Workshop on Computer Networks

An Adjustable QoS Scheduler for Integrated Services with Traffic Correlation

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***Abstract*- In this paper, the design of a QoS scheduling scheme for the integrated services is proposed by considering the correlation property of the arriving traffic. The basic concept of the Weighted Fair Queueing (WFQ) is adopted in the proposed scheme. However, the correlation property of the traffic stream is applied as the heuristic to adjust the share weight factors of each traffic type dynamically. The Auto Regressive Integrated Moving Average (ARIMA) model is applied in this paper to characterize the correlation property. And the share weight factors are derived from the parameters of the AR part and MA part. Experimental simulations are performed to illustrate the effectiveness of the proposed scheme. In addition to comparing the performance of each service types, we also define a fair play parameter (FPP) to examine the fairness index of the proposed scheme. The experimental results indicate that the fairness among service classes can be achieved, especially when link capacity is limited.**

I. INTRODUCTION

As various kinds of services have been deployed in internet, one of the most important issues is to effectively arrange the network resources so that different network services can meet their quality requirements. In order to achieve the quality of services (QoS), Internet Engineer Task Force (IETF) formed a working group in early 1990 to study on this issue. This working group has defined the new resource allocation architecture and the new service models for the needs of different service classes.

The Integrated Service Working group proposed two new service models [1]: the Guaranteed service and the Controlled-load service models. The Guaranteed service model has been designed for the applications of requiring absolute guarantees on delay. The Controlled-load service provides a less firm guarantee. The Integrated Service architecture is a kind of per-flow resource reservation, thus, it mainly provides an end-to-end QoS guarantee manner. To achieve resource assurance for an application, it must make a reservation before it starts to transmit traffic into the network. And it is noted that the efficiency and the fairness of the packet scheduling is also a critical point for the provisioning of QoS.

Several packet-scheduling methods have been proposed [2, 3]. Among them, the Weighted Fair Queueing (WFQ) method [2] segregates the traffic into a number of queues to provide bandwidth allocation. And the pre-assigned weight for each queue is given. The weight represents the percentage of the queue being served by the scheduler when comparing to the other queues. If a queue is empty, the other queues will share all available bandwidth according to their respective weights. Although WFQ is the most popular algorithm used in today's internet, for bursty traffics the hard delay bounds of WFQ are very conservative as they reflect the worst case of traffic scenario; typically the actually delay distributions are far below the bounds [4]. Thus, as a Guaranteed Rate (GR) scheduler, WFQ is insensitive and unfair to distribute the instantaneously excess bandwidth being distributed. The Differentiated Multi-layer Gated Frame Queueing (DMGFQ) method [3] allows a late-arrived user to gain its agreement bandwidth. In other words, the residual bandwidth released from other terminated connections is fairly shared among other active connections to their pre-determined weights. Because the DMGFQ mainly supports differentiated services (that is, the service classification is based on per-class mechanism), it cannot provide Guaranteed service in the bandwidth allocation. So the DMGFQ is still insufficient for the needs in integrated service.

Basically, internet traffic has self-similar and correlation properties [5, 6]. And the correlation property can be regarded as the heuristic for the packet scheduling. Therefore, in this paper, a novel packet-scheduling scheme based on the traffic correlation is proposed. In [6], the traffic behavior of internet has been characterized by using the Auto Regressive Integrated Moving Average (ARIMA) model. Autoregressive model describes the current observation values at present period, which is influenced by the former periods. And Moving Average model estimates the relationship between present observation value and the former periods' interference. Based on the ARIMA models, we determine the correlation-based share weight factors for each traffic flow. This decision method is quit different to the other proposed scheduling algorithms, such as WFQ and DMGFQ. ARIMA model can be applied to predict the arriving traffic according to the correlation properties of the model. Thus, by utilizing these characteristics can lead to the development of an effective scheduling scheme without the disadvantages in WFQ and DMGFQ. The fair play parameter (FPP) is also defined to examine the fairness of the bandwidth allocated and the bandwidth required of each service type.

This paper is organized as follows. The basic principle of ARIMA modeling for internet traffic is introduced in the following section. The proposed correlation based bandwidth allocation scheme is described in section III; and the performance of the proposed scheme is examined through experimental examples in section IV. And the conclusion is provided in the last section.

II. CORRELATION ANALYSIS BY USING ARIMA

Time series are a set of the continuous observation values that appear in a sequence of time, or more precisely, a set of sequencing observation values that produced from time-continuous observation for a dynamic system. In this paper, the time domain analysis method is applied. Its main idea is to utilize autocorrelation function and cross correlation function for the establishment of Stochastic Time Series. In network behavior, the traffic characteristics are very complex. We can only use empirical information to identify the model parameters. Box and Jenkins proposed a try and error recursion method, and the steps are shown in Figure 1 [7].

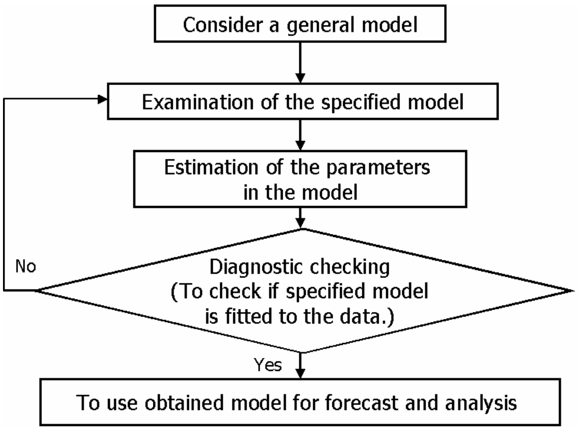

Figure 1. Process of model establishment

Basically, an ARIMA model can be applied to describe both the autoregressive (AR) and moving average (MA) characteristics of a non-stationary time series [8, 9]. A general ARIMA model of a non-stationary time series Z_t, denoted as $ARIMA(p,d,q)$, can be stated as following,

$$\phi_p(B)(1-B)^d Z_t = C + \theta_q(B)a_t \quad \text{...........(1)}$$

Where $\phi_p(B)$ and $\theta_q(B)$ represent the AR and MA parts respectively; B is the back shift operator ($B^i Z_t = Z_{t-i}$); and a_t is the white noise process (i.e. i.i.d innovation process).

It is noted that d is the difference order to make a stable trend of the time series (e.g. d =1 implies a linear trend of the time series). The process of finding the traffic models is as follows. Basically, the recursion method can be divided into the following steps:

(a) Adopt a general model in accordance with the interrelation between theory foundation and actual problem.
(b) Use obtained data and the understanding of the system to conjecture a suitable model and conform to principle of parsimony. This kind of model is called a tentative model.
(c) Use statistical theorem to estimate parameters of the tentative model.
(d) Diagnose and check the model obtained in the above steps to check if it is applicable to real application. It may return to (a) if it is necessary.

In order to determine a suitable model for the time series, the parameters of AR and MA parts shall be estimated through the ACF (Auto Correlation Factor) and PACF (Partial ACF) test. We use the following functions to determine the AR and MA models degrees:

■ Sample ACF (Sample Autocorrelation Function)---

$$\hat{\rho}_k = \frac{\sum_{t=1}^{n-k} (Z_t - \overline{Z})(Z_{t+k} - \overline{Z})}{\sum_{t=1}^{n} (Z_t - \overline{Z})^2} \text{…………..…..(2)}$$

The set $(\hat{\rho}_k, k = 1, 2, ...)$ is called the sample autocorrelation function (SACF) of Z_t. The lag k SACF $\hat{\rho}_k$ is an estimate of the lag k autocorrelation of a stationary time series $\{ Z_t \}$.

■ Sample PACF (Partial Autocorrelation Function)---

$$\hat{\phi}_{11} = \rho_1 \text{……………………………….(3)}$$

$$\hat{\phi}_{kk} = \frac{\begin{vmatrix} 1 & \rho_1 & \rho_2 & \cdots & \rho_{k-2} & \rho_1 \\ \rho_1 & 1 & \rho_1 & \cdots & \rho_{k-3} & \rho_1 \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ \rho_{k-1} & \rho_{k-2} & \rho_{k-3} & \cdots & \rho_1 & \rho_k \end{vmatrix}}{\begin{vmatrix} 1 & \rho_1 & \rho_2 & \cdots & \rho_{k-1} \\ \rho_1 & 1 & \rho_1 & \cdots & \rho_{k-2} \\ \vdots & \vdots & \vdots & & \vdots \\ \rho_{k-1} & \rho_{k-2} & \rho_{k-3} & \cdots & \rho_1 \end{vmatrix}} \text{…………….(4)}$$

The software tool, called “the SCA Statistical System”, is applied to assist the above calculations. When the values of p and q are both not zero, only using ACF and PACF can’t properly judge the model type. At this time, the EACF (Extended Autocorrelation Function) shall be performed. The procedures of EACF formula are not shown here because of its complexity, but the EACF function is also included in the software.

III. THE CORRELATION BASED SCHEDULING SCHEME

We can image a situation that the Guaranteed service is assumed to be the most likely assigned service type in the network and these types always exceed the agreement, then, the highest priority traffic types will occupy all the resource. An effective approach is to allocate the most available bandwidth to the Guaranteed service when the scheduler suffers the Guaranteed service without exceeding the agreement, and to distribute just comfortable bandwidth to the exceeding components in the Guaranteed service and the remainder service types when it meets both of them. Figure 2 shows the basic operation of the scheduler. When the packet arrives, the scheduler differentiates the service types of the arrived packet. The Guaranteed and Controlled-load services’ traffic can use the allowable bandwidth, which pre-determined in the agreement. If the traffic of each type exceeds the allowable bandwidth, the exceeded part will be backlogged in the waiting queue (named as the G-queue and C-queue). And further, the traffic in the G-queue will process with the C-queue in accordance with share weight factor individually. If there is any packet fail to be handled by scheduler because of bandwidth limitation, they will be queued until next processing time.

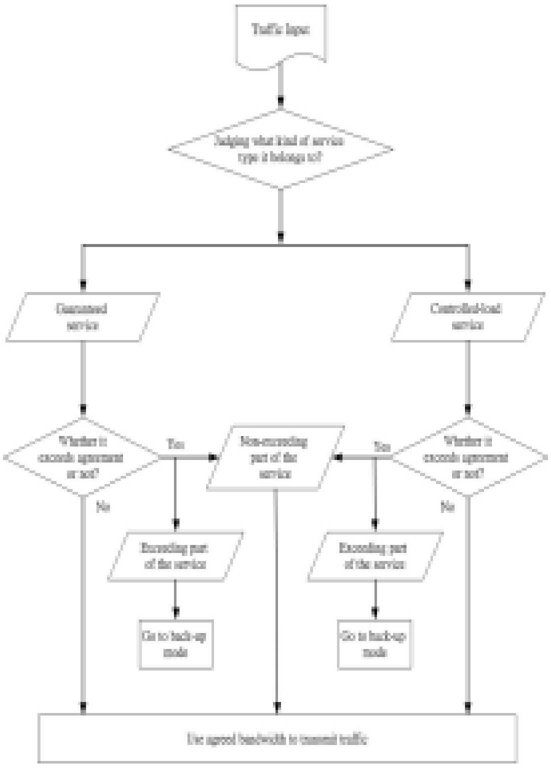

Figure 2. Scheduler logic operation

As indicated in section II, the ARIMA model is applied to characterize the traffic behavior of each service type. The basic concept of the scheme is to intuitionally use the inspiring of the ARIMA model. It only considers the AR parameter and MA parameter and tends to visualize them. The definitions of notations to calculate share weight factor are as follows.

$ARIMA(x_j^i, z_j^i, y_j^i)$: Represent the model of the arriving traffic j, its service type may be Guaranteed or Controlled-load service and the superscript i indicates the service type of j_{th} traffic flow.

$SF_j^i[n]$: The share weight factor of traffic flow j of the service type i at the n_{th} arrival.

$A_j^i[n]$: The practical data volume of the n_{th} arrival of the j_{th} traffic flow of service type i which is queued in the traffic buffer.

Since the parameter x_j^i reflects the influence of the current data affected by the past x_j^i period data, we consider this effect in (5). And y_j^i indicates how the current data influenced by the past y_j^i period interference, we reflect it in (6). These two properties are applied to create the definition of share weight factors. We derive the following formulas to calculate the share weight factor:

$$AR_j^i = \frac{A_j^i[n] + A_j^i[n-1] + \ldots + A_j^i[n - x_j^i]}{(x_j^i + 1)} \quad \ldots\ldots(5)$$

$$MA_j^i = AR_j^i + \ldots + (A_j^i[n] - A_j^i[n - y_j^i]) \quad \ldots\ldots\ldots(6)$$

$$SF_j^i[n] = \frac{MA_j^i}{\sum_{i,j} MA_j^i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

We must check the MA_j^i of each service type whether it is minus or not. If it is positive, we just use (7) to calculate the normalized share weight factors so that we can let the sum all service types' share weight factor be conformed to 1. And if there is any MA_j^i being minus (the situation which is seldom arisen in our procedure except for the large standard deviation occurring in the data series), we should add each MA_j^i a quantity of $(n \times Average\ of\ its\ traffic\ series)$, where $n = 1, \ldots, k$. n is chosen to let the adding result of all MA_j^is to be positive. Then, we can use (7) to calculate the normalized share weight factors.

In [10], a fairness index was defined to judge the fairness level could be achieved. It is the index of utilization within a link. In this paper, we create a performance parameter, named Fair Play Parameter (FPP), to examine the fairness of each traffic flow in the link. FPP is defined as:

$$(FPP)^i_j = \frac{\sum_t \frac{B^i_j(t)}{M^i_j(t)}}{\sum t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where

$(FPP)^i_j$: The Fair Play Parameter for the j_{th} traffic flow of service type i.

$B^i_j(t)$: The actually transmitted traffic for the j_{th} traffic flow of service type i in each processing time t.

$M^i_j(t)$: The agreed bandwidth for the j_{th} traffic flow of i service type.

The FPP can express the fairness of each service type individually. Based on the definition provided in (8), it is fairer for each service type if the value of FPP is closer to 1.

IV. EXPERIMENTAL EXAMPLES

In this paper, two series of traffic are collected from a specific network as the traffic sources for experiment. These two traffic sources are treated as the Guaranteed service and the Controlled load service, respectively, during the simulation. The following assumptions are considered:

- At each processing time both of two service types' traffic, if they arrive, enter into scheduler simultaneously.
- The packets in output buffer are not in sequence. The buffer only judges whether the content exceeds an upper bound or not.
- The packets processing time is ignored.

During the experiment, the guarantee bandwidth of Guaranteed service type traffic is set as 279.36 Mbytes (it is obtained by Guaranteed traffic data series' average) and the maximum transmission of Controlled-load service type traffic is 32.02 Mbytes (it is obtained by Controlled-load traffic data series' average adding one fourth standard deviation value). Obviously guarantee bandwidth is larger than maximum transmission bandwidth. This is because Guaranteed service requires absolute guarantees on delay. The main goals carried out in the simulation of this paper are:

- To prevent the guaranteed service traffic of grabbing over-agreed bandwidth from other lower priority service.
- With the cooperation of the share weight factors and the ARIMA model, we can fairly allocate the residual bandwidth between to all service types.

Fig. 3 illustrates the logic scheme of our simulation architecture. It notes that the share weight factor calculator will use the information, which obtains from the traffic buffer (that is, ARIMA model form) to dynamically determine the weighting of each queue. In practice, empirical data at least need a quantity of more than 50 when estimating the ARIMA model. So we calculate the share weight factor every 200 arrivals (these packets are queued in the traffic buffer) and refresh the share weight factor about each queue (G-queues and C-queues) with an interval of 200 arrivals.

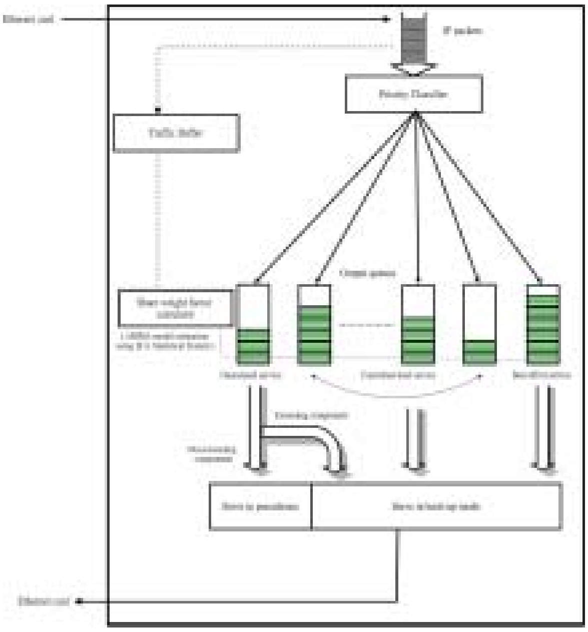

Figure 3 Logical architecture

The simulation results of the real-time transmission rate for each service type shown in Figure 4. In this paper, traffic is defined as real-time transmitted if it can be transmitted before the scheduling process of the next arrival. It is noted that the Guaranteed service has a higher real-time transmission rate than the Controlled-load service. The reason is that the Guaranteed service requires the absolute assurance on delay. And in the Figure 5, it shows that the portion of traffic transmitted by the residual bandwidth, which shows that the Guaranteed service has lower transmission ratio than the Controlled-load (while the link capacity is far larger than the sum of two types' guarantee bandwidth). The occurrence of this phenomenon results from that the greater parts of traffic belonging to Guaranteed service are transmitted by the bandwidth allocated at the beginning of time slot.

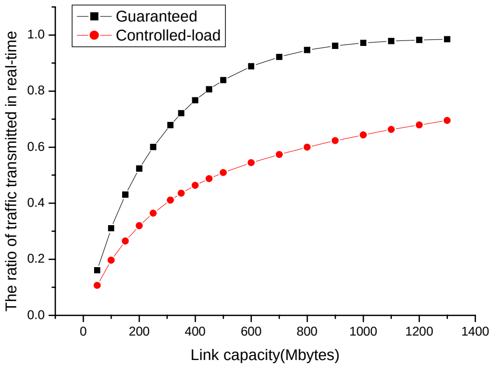

Figure 4. The amount of traffic transmitted in real-time

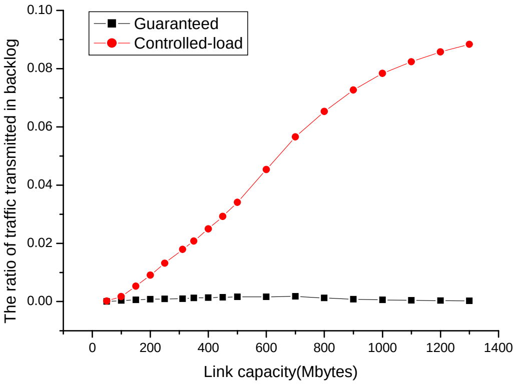

Figure 5. The ratio of traffic transmitted in backlog

In Figure 6, the ratio of Guaranteed service's traffic transmitted in delay increases with the declined link capacity. And while link capacity decreases to 300 Mbytes, the ratio of traffic transmitted in delay starts to declines. This is due to the output buffer of Guaranteed service is going to be crammed, and some traffic, which originally should be transmitted in delay, are discarded. Thus, loss rate follows to increase (see Figure 7). The same circumstances occur in Controlled-load service. It is noted that the loss rate of the Guaranteed traffic is much higher than which of the Controlled-load traffic when the link capacity is low. The reason is that the Guaranteed traffic is assumed as delay sensitive and the buffer allocated to the Guaranteed traffic is much smaller than that allocated to the Controlled-load traffic during the simulation (80000 Mbytes and 85000 Mbytes, respectively).

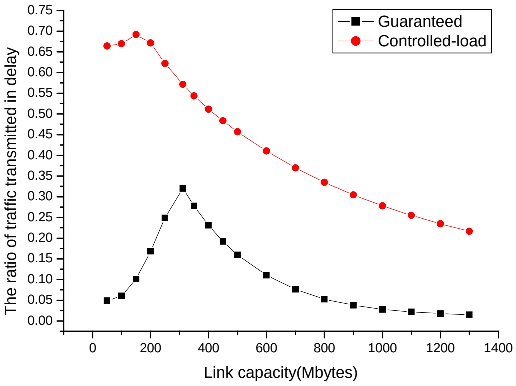

Figure 6. The ratio of traffic transmitted in delay

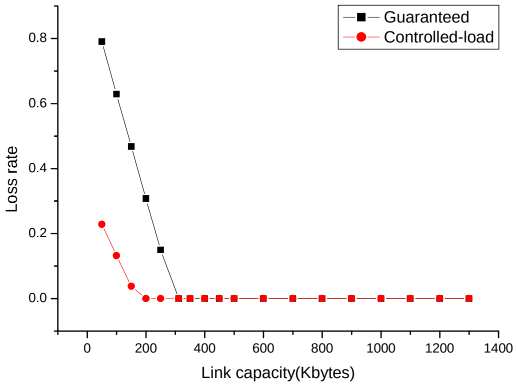

Figure 7. Loss rate

Figure 8 illustrates the Fair Play Parameter (FPP) of each service type. It is noted, according to (8); if the actual transmitted traffic is less than the agreed bandwidth, the value of FPP will be smaller than 1. So the value of FPP will be much smaller than 1 when the link capacities are high. In contrast with Figure 4, we can see that in Figure 4 when link capacity exceeds 600 Mbytes, the real-time transmission rate of Guaranteed service is approach to be stable and at the same time the Controlled-load service’s real-time transmission rate is still in raising. Recall this phenomenon to Figure 8 we can find that because of this phenomenon, the value of the FPP of Controlled-load service gets greater than the Guaranteed service. Thus, the FPP of Controlled-load service is higher than the Guaranteed service, when link capacity exceeds 600 Mbytes. As the link capacity increasing, most of the Guaranteed traffic can be transmitted in real time and the real-time transmission ratio is approaching to be stable, and at the same time, the real-time transmission ratio of the Controlled-load traffic is still increasing (as indicated in Figure 4). Thus, the bandwidth is much more over allocated to the Guaranteed traffic than the Controlled-load traffic when the link capacity exceeds 600 Mbytes, and therefore, the FPP value of the Controlled-load traffic is slightly higher than that of the Guaranteed traffic.

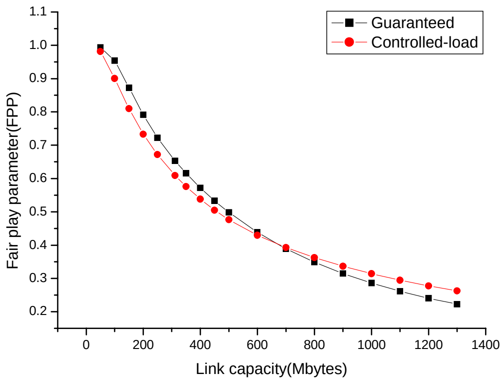

Figure 8. Fair play parameter

V. CONCLUSIONS

In this paper, we propose an adaptive scheme of QoS scheduling by using the heuristic of traffic correlation. The ARIMA model is applied to capture the correlation characteristics of the internet traffic. And the parameters of the AR part and MA part are used to derive the share weight factors of each service. The share weight factors are then applied to adjust the efficiency and the fairness of the bandwidth arrangement when the arrival traffic exceeds its allowable bandwidth. Our experimental results illustrates that the proposed scheme can effectively schedule QoS traffic in a fair manner. However, we only consider the autocorrelation within the same traffic stream. If the correlation properties among different traffic streams can be studied well, it will be very helpful in the allocation of network resource for the multiple traffic streams that sharing finite bandwidth.

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