

A Feedback based Probability Selection for Frame forwarding in AVB switched Ethernet

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Abstract: In order to support real-time quality of service in time-sensitive and time-tolerant coexisting network in Ethernet, a set of IEEE standards for transporting and forwarding real-time content over Ethernet are proposed that known as Audio Video Bridging (AVB). By bandwidth reservation and priority isolation, AVB traffic are re-mapped into the highest Ethernet frames and are always prior forwarding, so the time delay can be ensured in the specific scope. However, the time-tolerant traffics are simply crude treated by Strict Priority (SP) selection and Best Effort (BE) forwarding. The consequence is that the lowest priorities are over-sacrificed when the bandwidth is limited. In this paper, we proposed a FeedBack based Probability Selection (FBPS) for frame forwarding to enforce a proportional queuing delay. By means of changing the probability of BE traffics been selected, the average queuing delay ration can be controlled in a fixed value. Which ensure high priority BE traffics can enjoy a relatively low latency, and low priority BE can also be operated as well. The experiment demonstrates the effectiveness of FBPS.

Keywords: QoS; Ethernet AVB; IEEE802.1Qav; Feedback Control; FeedBack based Probability Selection

1. Introduction

As the digital audio and video processing technology has laid a solid technology foundation for the intelligence of automation, avionics and automotive, the demands of standard network technologies for common device are created. Due to the high bandwidth, low cost, easy scalability, high flexibility and IP-based network compatibility, switched Ethernet network for video/audio mixed usage is a common solution. However, multimedia which coexists with traditional control systems will lead to high diversity in size, intensity and timing requirements when the traffic traverses the channel. Adapting standard networks could use compatible technology, but tight quality of service control was difficult [1].

IEEE 802.1 Audio/Video Bridging Task Group (AVB TG) implements a set of protocols on Ethernet which are known as Audio Video Bridging (AVB). AVB implements synchronization services in IEEE 802.1AS [2], Stream Reservation Protocol (SRP) in IEEE 802.1Qat [3] and frame forwarding for AVB traffic in IEEE 802.1Qav [4], where IEEE 802.1AS and IEEE 802.1Qat are the prerequisite for traffic forwarding.

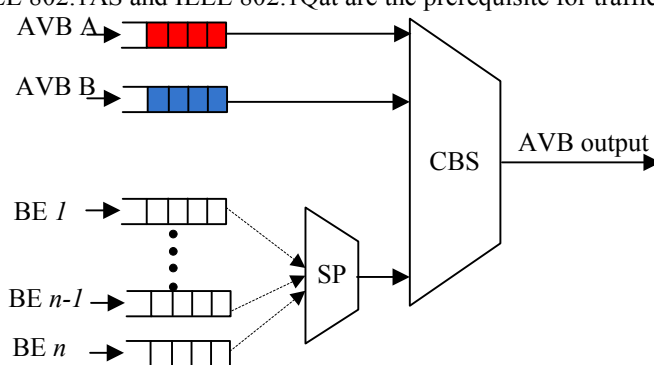


Figure 1. Transmission selection scheme in IEEE 802.1Qav

The IEEE 802.1Qav standard specifies mechanisms to provide guarantees for time-sensitive (i.e. bounded latency and delivery variation), loss-sensitive real-time audio/video data transmission (AV traffic). It separates the network traffic into different traffic classes by using priority mechanism as specified in IEEE 802.1Q. Each traffic uses a dedicated queue with the scheduling of FIFO (First-IN-First-Out) order. As shown in Figure 1, IEEE 802.1Qav supports two transmission selection algorithms in a switched Ethernet network: Credit Based Shaper (CBS) and Strict Priority (SP).

- 1). The algorithm defines credits associated to each of the stream reservation (SR) classes (SR-A, SR-B) where a transmission is only allowed when the credits given in bits are greater or equal than zero and no other frames are transmitted at the same time (no conflicting frames). The credits are increased at a rate of *idleSlop*, when SR classes are waiting for transmission, while decreased at a rate of *sendSlop*, when SR classes are dequeued and transmitted.
- 2). SP selection algorithm is used as the default algorithm to select legacy Ethernet frames i.e. Best Effort (BE) frames for transmission. The frames are selected by their priority values. At first, legacy Ethernet frames are selected from the highest non-AVB priority queue until the queue is empty and frames from other non-AVB queues are selected successively based on the priority values.

The initial design of CBS is used to ensure the fair scheduling of the low-priority frames and smooth out the traffic flow to greatly reduce the possibility of dropped packets due to congestion. However, there still exists the over-sacrifice condition of low non-AVB priority. As shown in Figure 2, there are $N = 6$ BE traffics and AVB traffics (SR-A and SR-B) in a switched Ethernet network. These different traffics are re-mapped to Ethernet frames by using Virtual Local Area Network (VLAN) tag encoded priority values. All traffics are transmitted on an 8-kHz beat. 20% bandwidth is reserved for SR-A and SR-B, which is ensured by time synchronization (IEEE 802.1AS) and bandwidth reservation (IEEE 802.1Qat). Legacy Ethernet frames are selected from the highest priority queues.

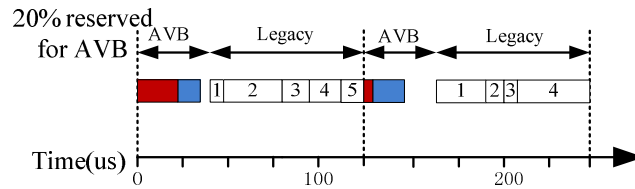


Figure 2. Over-sacrifice of non-AVB low priority frames

In the worst case, a mass of higher BE traffics will block the transmission of lower priority until its queue is empty. For example, the BE frames prioritized 6 in the first and second transition period always have no chance to be transmitted. This phenomenon is named as low priority's starvation.

AVB has become a hot point for the researchers. Lim H T etc. mainly simulated the protocols specified in the IEEE 802.1 AVB standard and compared the performance with the legacy mechanism [5-6]. Paper [7] simulated several cases in order to decide the optimal bandwidth allocation ratio for the scheduled traffic by adjusting scheduled traffic's MTU size. Paper [8] used the shaper context to limit the workload and tighten the worst-case latency metric. Paper [9] presented an approach to mitigate the effect of such interference and reduce the latency for high priority traffic in IEEE 802.1 AVB Networks. However, all the researches focused on the performance analysis and improvement in AVB but without the consideration of the over-sacrifice of low non-AVB priority. In this paper, we propose a probability selection approach based on feedback based control to realize the proportional delay differentiation. Instead of SP algorithm, the approach controls the average delay ratio of BE traffics with different priorities to be a pre-fixed value. On one hand, a desired fixed delay ratio between the BE traffics is differentiated. The higher priority means a lower delay. On the other hand, even the lowest priority traffics still have the chance to be transmitted, which can prevent the over-sacrifice of low priorities.

2. Probability Selection Architecture and Controller Design

2.1. Proportional Delay Differentiation

Supposing there are N classes of BE traffics in AVB switched Ethernet. The proportional delay differentiation (PDD) scheme is adopted to avoid the over-sacrificed of low priority. The control object is to maintain the actual QoS parameters to meet the Eq. (1).

$$\frac{\varsigma_i}{\varsigma_j} = \frac{\delta_i}{\delta_j}, i = j = 1, \dots, N \quad (1)$$

where ς_i is the average queuing delay of class i and δ_i is the corresponding priority parameter set by upper layer protocol like re-mapping in IEEE 802.1Q. The class with smaller δ means a higher priority and expects a lower delay.

Define $p_i(k)$ be the transmission probability of class i at the k^{th} sampling period and it obeys the constraint of Eq.(2):

$$\sum_{i=1}^N p_i(k) = 1 \quad (2)$$

Obviously, a class with a higher selection probability waits a shorter queuing time. Meanwhile, the traffics even with the lowest priority always have the chance to be scheduled. So the initial idea of the probability selection control is to realize the PDD guarantees shown as Eq.(1) by adjusting the selection probability of different BE traffic classes.

2.2 System Modeling

Figure 3 shows the feedback control model of probability selection architecture in AVB. The output of selection controller is the probability vector which has only $N-1$ independent variables:

$$X(k) = [p_1(k), p_2(k), \dots, p_{N-1}(k)]^T \quad (3)$$

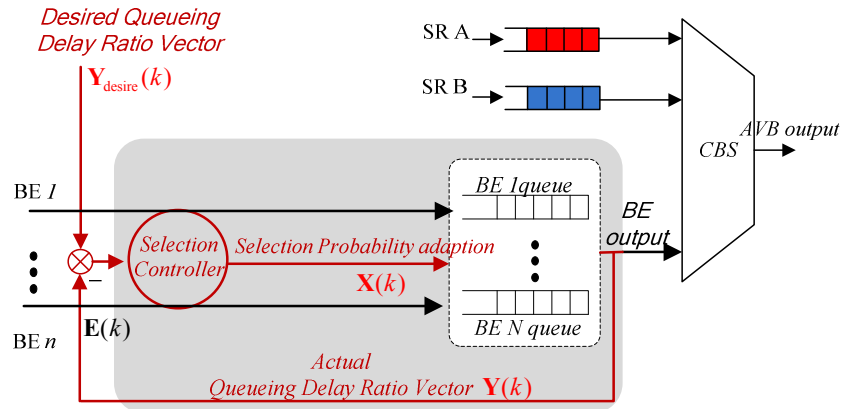


Figure 3. Feedback control model of probability selection architecture

Supposing $y_i(k)$ and $y_{i_{\text{desire}}}$ are the normalized delay and desired QoS value respectively according to Eq. (1).

$$y_i(k) = \frac{\varsigma_i}{\sum_{l=1}^N \varsigma_l}, y_{i_{\text{desire}}} = \frac{\delta_i}{\sum_{l=1}^N \delta_l}, 1 \leq i \leq N \quad (4)$$

Because of $\sum_{i=1}^N y_i(k) = 1$ and $\sum_{i=1}^N y_{i_{\text{desire}}} = 1$, both the system output vector and the reference input vector also have $O = N-1$ independent variables:

$$Y(k) = [y_1(k), y_2(k), \dots, y_{N-1}(k)]^T, Y_{\text{desire}} = [y_{1_{\text{desire}}}, y_{2_{\text{desire}}}, \dots, y_{N-1_{\text{desire}}}]^T \quad (5)$$

$E(k)$ is the deviation between the measured normalized delay and its desired value.

$$E(k) = Y(k) - Y_{\text{desire}} \quad (6)$$

The controller operates by responding to the deviation, i.e. adjusting queuing delay by changing the selection probability. Thus the proportional delay differentiation is sustained. The inherent self-stabilization of feedback mechanism ensures the system good running despite of the uncertainty of traffic flow and interfering data.

The mathematical model can be established based on the variables definition above. Strictly speaking, a discrete and nonlinear model is required for the probability selection architecture. However, such a nonlinear model is not amenable to the straightforward theoretical design and analysis. So the following linear model is used to approximate the system. Supposing r -order could be precise enough, the Z-domain transformation is:

$$\begin{aligned} A(z^{-1})Y(k) &= B(z^{-1})X(k) + \Xi(k) \\ A(z^{-1}) &= I - A_1 z^{-1} - \dots - A_r z^{-r}, A_i \in R^{O \times O}, 0 < i \leq r \\ B(z^{-1}) &= B_1 z^{-1} - \dots - B_r z^{-r}, B_i \in R^{O \times I}, 0 < i \leq r \end{aligned} \quad (7)$$

where $\Xi(k) = [\varepsilon_1(k), \varepsilon_2(k), \dots, \varepsilon_{N-1}(k)]^T$ is O -order white noise sequence. Then Eq. (7) can be rewritten as:

$$\begin{aligned} Y(k+1) &= \Theta \Phi(k) + \varepsilon(k+1) \\ \Theta &= [B_1, \dots, B_r, A_1, \dots, A_r] \in R^{O \times (O \times 2 \times r)}, k \geq r-1 \\ \Phi(k) &= [X^T(k), \dots, X^T(k-r-1), Y^T(k), \dots, Y^T(k-r-1)]^T \end{aligned} \quad (8)$$

We take Recursive Least Square (RLS) algorithm to estimate the parameter matrix Θ and F -test to determinate the system order. The mathematical details can be seen in our previous paper [10].

2.3 Controller Design

According to section 2.2, the system transfer function in Z -domain can be described as $G(z) = Y(z)/X(z)$. Supposing the controller transfer function is $D(z)$ and the closed-loop transfer function is:

$$F(z) = \frac{D(z)G(z)}{1 + D(z)G(z)} \quad (9)$$

Thanks for the Least-Beat Control approach, the system output can follow the input signal in very several sampling time, and can limit the steady-state error to zero (zero steady-state error system). The typical input signal can be described as Eq. (10), such as unit-step function, unit-ramp function and unit of acceleration function.

$$Y_{desire}(z) = \frac{A(z)}{(1 - z^{-1})^m} \quad (10)$$

So the deviation E is

$$E(z) = F_e(z)Y_{desire}(z) = \frac{F_e(z)A(z)}{(1 - z^{-1})^m} \quad (11)$$

where $F_e(z) = 1 - F(z)$. According to the expiration-value theorem, the system steady-state error is:

$$E(\infty) = \lim_{z \rightarrow 1} (1 - z^{-1})E(z) = \lim_{z \rightarrow 1} (1 - z^{-1}) \frac{F_e(z)A(z)}{(1 - z^{-1})^m} \quad (12)$$

If $E(\infty) = 0$, F_e must has factor of $(1 - z^{-1})^m$. Take the worst condition i.e. the unit-step function as the input signal which means $m = 1$. Put $F(z) = z^{-1}$ into Eq. (9), there is

$$\frac{D(z)G(z)}{1 + D(z)G(z)} = z^{-1}, D(z) = \frac{z^{-1}}{(1 - z^{-1})G(z)} \quad (13)$$

2.4 Probability Selection

In order to transmit the corresponding frames according to their selection probability $p_i(k)$ calculated by the controller, a threshold vector is defined for all the priorities as follows.

$$\Lambda(k) = [\lambda_0(k), \lambda_1(k), \dots, \lambda_{N-1}(k), \lambda_N(k)]^T, 0 = \lambda_0(k) < \lambda_1(k) < \dots < \lambda_{N-1}(k) < \lambda_N(k) = 1 \quad (14)$$

During the BE transmission period, if there is no other BE frames transmitted at the same time, the frames selection is operated as follows:

- 1). First, generate a random number $s(k)$ submitted to the uniform distribution in the range of $[0,1]$, i.e. $s(k) \square U(0,1)$;
- 2). Second, compare $s(k)$ with the threshold vector. If $\lambda_{i-1} < s(k) < \lambda_i, i = 1, 2, \dots, N$, then the package from the i^{th} priority queue is transmitted;
- 3). It is intuitional to draw the value of threshold parameters:

$$\begin{cases} p_1(k) = \lambda_1(k) \\ p_2(k) = \lambda_2(k) - \lambda_1(k) \\ \vdots \\ p_{N-1}(k) = \lambda_{N-1}(k) - \lambda_{N-2}(k) \end{cases} \quad (15)$$

3. Experiments and Results

3.1 Configuration

We take simulation to test the performance of FeedBack based Probability Selection (FBPS) algorithm. AVB Switcher forwards the prioritized Ethernet frames. The total output bandwidth of switcher is 100Mbps, and 20% bandwidth is reserved for AVB and the transmission is 8kHz beat. Besides AVB traffics, there are other three kinds of BE traffics, which are marked as BE 1, BE 2 and BE 3. Define BE 1 be the highest priority that must be transmitted first by SP. Because AVB traffics and BE traffics are isolated strictly by bandwidth reservation, so we only analysis the feature of BE traffics in the following simulation. In all the BE traffics, the Ethernet payload size submits the Pareto distribution. The maximum payload is 1500byte and the average length is 700byte. The

depth of all the BE queues is 1000 frames.

Considered the worst case:

- 1). The arriving rate of the highest priority (BE 1) changes between 400-1200 frames/second with the period of 600s;
- 2). The arriving rate of the medium priority (BE 2) is nearly constant at 600 frames/second;
- 3). The lowers priority (BE 3) changes with the same period but opposite phase of BE 1.

The experiment operates last 2000s and the selection controller starts at about 1000s. The period changed traffics are equivalent to positive and negative step-function signals for a control system, which is theoretically the worst case for a controller.

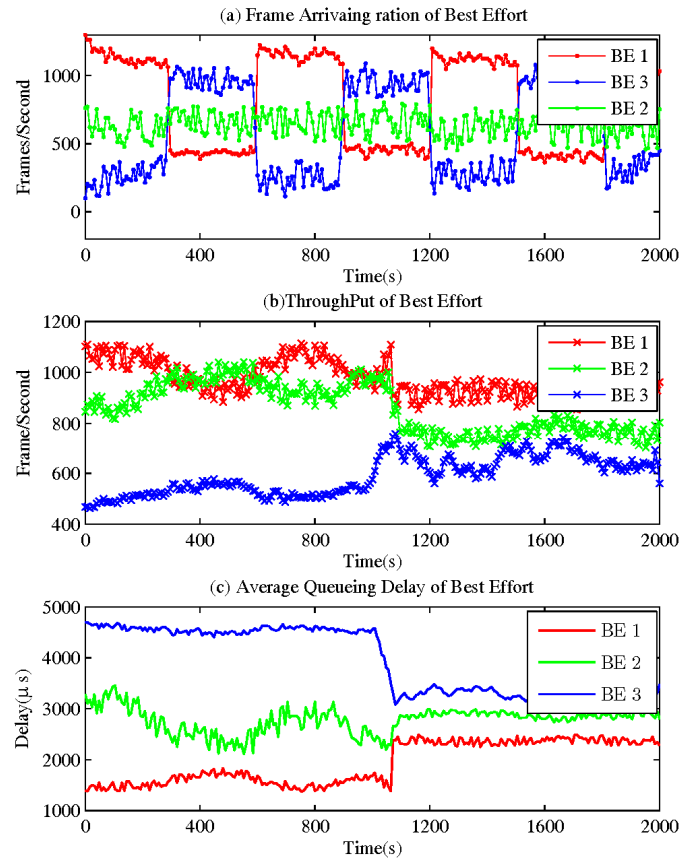


Figure 4. Throughput and Queuing Delay of BE traffics in FBPS

3.2 Results

The results are shown in Figure 4.

In the former 1000s, original SP of AVB is adopted for the BE traffics transmission.

- 1). Because BE 1 traffic frames are always firstly filled in the legacy bandwidth, so the throughput of BE 1 allows the tendency of the arriving rate and queuing delay is relative small;
- 2). The throughput and delay of BE 1 show a little fluctuates because of the changing queuing length caused by the arriving rate, which will in turn influence the throughput and delay;
- 3). Although the arriving rate of BE 2 is nearly constant, the throughput changing with BE 1 but in opposite phase. This is because the legacy bandwidth can be used by BE 2 only after the transmission of BE 1 frames. Bandwidth is fixed, so throughput of BE 2 fluctuates with BE 1 arriving rate. The average delay of BE 2 also shows the same phenomena with throughput. The higher throughput responds to the lower delay.
- 4). The throughput of BE 3 is low and correspondingly the delay is high no matter how the arriving rate changes. It is because the former two traffics (BE 1 and BE 2) have occupied most of the bandwidth,

and there is nearly no chance for BE 3 transmission (the starvation of BE 3).

FBPS operates after 1000s. The desired queuing delay ratio is set to be $\delta_1 / \delta_2 / \delta_3 = 2 / 3 / 4$.

- 1). The analysis of BE 3 shows that FBPS can effectively inhibit the over-sacrifice of low priority, and supports the fairness of BE traffics. Although the cost of the fairness is the performance decrease (delay and throughput) of other higher BE classes, the QoS for all BE traffics can be guaranteed.
- 2). The average queuing delay ratio can converge to a constant value as we set before. This illustrates the validity of the FBPS algorithm. Meanwhile, the controller presents a better dynamic performance, i.e. setting time and overshoots which is accordant to the theory design in Section 2.3.
- 3). It is worth mention that the system is always stable although the arriving rate of BE 1 and BE 2 keeping step changes. This proves again that FBPS has a great robustness because of the feedback scheme.

4. Conclusion

As the consumer demands for multimedia applications of Ethernet have been huge increased which draws higher requests in the network bandwidth and quality of service (QoS), AVB has been regarded as the feasible technology for the next generation. It is completely compatible with the existing Ethernet scheme. At the same time, by the guarantee of bandwidth, latency and time synchronization, Ethernet AVB provides perfect QoS to support different kinds of multimedia applications. Different with other researches which mainly focus on the SR traffics, we try to find an approach to support the QoS of BE traffics. The feedback based probability selection algorithm is proposed in this paper to realize the proportional delay differentiation in BE traffics, and the experiments show the validity and robustness. On one hand, a desired fixed delay ratio between the BE traffic is differentiated. On the other hand, even the lowest priority traffics still have the chance to be transmitted, which can prevent the over-sacrifice of low priorities.

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