Bandwidth Contention with Backpressure Scheme over VDSL Network

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Summary -- *Bandwidth Contention in VDSL network occurs whenever the demand of bandwidth consumption exceeds the network capacity per se, causing lower throughputs and higher traversal time (delays). If the bandwidth contention cannot be ease nor appropriately controlled, some sessions transported by the network may not meet their quality-of-services (QoS). An existing method may simply reduce incoming traffic rate to boggle down their in-flow. Another method may try to believe in the end-to-end protocols for the recovery of lost packets. However, in this paper, a conservative method, called backpressure scheme, is proposed in order to ensure that no frames will be dropped nor discarded during the transmission, even if the contention arises. Backpressure scheme is introduced then will be evaluated by comparing versus traditional policing mechanisms, namely, Leaky Bucket(LB), Jumping Window(JW) and Triggered Jumping Window(TJW) and versus other backoff schemes, namely, pseudorandom backoff scheme (PB), random backoff scheme (RB) and exponential backoff scheme (EB). Simulation results show that over VDSL network, the backpressure scheme outperforms by improving throughputs while on the other hands, reducing dropped frames.*

***Key words* --** Policing mechanisms, backoff schemes and backpressure scheme.

1. Introduction

In most networks, if a network device receives more frames than it can forward, then the device buffers the backlog. However, once the buffer is filled up then the device begins to discard frames. This may lead to a congestion stage. Subsequent retransmissions will normally occupy and contend more network resources, resulting degraded throughput. An alternative approach is to perform hop-counts in flow control, or to conserve discarded frames by employing backpressure scheme [1]. Hop-counts in flow control will combine two mechanisms. The first is a strict portioning of the available buffer space among the flows, and selective backpressure based on a flow. The other fair queuing to all resources shared by flows within a single network device. The results are twofold: frames are never dropped due to congestion within the network, and the available bandwidth is fairly allocated by all competing active flows. With no contention in time, each flow has access to the entire bandwidth on each link; but when there is contention, each flow obtains a fair share of the bandwidth.

In this paper, backpressure scheme is applied and evaluated by using a high-speed network model such as VDSL network. There are many previous studies involving backpressure [2],[3], however, backpressure scheme compared vis-à-vis the policing mechanisms over VDSL and vis-à-vis backoff schemes is never yet investigated.

This paper is organized as follows. In section II, an overview of backoff schemes is summarized. Section III, an overview of the most significant policing mechanisms is discussed. The backpressure scheme is introduced in section IV. Section V shows the simulation model. Section VI contains a comparison of the performance collected by backpressure, traditional policing mechanisms and backoff schemes. In section VII, the conclusion and recommendation for future research are drawn.

2. Backoff Schemes

Backoff computation will allow each source to postpone the message transmission whenever the transmission is aborted. Backoff computation comprises of exponential backoff, random backoff, linear backoff and quadratic backoff as described in several papers [4],[5],[6]. Messages sent by senders in an Ethernet network may be retransmitted after T trials where T is selected randomly from $\{1,2,3, \dots ,\min(20,2b)\}$ and b is the number of times the station has tried to send the packet but failed. Previous studies show that the backoff scheme will affect on the network performance as the offered load increases. However, simplification or modification of backoff scheme can lead to very different analytical results [4],[6].

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2.1 Pseudorandom Backoff (PB)

In PB scheme, the backoff computation is performed based upon their queue disciplines. They are FIFO, LIFO and priority level for instance. In this paper, the FIFO and the maximum queue size are preset.

2.2 Exponential Backoff (EB)

EB is an algorithm being widely used in case of extensive traffic load. In EB, each node will double their backoff time after each retry but not beyond the maximum value (EBmax), and decreases the backoff time to the minimum value (EBmin) once the retry is successful. EB can be computed by the following set of equations:

EBT ← min(double_time,EBmax) if retry fails EBT ← EBmin if retry succeeds.

The EBT is the backoff interval time. The values of the EBmax and EBmin are predetermined, based on the possible range of number of active nodes and the traffic load of a network. For example, EBmax and EBmin are usually set to be 1024 and 2, respectively. Although some researchers found that the throughput in the Ethernet network will be degraded as the backoff interval does not correctly represent the actual contention of the bandwidth [4],[6] but we experience somehow the EB can help improve the performance of the system regarding to the fluctuation of telecommunication traffic.

2.3 Random Backoff (RB)

Another approach is the use of the random backoff (RB) technique. In order to avoid repeated retry by one particular node based upon the detection of non availability of transmission, the sender is required to wait for a random period of time before next retry. In RB, the duration of the backoff is usually selected randomly in the range from 0 to a maximum time duration.

2.4 Backoff Interval Time Essentials

The backoff interval is dynamically controlled by each backoff schemes as described above. Setting the length of the backoff interval is, however, not a trivial task. On one hand, with a fixed number of ready nodes, small backoff intervals do not help reduce the correlation among the retrying nodes to any appropriate low levels. These results are moreover raising too high number future retries, lowering the throughput. On the other hand, too large backoff intervals introduce unnecessary idle time on the waiting for retry (waiting time in queue), increase the average packet delay and unneeded preparation of buffer to handle the size of queue, also eventually would degrade the system's performance [8].

2.5 Deadlock

Messages are formatted into a packet prior to the transmission then kept in the buffer (queue) to be ready for sending until the transmission to the destination is acknowledged. Queue deadlock arises whenever a set of waiting packets in queue can no longer find the chance of being sent (no bandwidth available). In contrary, bandwidth per se will be available whenever waiting packets are no more left in queue (the retry becomes less). Thus the solution often employed to avoid this type of deadlock is to backoff the retransmission far enough the retry would not produce any jeopardy. Once the retry does not cause any impacts to the availability of the bandwidth, the deadlock seems to be far reachable. These solutions somehow may not be practical in some systems with no backoff scheme installation.

2.6 Waiting Time in Queue

It is significant to describe a queue policy, called threshold-based queue management.

Consider a workstation that consists of a single machine *M* and an infinite buffer *B*. The average waiting time in the buffer of single-machine station *BM* can be approximated by :

$$\phi q = \left(\frac{C_a^2 + C_e^2}{2} \right)\left(\frac{u}{1-u^{t_e}} \right) \qquad (1)$$

C_a = the coefficient of variation of the arrival times

C_e = the corresponding coefficient of variation

t_e = the mean processing time of station

u = utilization

The utilization of a workstation is defined by the quotient of mean arrival rate *ra* and mean capacity *re* :

$$u = \frac{r_a}{r_e} \qquad (2)$$

r_a = mean arrival rate $=1/t_a$

r_e = mean capacity of the machine $=1/t_e$

t_a = mean inter-arrival time

Equation 1 holds for a so-called G/G/1-queueing system. The notation G/G/1 indicates that the distribution of arrival times as well as process times are taken completely general (e.g. uniform, exponential, gamma, etc.), and that the station has 1 machine. Equation 1 is composed of three terms: a variability term $\left(C_a^2 + C_e^2\right)/2$ a utilization term *u*=(1-*u*), and a term with the process time *te*. The variable term implies that the average waiting time in the queue is proportional to the sum of squared coefficients of variation of the arrival times and the processing times. Thus if both the arrival times and the processing time are constant (deterministic), the queue will always be empty providing that the arrival rate is smaller or equal to the processing capacity. But if there is (even only a little) variation, then on average there will be lots waiting in the queue. The higher the variation the longer waiting time in the queue becomes. The utilization term shows that the average waiting time of more queues increases in a nonlinear fashion for increasing utilization. It is important to notice that if the utilization approaches next to one, the average I/O cycle time becomes very large (likely to have difficult chance in queue releasing). For u = 1 the system even becomes unstable, expressed by an infinite waiting time. As a consequence, no station can ever be utilized for the full hundred percent all the time. In the industry, this simple observation is often overlooked. If utilization is smaller than one, we can clearly see that there is no technical problem of congestion or deadlock, provided that the figure of utilization is not above the range between 70% to 80% in practice. The higher the utilization factor of the purchased station is, the larger the average waiting time in the queue will be, which results in longer end-to-end delay (meaning that the longer time to traverse from source to destination) [9].

There are many previous studies involving backoff algorithms [4],[7],[8] however, the behavior of backoff concept applicable to waiting time in the queue with policing mechanisms is never yet investigated. In this paper, we proposed comparisons of the performance between pseudorandom backoff (PB), exponential backoff (EB) and random backoff (RB) versus leaky bucket policing mechanism.

3. Description and Modeling of Traffic Policing

Traffic policing allows us to control the maximum rate of traffic sent or received on an interface during the entire active phase and must operate in real time.

In addition to these requirements, mechanism of parameter violations must be short to avoid flooding of the relatively small buffers in the network. To meet these somewhat conflicting requirements, several policing mechanism have been proposed so far. Several mechanisms have been proposed which are described in following sections.

3.1 Traffic source models

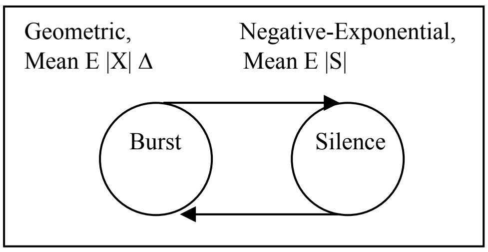

Figure 1. The burst/silent traffic model.

In the simulation, a burst traffic stream from a single source is modeled as an burst/silence traffic stream. The burst-period represents an input flow and silent period represents an off period of the input traffic. The ON/OFF traffic characteristics are generally known as the telecommunications oriented traffic, such as the human being speech. Burst-periods and silence-periods are strictly alternating. The number of frames per burst is assumed to have a geometric distribution with mean E[X]; the duration of the silence phases is assumed to be distributed according to a negative-exponential distribution with mean E[S]; and inter-packet time during a burst is given by Δ. With

$$\alpha\text{-}1 = E[X] \times \Delta$$

and

$$\beta\ 1 = E[S]$$

3.2 Policing Mechanism Models

Various congestion control traffic policing mechanisms had been studied by [10],[11],[12],[13],[16]. The policing mechanisms are categorized as follows.

3.2.1 The Leaky Bucket Mechanism

One of the most mentioned policing mechanism in literature is known as leaky bucket (LB). The LB mechanism consists of a counter, which is incremented by 1 each time a frame is generated by the source and decremented in fixed intervals as long as the counter value is positive. If the momentary frame arrival rate exceeds the decrement rate, the counter value starts to increase. It is assumed that the source has exceeded the admissible parameter range if the counter reaches a predefined limit, and suitable actions (e.g. discard or mark frame) are taken on all subsequently generated frame until the counter has fallen below its limit again. This mechanism is easy to implement by using. e.g., one counter for the system state. one counter for the measurement of the decrement interval, and variables for the counter limit and for the length of the decrement interval. The additional implementation effort needed for header decoding and for the realization of the policing action is not considered here normalization condition for probability distributions because it is identical for all the mechanisms [10],[11],[13],[14],[15].

3.2.2The Jumping Window Mechanism (JW)

The JW mechanism limits the maximum number of frames accepted from a source within a fixed time interval (window) to a maximum number N . The new interval starts immediately at the end of the preceding interval (jumping window) and the associated counter is restarted again with an initial value of zero. Therefore, the time interval during which a specific frame is influencing the counter value varies from zero to the window width. The implementation complexity of this mechanism is comparable to the complexity of the LB mechanism. Counters are needed to measure the interval T and to count the number of arrivals, and variables are needed for the counter limit and the interval length T. The probability that policing actions must be taken on a frame can be computed by using the counting process for the frame arrivals. which characterizes the number of arriving frames in an arbitrary time interval. For example, the counting process for negative-exponential inter-arrival times is a Poisson process.

3.2.3 The Triggered Jumping Window Mechanism (TJW)

The time window is not synchronized with source activity in the JW mechanism. To avoid the ambiguity problems arising from that fact, the "triggered jumping window" mechanism has been proposed, where the time windows are not consecutive but are triggered by the first arriving frame. The implementation complexity for this mechanism is comparable to the complexity of the mechanisms described above [10],[11].

4. Backpressure Scheme

With backpressure scheme, it works like XON /XOFF techniques to prevent buffer overflows and transient congestion in network. Congestion control is invoked by triggering XON/XOFF flow control messages. The XOFF flow control message is sent to the upstream when buffer exceeds the upper threshold. When a sever receives an XOFF signal, it pauses sending frames until it receives an XON signal from the same server or until the time in XOFF message expires. The XON signal is triggered when the buffer at the congested server descends below the lower threshold.

When frames arrive at a buffer of server, the backpressure algorithm is activated. If the queue is not full and less than threshold then the sever sends message to source hob that can send double transmission rate to the receiver hob and the frame is transmitted without delay. If the buffer exceeds the upper threshold then the receiver hob sends the message to source hob that can reduce a half transmission rate[17],[18].

Backpressure algorithm is described as follows.

```
START_CHCK:
  IF Simulation Time Reached THEN GOTO
FINISH:
  ELSE
      { IF QDESTN  <  QTHRESHOLD
        THEN  MARK  AS  HUNGRY;
        ELSE  MARK  AS  RETARDING;
HUNGRY:  DOUBLE TRX RATE;
                 GOTO START_CHCK;
RETARDING : REDUCE TRX RATE INTO
HALF;
GOTO START_CHECK;
   }
FINISH: /** end of transmission **/.
```

Figure 2. Backpressure algorithm.

5. Simulation Model

The following figure 3 shows a simulation model used in this paper.

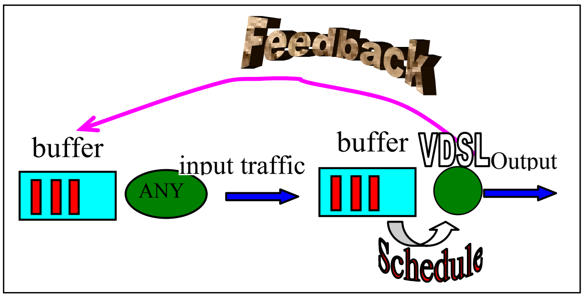

Figure 3. Simulation model.

5.1 Input Traffic

This research focuses the input data, which is generally burst type. Voice and video sources can be continuous or burst type, depending on the compression and coding techniques used. There are three components with certain characteristics that must be examined before the simulation models are developed.

The pattern of arrivals input traffic mostly is characterized to be *Poisson arrival processes*. The probability of the inter-arrival time between event t, is defined by the *inter-arrival time probability density function (pdf)*. The following formula gives the resulting probability density function (pdf), which the inter-arrival time t is larger than some value x when the average arrival rate is λ events per second:

$$fx(t) = \begin{cases} e^{-\lambda t}, \text{ for } & t \geq 0 \\ 0 \quad , \text{ for } & t < 0 \end{cases}$$

$$p(t \leq x) = Fx(x) = \int_0^x e^{-\lambda x} dx = 1 - \lambda e^{-\lambda x}$$

$$p(t > x) = 1 - Fx(x) = \lambda e^{-\lambda x}$$

In this paper, we adopt the ON/OFF burst model [1],[2].

5.2 Service Facility Characteristics

In this paper, service times are randomly distributed by the *exponential probability distribution*. This is a mathematically convenient assumption if arrival rates are Poisson distributed. In order to examine the traffic congestion at the entrance of VDSL downstream link (data rate is 15Mbps)[17], the service time used in the simulation model is specified by the speed of this VDSL link, resulting that a service time is set to be exponential distribution with mean 216 µs, where the frame size is 405 bytes

[181] The buffer size at the entrance to VDSL network is set to be 1,024 frames [20]. Once it is exceeding the buffer size then it is considered to be a non-conforming frames (or dropped frames).

5.3 Source Traffic Descriptor

The source traffic descriptor is the subset of traffic parameters requested by the source (user), which characterizes the traffic that will (or should) be submitted during the connection. The relation of each traffic parameter used in the simulation model is defined as follows. Peak frame rate (PFR)= $\lambda a = 1/T$ in units of frames/second, where T is the minimum inter-frame spacing in the unit of seconds

5.3.1 Backoff Scheme in Policing Mechanism for VDSL Network

The simulation will set parameters for backoff scheme as follows.

PFR = λa = 9 Mbps(~2,778 frames/s) giving that T=360 μs.

5.3.2 Backpressure Scheme

The simulation will set parameters for backpressure scheme as follows.

Maximum buffer size =1024 frames and service time is identical to exponential distribution with mean 216 μs as specified in previous section.

6. Results and Discussion

The comparison between backpressure, policing mechanisms and backoff schemes is shown in figures below. The comparison between backpressure (BP) and existing policing mechanism (LB,JW,TJW) is shown in figure 4-6.

The simulation results as of BP ,LB, JW and TJW will be compared. The input frames (varying from 5 to 25 Mbps) with burst/silence ratio of 100:100 are performed by simulation and results are shown in Figure 4. It clearly determines that the backpressure (BP) outperforms and policing mechanisms (LB,JW, TJW) are the worst if the conforming frames are taken into account.

Figure 5 demonstrates that backpressure has not dropped frames. The highest number of dropped frames as shown in this figure is traditional policing mechanisms with burst/silence ratio as of 100:300. Results assure that as far as we can eliminate the problem of dropped frames and can guarantee that there is not delay time. It is a factor of QoS.

In Figure 6, the simulation result determines more utilization of backpressure comparing to the other policing mechanisms with burst/silence ratio of 100:100. The increment of utilization factor seems not to be relevant to the performance improvement. The higher utilization may cause an approach of bottleneck situation, which can in general boggle down the system. In fact the step up from 79% to 82% in BP will not affect the situation of bottleneck as the utilization does not exceed 85 % yet.

We found out that, from simulation result in backpressure has no dropped frame, which is better than other policing mechanisms. It is suitable for real time application, which is not affected by delay time and dropped frame.

This section indicates simulation results from backpressure and all backoff algorithms, that are, BP, EB, PB and RB performance will be compared. The input frames (frame rate varies from 5 Mbps to 25 Mbps) with burst/silence ratio of 100:100 performed simulation results as shown in figure 7. It clearly determines that the BP is the best of throughput guarantee. Throughput is one of factor of QoS to help guarantee higher reliability of network performance. In conclusion, the BP may assure higher reliability to handle real time applications such as multimedia traffics compared to other EB, PB and RB.

Figure 8 complies results in the sense that BP will produce lowest dropped frames compared with other backoff schemes. In other words, we can help conserve the conforming frames by reducing number of dropped frames. A regular network may cause a poor QoS by higher non-conforming or dropped frames. Especially, a quality of multimedia traffics such as video during the online display mode may drop or cause a threat for the viewer while the quality of audio traffics may have less impact since the unclear situation would be ironed out by hearing intelligent function of human being.

In figure 9, the result determines that the utilization of the RB scheme is the lowest. From this viewpoint, the processing unit will be available for other sources in terms of sharing. The result is in the line of low processing power required by RB because RB produces less conforming frames and higher dropped frames. Most frames are discarded before transferring (entering the network) to the entrance of the VDSL network. It seems like RB makes less congestion but it will reflect the lower throughput in return.

Simulation results from backpressure and all backoff algorithms, that are, BP, EB, PB and RB performance will be compared. The input frames (frame rate varies from 1 Mbps to 30 Mbps) with burst/silence ratio of 100:100 performed simulation results as shown in Figure 10. It clearly determines that the BP is the best of throughput guarantee. Throughput is one of factor of QoS to help guarantee higher reliability of network performance. In conclusion, the BP may assure higher reliability to handle real time applications such as multimedia traffics compared to others.

Figure 11 complies results in the sense that BP will produce lowest dropped frames compared with other backoff schemes. In other words, we can help conserve the conforming frames by reducing number of dropped frames. A regular network may cause a poor QoS by higher non-conforming or dropped frames. Especially, a quality of multimedia traffics such as video during the online display mode may drop or cause a threat for the viewer while the quality of audio traffics may have less impact since the unclear situation would be ironed out by hearing intelligent function of human being.

In figure 12, the result determines that the utilization of the TJW is the lowest. From this viewpoint, the processing unit will be available for other sources in terms of sharing. The result is in the line of low processing power required by TJW because TJW produces less conforming frames and higher dropped frames. Figure 13 and 14 show that BP has to make all frames wait longer in queue at the sender and next to the entrance of VDSL network. It is due to less packets dropped and higher number of successful retry (make all possible retransmission). It is apparent that both MQL and MQT for both schemes are higher in general while RB makes less. Positively, with the same size of the buffer, BP is proven to be high-risk-high-return while RB seems to be a conservative scheme

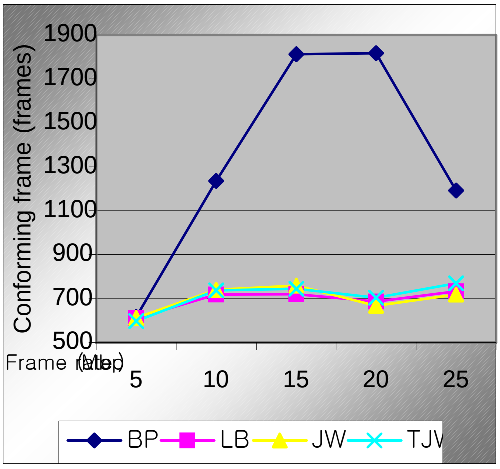

Figure 4. illustrates the conforming frames for burst : silence = 100:100

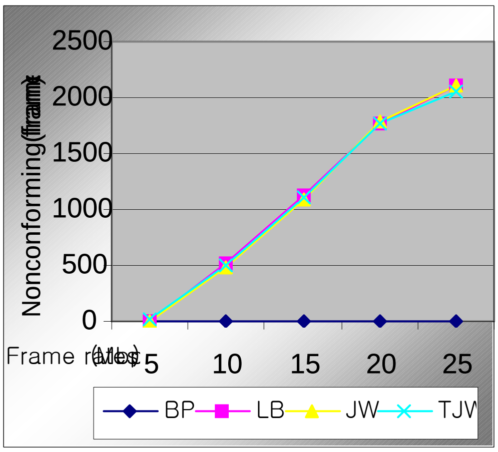

Figure 5. illustrates the non-conforming frames for burst : silence = 100:100.

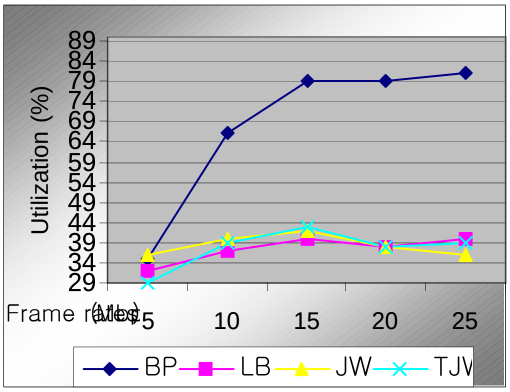

Figure 6. illustrates the utilization comparison between BP, LB, JW and TJW at burst : silence = 100:100.

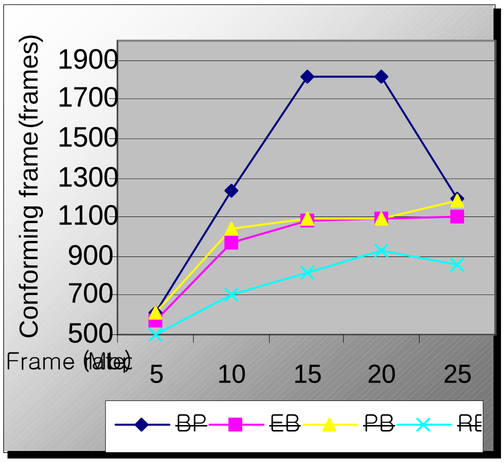

Figure 7. illustrates conforming frames comparison between BP, EB, PB, RB with variable input rate, τ=1260 microsec. and burst : silence =100:100.

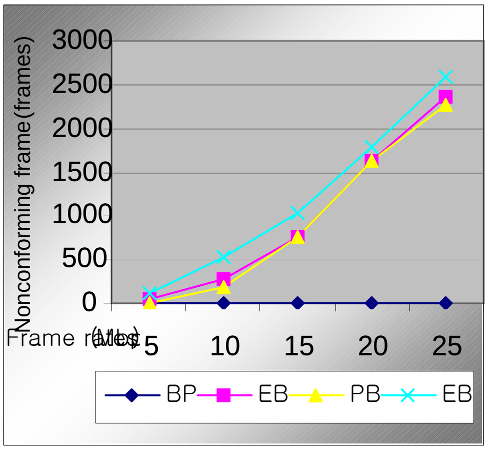

Figure 8. illustrates non-conforming frames comparison between BP, EB, PB, RB with variable input rate, τ =1260 microsec. and burst : silence =100:100.

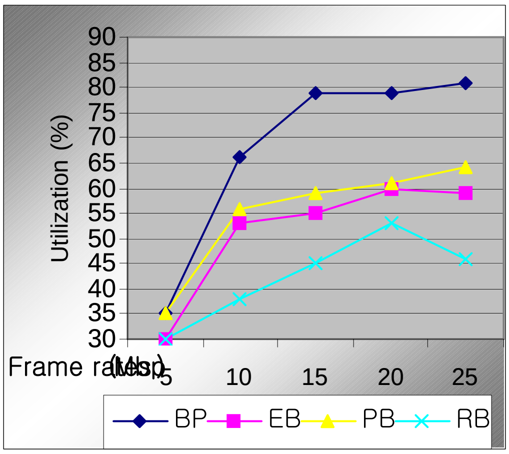

Figure 9. illustrates the utilization comparison between BP, EB, PB, RB with variable input rate, τ =1260 microsec. and burst : silence =100:100.

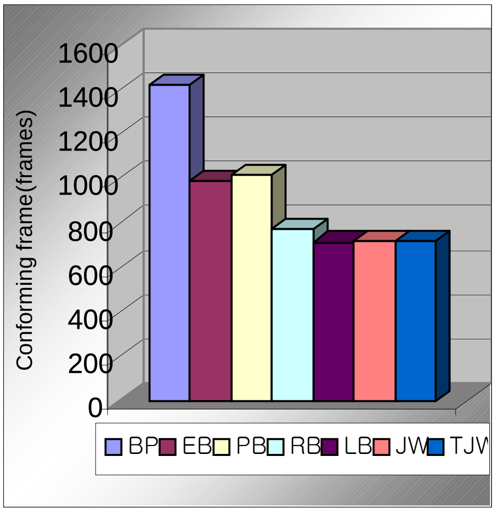

Figure 10. illustrates conforming frames with variable input rate, τ=1260 microsec. and burst : silence =100:100.

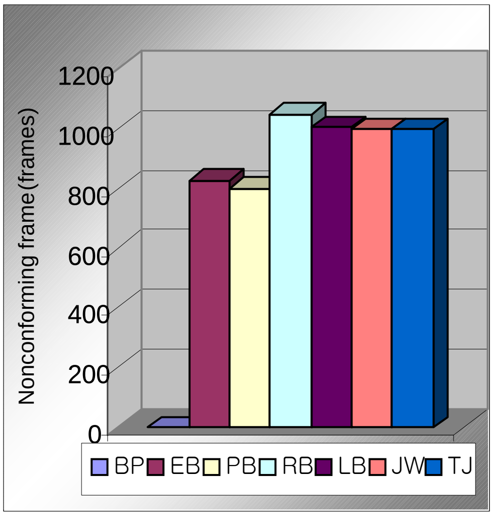

Figure 11. illustrates non-conforming frames with variable input rate, τ =1260 microsec. and burst : silence =100:100.

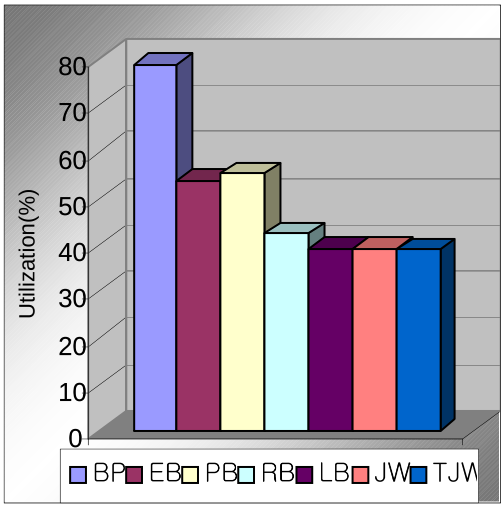

Figure 12. illustrates the utilization with variable input rate, τ =1260 microsec. and burst : silence =100:100.

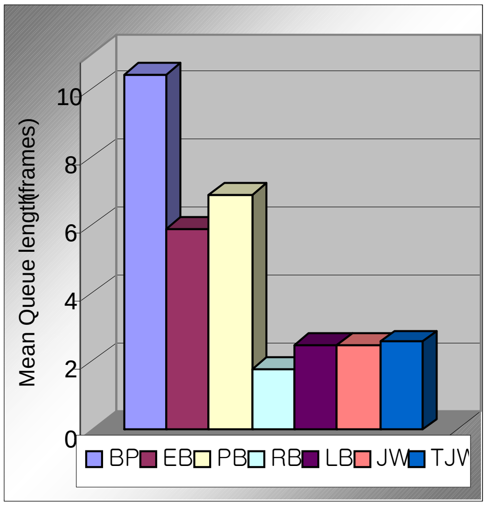

Figure 13. illustrates the mean queue length with variable input rate, τ =1260 microsec. and burst : silence =100:100.

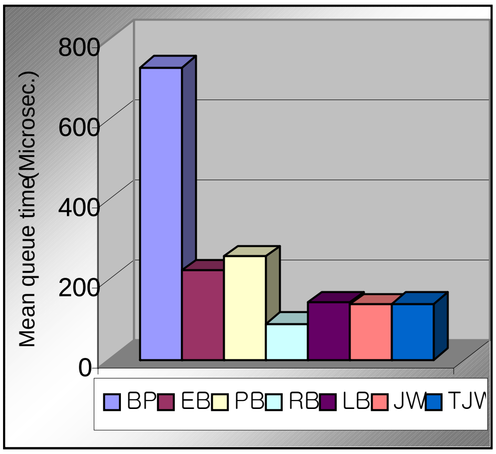

Figure 14. illustrates the mean queue time with variable input rate, τ =1260 microsec and burst : silence =100:100.

7. Conclusions and Recommendations for Future Research

In this paper, we divided conclusion into three parts. We carried out a comprehensive study to investigate the performance of backpressure; namely BPand three selected traditional policing mechanisms; namely LB, JW, TJW with fixed types of traffic sources. This study was accomplished through simulation. A simulation model was developed.

We found out that, from simulation results backpressure outperforms in terms of throughput metrics with various burst/silence sources, provided that source traffics are lower than 15 Mbps.

We carried out a comprehensive study to investigate the performance of backpressure; namely BP and three selected; namely: exponential (EB), pseudorandom (PB) and random backoff (RB) schemes with fixed types of traffic. The study was accomplished through simulation after developing an analytical queueing model.

We found that based on simulation results in general, backpressure is the best throughput and non-conforming frames compared to others (EB, PB, RB). Only the case that the network seeks for sharing or availability of the utilization, random backoff scheme will be the only choice. backpressure is suitable for multimedia traffics such as voice, video and data

In any case, the tradeoff backpressure is more frames waiting longer in queue if the traffic is high (more than 15 Mbps). We can solve this problem by increasing peak rate of VDSL switch.

We carried out a comprehensive study to investigate the performance of backpressure; namely BP three selected traditional policing mechanisms; namely LB, JW, TJW and three selected; namely: exponential (EB), pseudorandom (PB) and random backoff (RB) schemes with fixed types of traffic sources. This study was accomplished through simulation. A simulation model was developed.

We found that based on simulation results in general, backpressure is the best in term of throughput and non-conforming frames compared to others (LB, JW, TJW, EB, PB, RB). The utilization of the JTW is the best in term of bandwidth and RB is the best in term of MQL and MQT. This problem can be solved by increasing higher data rate of server.

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