An Integrative Scheme of Differentiated Services base on Proportional Delay Differentiation

Jih-Hsin Ho*, Wen-Shyang Hwang, Ce-Kuen Shieh ***

**Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan, R.O.C.*

***Department of Electrical Engineering, National Kaohsiung University of Applied Science, Kaohsiung, Taiwan, R.O.C.*

E-mail: hjsin@kungsrv.ee.ncku.edu.tw wshwang@mail.ee.kuas.edu.tw

Abstract

This paper proposes an integrative scheme of Differentiated Service (DiffServ) for the IP-based network. In the scheme, Quality of Service (QoS) is ranked according to the level of both the queuing delay and the drop precedence that base on the relative differentiated service; it doesn't take the resource reservation problem into consideration for making its implementation more simple and flexible.

In this paper we will proposes an implemented architecture including Edge Routers and Core Routers, and the PHB (Per-Hop-Behavior) architecture of the routers are generalized. We adopt ERED (Extended Random Early Discard) mechanism for drop precedence and using proportional delay differentiation for queuing delay. In the proportional delay differentiation topic, we propose a new WTP (Waiting Time Priority)-Like algorithm. Besides, a new Stochastic Petri Net model of the PHB model is given, and the performance of whole implemented PHB architecture is analyzed too.

Ⅰ. Introduction

So far there are two approaches for achieving end-to-end quality of service (QoS) in IP-based network: Integrated Service (IntServ) and Differentiated Service (DiffServ) [1], where IntServ is more complex and less scalable than DiffServ. Over the past years, there has been an amount of research studying in the field of DiffServ field that is worth studying.

Today's Internet comprises of multiple interconnected domains. Each domain is constructed by core routers in the insider, and through edge (boundary) node that include Ingress Router and Egress Router. A DiffServ domain scenario is shown as in Fig.1. Before entering a DiffServ domain, the different data flows are aggregated by classifying and traffic conditioners in the edge router. Finally, packet is assigned a Differentiated Service Code Point (DSCP) by the marker for mapping a small number of Per Hop Behaviors (PHBs). Afterward, the data packet is transferred to core routers.

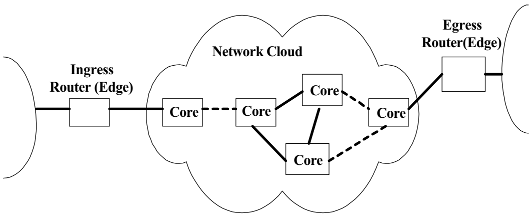

Fig.1. DiffServ domain scenario

Core routers process packets only based on PHBs that encoded in DSCP of the packet header. Currently, The Internet Engineering Task Force (IETF) has defined one class for Expedited Forwarding (EF) [1] and four classes for Assured Forwarding (AF) [2].

Currently, the AF PHB [2] defined by IETF specifies four traffic classes with three- drop precedence levels (or three colors) within each class. There are twelve DSCPs for AF class. Within an AF class, there are three colors to choice to mark as green, yellow, and red, where green has the lowest drop probability and red has the highest drop probability. assured service", it is expected that the scheme can be used for supporting differentiated services through an

In this paper we will proposes an implemented architecture including the Edge Routers and Core Routers. In Edge Router and Core Router PHB architecture will be generalized. We will adopt ERED (Extended Random Early Discard) mechanism for the drop precedence level and using proportional delay differentiation for queuing delay. In the proportional delay differentiation, we propose a new WTP (Waiting Time Priority)-Like algorithm, and an stochastic Petri Net models of the PHB model. The performance of the whole PHB implemented architecture is analyzed too.

This paper is organized as follows: Section II proposed the integrative scheme of DiffServ, together with the implemented architecture. An stochastic Petri Net models of PHB model is constructed in Section III. The performance analysis of the model is discussed in Section IV; finally a conclusion is given in Section V.

Ⅱ. Implemented Architecture

In this section, an integrative scheme of differentiated services will be presented, in which DiffServ implemented architecture divided into two modules: DiffServ (DS) classifier module and DiffServ (DS) queuing discipline module. The DS implemented architecture is shown in Fig.2. Whole DiffServ domain scenario has been discussed in the above chapter. Within this domain, the edge routers contain two modules but the core routers only contain DS queuing discipline module.

A. DS Classifier Module

This module is responsible to classify any incoming data flows or data packets in the edge routers to find the corresponding traffic profiles with a DSCP for them.

The DS classifier module classifies a data packet using the parameters of burst rate and burst size derived from the packet's characteristic corresponding the Service Level Agreement (SLA) or Profile-List through a token bucket mechanism. If the packet's traffic rate is within the SLA, the packet is called "In-of-Profile"; otherwise, it is called "Out-of-Profile". The in-of-profile packets are marked with DSCP bits in the packet's IP header, and the packets are transmitted to the DS queuing discipline module. The out-of-profile packets are handled by policer.

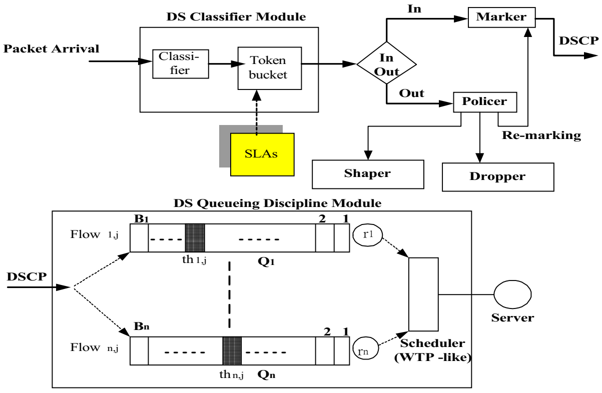

Fig.2. DiffServ (DS) implemented architecture

B. DS Queuing Discipline Module

DS queuing discipline module is named PHB module too. A more general AF PHB will be introduced. In the Fig.2, there are n queues, and they are numbered with the priorities of queuing delay level. Let Q_i denote the queue with level i, whose buffer size is Bi. The Q_1 has highest scheduling priority and Q_n has the lowest scheduling priority. In each Q_i, there are several drop precedence levels ranking j. The ranking $j+1$ has lower loss precedence than ranking j. Let $Flowi,j$ denote the traffic aggregate with queuing delay level i and drop precedence ranking j.

B.1 Drop Precedence Ranking

Within an AF class, a packet is marked as one of three colors — *green, yellow, and red* — where *green* has the lowest drop probability and *red* has the highest drop probability. Here we use ERED (Extended RED) for service differentiated of different colors. ERED scheme has three parameters: minimum threshold, maximum threshold and drop probability for three- color packets. Formally, if the queue length is n at the arrival of a packet, the probability of the packet to be accepted into the queue is

$$\alpha(n,Qi) = p_G\alpha^G(n,Qi) + p_Y\alpha^Y(n,Qi) + p_R\alpha^R(n,Qi) \qquad (1)$$

Where p_G is the probability that a packet is an *green* packet, p_Y is the probability that a packet is an yellow packet and p_R is the probability that a packet is an *red* packet.

$$p_G + p_Y + p_R = 1 \qquad (2)$$

Where $\alpha^G(n,Qi)$, $\alpha^Y(n,Qi)$ and $\alpha^R(n,Qi)$ respectively are the probabilities of an *green*, *yellow* and *red* packet to be accepted into the queue Qi. Base on the properties of ERED, we have

$$\begin{bmatrix} \alpha^G(n,Qi) = 1, n \le \min^G \\ \alpha^Y(n,Qi) = 1, n \le \min^Y \\ \alpha^R(n,Qi) = 1, n \le \min^R \\ \alpha^G(n,Qi) = 0, \max^G < n \\ \alpha^Y(n,Qi) = 0, \min^Y < n \\ \alpha^R(n,Qi) = 0, \min^R < n \\ \alpha^G(n,Qi) = 1 - \frac{p^G(n-\min^G)}{\max^G - \min^G}, \min^G < n < \max^G \\ \alpha^Y(n,Qi) = 1 - \frac{p^Y(n-\min^Y)}{\max^Y - \min^Y}, \min^Y < n < \max^Y \\ \alpha^R(n,Qi) = 1 - \frac{p^R(n-\min^R)}{\max^R - \min^R}, \min^R < n < \max^R \end{bmatrix} \qquad (3)$$

B.2 Queuing Delay Level

The proportional delay differentiation service model first is proposed in [3][4] by Dovrolis. The model has two objectives. First, it should provide consistent service differentiation between classes. Second, it should allow the quality spacing by network operator. So this model has advantages of predictable and controllable in the differentiated service. Dovrolis proposed an algorithm called the Waiting-Time Priority (WTP) scheduler, is based on Kleinrock's Time-Dependent Priority algorithm [5].

We suppose that each router has a pre-specified number of delay classes (N=4) and provides a set of control variables r_i, where $r_4 < r_3 < r_2 < r_1$, queues of different delay classes are served such that the average delay experienced by packets in a delay class is inversely proportional to the control variable. That is

$$\frac{\overline{d_i}(t)}{\overline{d_j}(t)} = \frac{r_j}{r_i} \qquad (4)$$

In other word, if $\overline{d_i}(t)$ is the average delay for class i at time t, then the goal is to achieve

$$\left|\overline{d_i}(t) r_i - \overline{d_j}(t) r_j\right| \to 0 \qquad (5)$$

In the WTP scheduler, the priority of a packet increases proportionally with its waiting time. Hence, when a router needs to select a packet for transmission at time t, it selects a queue j for transmission such that

$$j \leftarrow \arg\max_i \{w_i(t) \times r_i\} \qquad (6)$$

In our scheduler called WTP-Like scheduler, the priority of packet increases proportionally with its delay time. The delay time at time t $d_i(t)$ which is transferred another formula by Little's theorem and formula (4) as shown in (7), where $B_i(t)$ is queue size and $\lambda_i(t)$ is arrival rate for each queue i.

$$d_i(t) = B_i(t)/\lambda_i(t) = k/r_i \qquad (7)$$

We improved the WTP scheduling reducing the computation of average waiting time instead of average delay time. The implementation for WTP-Like algorithm is shown in Fig. 3. In **De_queue** procedure, it selects a queue j for transmission such that

$$j \leftarrow \arg\max_i \{B_i(t) \cdot r_i / \lambda_i(t)\} \qquad (8)$$

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En_queue Procedure ( )
{$B_i(t) \leftarrow B_i(t)$ +1}; /* for each corresponding delay class*/
De_queue Procedure ( )
{ $j = max_i$ { $B_i(t)$ $r_i$ / $\lambda_i(t)$}};
  transmit from delay class $j$;     /* select a packet to
                                      transmit from a queue */
  $B_j(t) \leftarrow B_j(t)$-1; }
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Fig.3. WTP-Like algorithm

III. Stochastic Petri Net Models

Generally speaking, the DS queuing discipline module (AF PHB) can be modeled with Stochastic Petri Net (SPN) models. Base on some basic knowledge on SPN, Fig.4 is the SPN model of DS queuing discipline module. The transitions and the places in Fig.4 are described as follows.

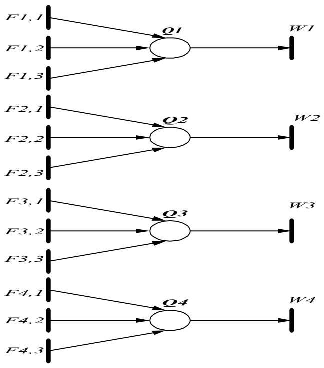

Fig.4. The Stochastic Petri Net model of AF PHB

In the SPN model, the probability associated with transition *Fi,j* is $\sigma i,j$, so that the actually firing rate of *Fi,j* is $\sigma i,j \times \lambda^j(Qi)$. And the probability associated with transition *Wi* is ξi, so that the actually firing rate of *Wi* is $\xi i \times \mu_i$. Here $\sigma i,j$ describes the ERED drop control policy in the condition of (3). And ξi describes the proportional delay differentiation service, which refers to WTP-Like algorithm as

$$\xi_i(Q_i) = \begin{cases} 1, i \leftarrow \arg\max_i \{B_i(t) \cdot r_i / \lambda_i(t)\} \\ 0, otherwise \end{cases} \qquad (9)$$

Ⅳ. Performance Analysis

Base on the SPN of AF PHB in the Fig.4, the number of packet in the four queues is a Markov process with state space $\boldsymbol{S}$={(0,Q1),(1,Q1),…….,(K,Q1),(0,Q2),(1,Q2)…… ,(K,Q2), (0,Q3),(1,Q3)……,(K,Q3),(0,Q4),(1,Q4)……., (K,Q4)}, where 0,1,2,….,K denote the queue length and K is the size of the queue. The above Markov chain with large state (│S│= 4 (K+1)) and multiple dimensions is a difficult problem. One of the possible ways accepts an approximate approach base on the analysis with one-dimension models. Since the SPN model in Fig.4 has been refined, each structural independent part is a submodels.

The state transition diagram of approximate approach is shown in Fig.5.

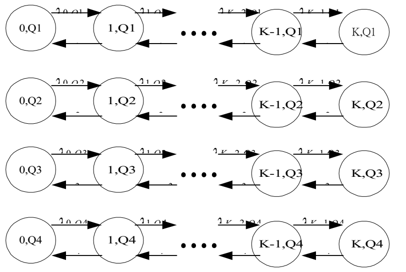

Fig.5. The State Transition Diagram of Approximate Approach

Since an ERED queue management scheme is assumed in our model. Some packets will be dropped and do not influence the state of the four queues. In ERED, when the queue length is n, the actual arrival rate of *Green* packets, *Yellow* packets, *Red* packets and all packets to four queues are

$$\begin{aligned} \lambda^G(n,Qi) &= \lambda_{Qi}\alpha^G(n,Qi) \\ \lambda^Y(n,Qi) &= \lambda_{Qi}\alpha^Y(n,Qi) \\ \lambda^R(n,Qi) &= \lambda_{Qi}\alpha^R(n,Qi) \\ \lambda(n,Qi) &= \lambda_{Qi}\alpha(n,Qi) \end{aligned} \qquad (10)$$

where we assume the packets arrive in the four queues according to a Poisson process with rate λ_{Qi} respectively. $\alpha^G(n,Qi)$, $\alpha^Y(n,Qi)$ and $\alpha^R(n,Qi)$ are given by equation (3). Then, when the queue length is n, the actual packet arrival rate (i.e. arrivals which will not be dropped before entering the four queues) is

$$\lambda_{n,Qi} = p_G\lambda^G(n,Qi) + p_Y\lambda^Y(n,Qi) + p_R\lambda^R(n,Qi) \qquad (11)$$

One challenge in our analysis is the relationship among submodels. We must to solve the mean service rate μ_i in steady (statistical- equilibrium) state.

The steady-state distribution, $\pi(s)$, $s\in \boldsymbol{S}$, is determined by the following balance equations:

$$\vec{\pi}(s)A = 0, \sum \pi(s) = 1 \qquad (12)$$

where

$$\vec{\pi}(s) = [\pi(0,Qi), \pi(1,Qi), \pi(2,Qi), \ldots., \pi(K,Qi)] \qquad (13)$$

$$A = \begin{bmatrix} -\lambda_{0,Qi} & \lambda_{0,Qi} & 0 & . & . & 0 \\ \mu_i & -(\lambda_{1,Qi}+\mu_i) & \lambda_{1,Qi} & 0 & . & 0 \\ . & . & . & . & . & . \\ 0 & . & . & \mu_i & -(\lambda_{K-1,Qi}+\mu_i) & \lambda_{K-1,Qi} \\ 0 & 0 & 0 & 0 & \mu_i & -\mu_i \end{bmatrix}_{(K+1)\times(K+1)} \qquad (14)$$

Let $loss^G{}_{Qi}$, $loss^Y{}_{Qi}$ and $loss^R{}_{Qi}$ be the drop probability for *Green* packets, *Yellow* packets and *Red* packets in each *Qi*, respectively. Using the **PASTA** (Poisson arrival see time averages) property [6] we have:

$$\begin{aligned} loss^G_{Qi} &= 1 - \sum\nolimits_{n=0}^{K} \alpha^G(n,Qi)\pi(n,Qi) \\ loss^Y_{Qi} &= 1 - \sum\nolimits_{n=0}^{K} \alpha^Y(n,Qi)\pi(n,Qi) \\ loss^R_{Qi} &= 1 - \sum\nolimits_{n=0}^{K} \alpha^R(n,Qi)\pi(n,Qi) \end{aligned} \qquad (15)$$

We can also get the effective throughput of packets as:

$$\begin{aligned} eff^G_{Qi} &= \lambda_{Qi} p^G \sum\nolimits_{n=0}^{K} \alpha^G(n,Qi)\pi(n,Qi) \\ eff^Y_{Qi} &= \lambda_{Qi} p^Y \sum\nolimits_{n=0}^{K} \alpha^Y(n,Qi)\pi(n,Qi) \\ eff^G_{Qi} &= \lambda_{Qi} p^R \sum\nolimits_{n=0}^{K} \alpha^R(n,Qi)\pi(n,Qi) \\ eff_{Qi} &= \lambda_{Qi} \sum\nolimits_{n=0}^{K} \alpha(n,Qi)\pi(n,Qi) \end{aligned} \qquad (16)$$

Applying Little's theorem, we have the mean delay of the queue Qi ($1\leq i \leq 4$), respectively

$$E(di) = \sum_{n=0}^{K} n\pi(n,Qi)/eff_{Qi} \qquad (17)$$

V. Conclusions

In this paper, we have presented an integrative scheme of Differentiated Service for the IP-based network. The scheme takes the drop precedence ranking and the queuing delay level into consideration. In queuing delay mechanism, we have proposed a WTP-Like algorithm to reduce the computation of average waiting time instead of average delay time. Using the ERED as the queue management policy. Base on stochastic Petri Net model, we obtained many approximate approach solutions such as loss probability, effective throughput and mean delay of the queue. Only how to obtain the mean service rate in each queue need to be further studied.

Our analysis is based on AF PHB (12 classes) in RFC 2597 and it can be easily extended to general PHB (more than 12 classes). Future work includes simulation of our scheme under both Poisson and self-similar arrivals and modeling of arrival traffic for both TCP and UDP.

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