extra queue / (rate + 1)) * rate) <
                 extra queue1)
              buffer_length1 -= (extra queue / (rate
                 + 1) * rate);
              Else
                 buffer_length1 -= extra queue1;
              }
        buffer_length2 = total size of buffer –
           buffer_length1;
        }
  }
Else {// reallocate unused buffer, if there is unused
     buffer
     unused buffer = total size of buffer -
        queue_lenght1 - queue_lenght2;
     If (unused buffer < 0)
        break;
        rate = c1 / c2;
     If (rate < 1) {
        rate = 1.0 / rate;
        buffer_length1 += (unused buffer / (rate + 1)
          * rate);
                }
     Else
        buffer_length1 += (unused buffer / (rate +
           1));
        buffer_length2 = total size of buffer -
           buffer_length1;
     }
```

2.2.3. HQS Approach

This approach is an extension from the UnBR approach. An unused buffer sharing policy is added into the UnBR and named as Higher-priority Queue Sharing (HQS) Approach.

Similar to the UnBR approach, this approach is only applied to top two priority queue, first priority traffic, VBR video/data and second priority queue, VBR video. Either one, VBR video/data or VBR video's buffer is full, it will get certain number of unused buffer from VBR video/data or VBR video buffer which not fully occupied as long as the buffer has more than five slots or five percent empty slots. For instance, if VBR video/data's buffer full, this approach will compute the unused buffer vacancy in VBR video traffic. If the unused buffer in VBR video traffic occupies more then 20% of the total VBR video's buffer size, then 20% of its unused buffer will be assigned to the VBR video/data.

The amount of unused buffer to be obtained is stated in Table 2. The aim of this approach is to fully utilize the buffer allocated as some of the buffers might not be used. This is due to the under estimation in the UnBR approach.

Table 2. HQS's buffer sharing table

Unused Buffer x (%)	Buffer's Volume to be Shared
x ≥ 20%	20%
15% ≤ x <20 %	30%
10% ≤ x <15%	40%
x < 10%	50%

3. Simulation

Source of VBR might dominate the bandwidth demand in the future. To improve the performance of the ATM networks, an accurate estimation of the amount of resources that the VBR must reserve becomes a very important issue [4]. Hence, in this research, the scope is focused on dynamic bandwidth allocation strategies and the correlation between buffer and bandwidth by catering for the VBR sources only.

To investigate the proposed algorithms and their efficiency, a single virtual path with 622 Mbps data rate is used in the simulation. Typically there could be variety of services using this path and so a number of source models are needed. The ON-OFF source model is used in this study to represent the VBR services in the ATM networks; they are VBR video, Connection Oriented data, VBR video/data and connectionless data. The cell stream from a number of sources is then input to the ATM switch buffers model. The buffer smoothes the arrival of cells to the ATM networks and also takes care of cell scale congestion. This buffer is a limited resource, critical to the performances of the simulation model. DTS model is where several bandwidth allocation strategies operate and where bandwidth is calculated and allocated to the buffers.

Multiple sources for each traffic are used in the experiment so that the simulation networks behave as a real network. The number of sources that suitable in this simulation is VBR video/data 13 sources, VBR video 12 sources, connection oriented data 22 sources and 24 sources for connectionless data as depicted in Figure 3. All sources are independent from each others. It indicates that cells generated by a source are not dependent on other sources' state, either active or idle [5].

The amount of time slice or cycle length allocated to a queue is depended on the bandwidth allocation strategy and the algorithm that was used. The cycle length is 30 slots of 150 Mbps network [7], which is equivalent to 7.68×10^{-5} second (cell size * cycle length / service rate). In order to obtain the same rate in 622 Mbps network, it would be about 120 slots. If the cycle length is too long then each queue would wait longer before DTS server visit it causing cell delay to increase. The cycle length for all strategies in this study is decided to be 100 time slots or 6.17×10^{-5} seconds (cell size * cycle length / service rate) [2]. The simulations are based on two millions arrivals; double of the [7]. For every cycle length, a new reallocation of bandwidth will be calculated, thus three priority queues will be provided among these 100 time slots. The total of the allocated bandwidth on three priority queues, VBR video/data buffer, connectionless data buffer and VBR video buffer equals the maximum cycle length. One time slot can only transmit one ATM cell or equal to one ATM cell transmission time.

Any bandwidth allocated and unused momentarily by three higher priority buffer (queue length equal zero) will be declared as spare slot and allocated immediately to delay insensitive buffer. This study assumes the connection oriented data is insensitive to delay, and cells in this buffer are transmitted only when there are spare slots available.

In this study, the buffer length will start from 200 and will keep increased by a value of 200 each time. Priority queue technique and First In First Out (FIFO) discipline are applied to the queue in this research. Each VBR's traffic has its own dedicated buffer as shown in Figure 3. The highest priority will have lowest cell lost and delay. The highest bandwidth should be assigned to the top priority. Link list data structure is used to represent the queue. Elements in the queue represent the ATM cells with source identity (id), arrival time (t) and pointer to next cell. Source identity indicates which source the cell is generated from, arrival time means the slot time once the cell is inserted to the queue.

Cell arrival and cell departure are the only events occur in buffer model. Once the cell is generated from the source, it will be inserted into the assigned queue with the rule that the buffer is not full. In case the buffer size is full and a cell is generated, the generated cell will be dropped and causes cell loss. Cell departure event happens when there is available bandwidth allocated. Cell departure event for the queue occurs cyclically and only one cell is transmitted at once time. While a cell queue is in transmission period, other queues have to wait for their turn. For VBR connection oriented data, its cell will only be transmitted if there is available bandwidth and no cell located in the other three queues. Cell departed from queues will be accumulated for their queuing time and queue length.

4. Experiment Results and Discussions

The abbreviations using in the graphs shown are explained as below. 'Standard' means the bandwidth strategy without implementation of any approach. UnBR denotes the bandwidth strategy with Unused Buffer Reallocation approach. HQS stands for bandwidth strategy with Higher-priority Queue Sharing while the Heuristic represents the strategy with Heuristic approach. In addition, 'Standard' is used as a reference point in the comparison to evaluate the effective of the approaches.

This section focuses on the impact of approaches to bandwidth allocated proportional to expected queue length with threshold value strategy by evaluating the CLR, average cell delay and average queue length. Eventually, an appropriate approach is suggested to be implemented in bandwidth allocated proportional to expected queue length with threshold value.

As shown in Figure 4, the 'Standard' has the worst performance while the Heuristic and UnBR show the best performance in the VBR video/data buffer for CLR. The graph shows a significant cell loss drop for all approaches at the 400 buffer size. Compare with the strategy without any approach (Standard), HQS, UnBR and Heuristic has 0.001609, 0.004737 and 0.004227 less cell loss ratio, respectively when buffer size is 200. In the other words, HQS gives 28.52% (0.005642 – 0.004033), UnBR gives 83.96% (0.005642 – 0.0009049) and Heuristic gives 74.92% (0.005642 – 0.001415) less cell loss ratio than Standard at 200 buffer size. Meanwhile, at 800 buffer size, 51.69% lower CLR for HQS, 91.82% lower CLR for UnBR and 95.14% lower CLR for Heuristic compared to Standard. Both UnBR and Heuristic approach also show good performance in VBR video/data buffer's CLR. The main reason for this is the secondary buffer in Heuristic approach and the increment of buffer allocated to VBR video/data in UnBR approach.

CLR for VBR video buffer is depicted in Figure 5. At buffer size 200 and 400, HQS performs well than others. It has 19.03% (0.009166 – 0.007421) less cell loss ratio than Standard while UnBR has 43.90% (0.009166 – 0.01319) and Heuristic has 1.38% (0.009166 – 0.009292) cell loss ratio higher than Standard when buffer size is 200. For 400 buffer size, both UnBR and Heuristic give higher CLR than Standard, UnBR 0.001603 (72.16%) and Heuristic 0.000207 (9.33%) more than the Standard's CLR while HQS shows 0.000305 (13.71%). Start from 600 buffer size and onward, Standard and Heuristic improve their performances and showing the lowest CLR. However, all approaches showing small CLR for 800 buffer size and following.

In Figure 6, the average cell delay of VBR video/data buffer is illustrated. Starting from 200 buffer size to 800, there is a significant difference between Heuristic and others. While buffer size is

1000 and above, UnBR shows the highest average cell delay and others have consistence delay which in between 0.000285 and 0.0003142 seconds. Obviously, Heuristic has higher average cell delay compared to Standard. It produces 0.0000719 seconds (68.18%) longer delay than the Standard at buffer size 200, but the difference becomes smaller as the buffer size increases. When the buffer size exceeds to 1000 and above, the average cell delay for Heuristic and HQS are close to the Standard, just approximate 5% higher. For the UnBR at above 800 buffer size, it requires around 10% more average cell delay than Standard. The secondary buffer in the Heuristic approach causes the cell to have longer queuing time.

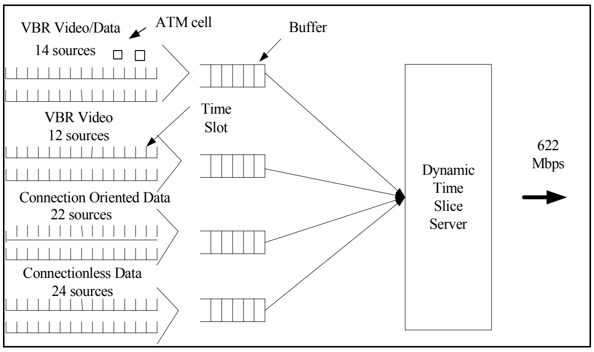
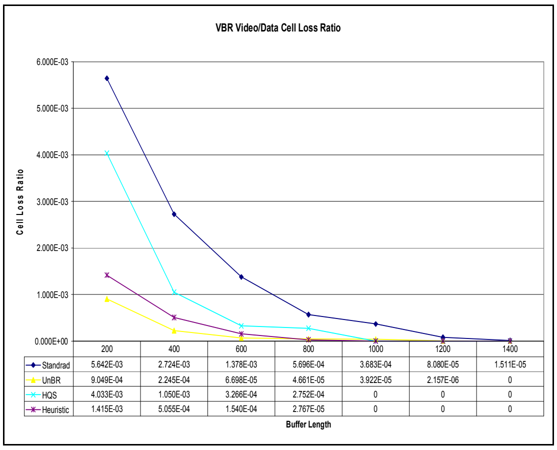
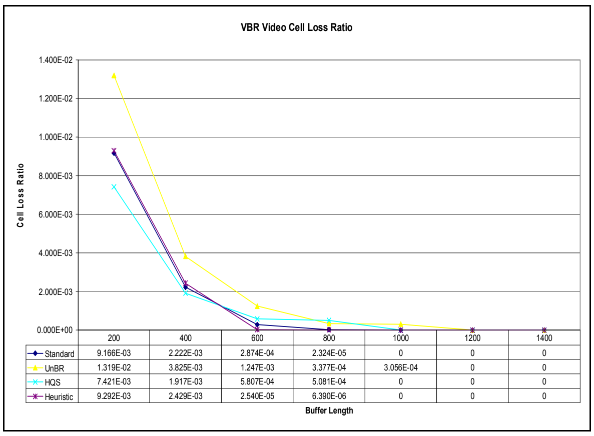


Figure 3. ATM simulation model.



	200	400	600	800	1000	1200	1400
Standrad	5.642E-03	2.724E-03	1.378E-03	5.696E-04	3.683E-04	8.080E-05	1.511E-05
UnBR	9.049E-04	2.245E-04	6.698E-05	4.661E-05	3.922E-05	2.157E-06	0
HQS	4.033E-03	1.050E-03	3.266E-04	2.752E-04	0	0	0
Heuristic	1.415E-03	5.055E-04	1.540E-04	2.767E-05	0	0	0

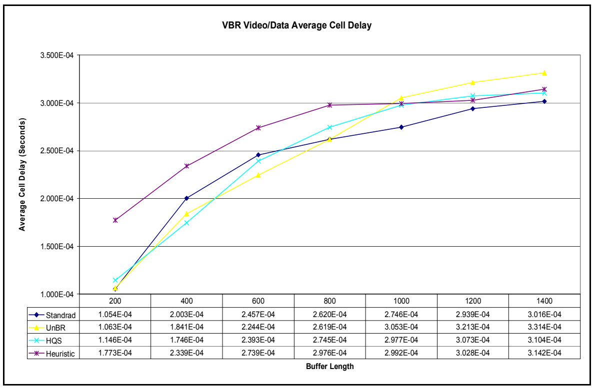
Figure 4. VBR videod ata cell loss ratio.



	200	400	600	800	1000	1200	1400
Standard	9.166E-03	2.222E-03	2.874E-04	2.324E-05	0	0	0
UnBR	1.319E-02	3.825E-03	1.247E-03	3.377E-04	3.056E-04	0	0
HQS	7.421E-03	1.917E-03	5.807E-04	5.081E-04	0	0	0
Heuristic	9.292E-03	2.429E-03	2.540E-05	6.390E-06	0	0	0

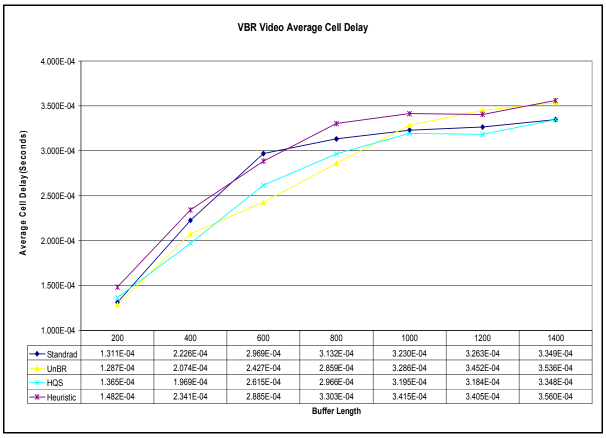
Figure 5. VBR video cell loss ratio.

The average cell delay of VBR video is shown in Figure 7. It shows that there are no significant differences between all approaches. The biggest difference is just only 18.27% (0.0000542 seconds) between the Standard and UnBR at 600 buffer size. The UnBR shows less average cell delay to Standard from 200 and it changes to surpass the Standard after the buffer size is 1000. It can be concluded that not much impact in VBR video buffer's average cell delay with the implementation of approach to the bandwidth strategy.



	200	400	600	800	1000	1200	1400
Standrad	1.054E-04	2.003E-04	2.457E-04	2.620E-04	2.746E-04	2.939E-04	3.016E-04
UnBR	1.063E-04	1.841E-04	2.244E-04	2.619E-04	3.053E-04	3.213E-04	3.314E-04
HQS	1.146E-04	1.746E-04	2.393E-04	2.745E-04	2.977E-04	3.073E-04	3.104E-04
Heuristic	1.773E-04	2.339E-04	2.739E-04	2.976E-04	2.992E-04	3.028E-04	3.142E-04

Figure 6.VBR videod ata average cell delay.



	200	400	600	800	1000	1200	1400
Standrad	1.311E-04	2.226E-04	2.969E-04	3.132E-04	3.230E-04	3.263E-04	3.349E-04
UnBR	1.287E-04	2.074E-04	2.427E-04	2.859E-04	3.286E-04	3.452E-04	3.536E-04
HQS	1.365E-04	1.969E-04	2.615E-04	2.966E-04	3.195E-04	3.184E-04	3.348E-04
Heuristic	1.482E-04	2.341E-04	2.885E-04	3.303E-04	3.415E-04	3.405E-04	3.560E-04

Figure 7. VBR video average cell delay.

As shown is Figure 8, VBR video/data buffer's average queue length, at 200 buffer size, all the strategies with implementation of approach have higher average queue length than the bandwidth strategy without approach; 'Standard'. UnBR, HQS and Heuristic show 0.926 (1.16%), 8.119 (10.17%) and 20.524 (25.74%) cells more than the 'Standard' (79.805 cells). HQS always gives lower average queue length than the 'Standard' although the buffer size is changing except for the 200 buffer size. Similar to the graph's pattern in VBR video/data buffer's average cell delay, it cuts through the 'Standard' average queue length at 1000 buffer size. For the Heuristic, its average queue length is close to the 'Standard', 10% higher when the buffer size is 1000.

In Figure 9, it depicts the average queue length of VBR video buffer. The graph is similar to the VBR video/data buffer's average queue length graph. HQS constantly produces average queue length that is lower as compared to the 'Standard' from 400 of buffer size. For UnBR, its average queue length is lower when buffer size is less than 800 and higher when buffer is above 1000 if compared to the 'Standard'. Overall, the Heuristic shows the highest average queue length along the experiment. At 1000 buffer size, the difference between Heuristic and 'Standard' is 12.73%, 31.438 cells higher than 'Standard'.

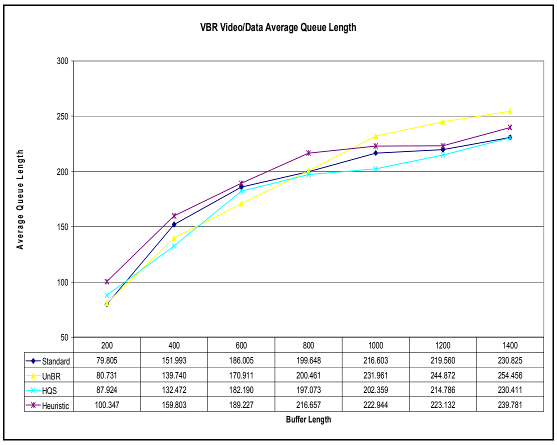


Figure 8. VBR videođ ata average queue length.

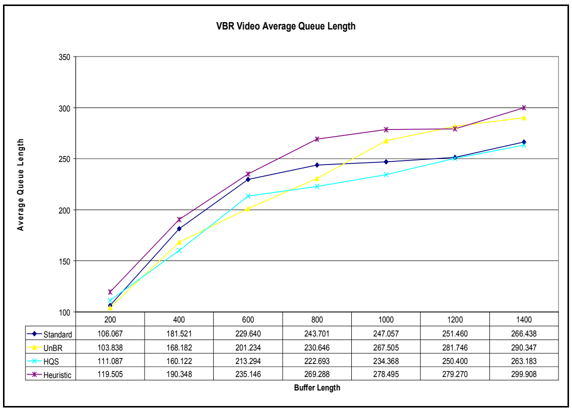


Figure 9. VBR video average queue length.

5. Conclusion

In conclusion, the differences in average cell delay and average queue length, HQS has lower cell loss ratio than 'Standard' for both VBR video/data and VBR video buffer. It can be elaborated that, the HQS successfully improves the CLR performance while the average cell delay increases approximate 3-15%. The UnBR and Heuristic approaches perform well for VBR video/data buffer's CLR but gives poor results in VBR video buffer's CLR. Moreover, Heuristic requires longer cell waiting time for VBR video/data buffer although it successfully reduces the CLR of VBR video/data.

By integrating new approaches into the existing bandwidth strategies, improvement of network performances and higher utilization of resources is achieved. Increasing the buffer size is not suitable for real time applications as increment of the buffer size will increase the delay. Although large buffer size is good to overcome bursty issues, in the cost saving perspective, but it is not recommended.

The achievements of the research are as follows:

- The proposed approaches, which are UnBR, HQS and Heuristic approach, has improved in CLR for the VBR video/data. However, the Heuristic approach has obvious longer average cell delay than others.
- Correlating the bandwidth and buffer, the network QoS performance has been improved. It has been proven by the result acquired for the UnBR and HQS approach. These two approaches result in CLR smaller than the Standard bandwidth strategy.
- All the proposed approaches in this research have successfully reduced the CLR for the highest priority traffic, which is the VBR video/data. However, there is no significant difference (5-15%) on the average cell delay after integrate the approaches with bandwidth strategy expect for the Heuristic approach.
- Both strategies used in this research show that there are improvements in QoS requirements especially for the top priority traffic by integrating new approach to the existing bandwidth strategy.
- From the results obtained, the sharing of network resources such as bandwidth and the buffer produces better performances.

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