Bandwidth Allocation in Virtual Network Based on Traffic Prediction

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Abstract—For future internet, network virtualization provides the feasibility of running multiple routing architectures on a shared physical infrastructure. This paper presents the design and evaluation of a bandwidth allocation algorithm based on multi-commodity flow problem solver, which integrated with a traffic predictor. The basic idea of our design is that some failure in the MFP computation implies that one or more links do not have enough available capacity, which violates the linear constraints on the commodities for each link when modeling MFP. To avoid producing bottleneck links, we employed traffic predictor. On one hand, MFP solver makes better resource utilization by making use of the thin pieces of available bandwidth, by which the virtual network can accept more service requests. On the other hand, the traffic predictor adjusts the link with the largest occupation (bottleneck link) by checking the traffic rate of a user link and adjusting the reserved bandwidth based on the Forecasting of the traffic history. Then we present the results of performance comparisons of the predictor-integrated algorithm and the allocation algorithm only by Solving MFP. The comparisons are based on the mean packet delay, the variance of the packet delay, and the buffer requirements. Our performance tests show that predictor-integrated algorithm works better than the allocation algorithm only by Solving MFP in terms of the three metrics listed above.

Keywords— bandwidth management; traffic management; virtual network

I. INTRODUCTION

Network virtualization provides the feasibility of running multiple routing architectures on a shared physical infrastructure[1,2,3]. In a virtual network, bandwidth guaranteed multi-path routing as a service can be provided with the support of programmable router[4].

Using virtual network (VN) over public networks such as Internet, service providers can package and ship user data

from multiple access points to the corresponding destinations in a safe and efficient way[5]. Various protocols have emerged to enhance the integrity of the confidential information transferred across public networks. The Internet has also been proven to be cheap and effective in delivering information all over the world [6,7].

In a virtual network, route computing with bandwidth allocation can be considered as a resource mapping problem, which can be reduced to the Multi-commodity Flow Problem (MFP) and solved in polynomial time[5,8]. However, in certain case, the VN providers must also provide bandwidth guarantees to users. Let us consider a user with two classes of traffic: a traffic stream which has stringent requirements on delay, jitter and packet loss rate; and a best-effort traffic which needs no QoS guarantee. To meet the QoS requirements, the available bandwidth and buffer space is reserved for the first traffic class based on the provisioning policy at the edge of the network (i.e., the access point). The best-effort traffic can take the rest of the resource whenever it is available. Without dynamic bandwidth resizing, each QoS link is reserved with a static bandwidth of b , which is decided by the QoS requirement. To maintain the QoS at an acceptable level, the reserved bandwidth must be significantly larger than the mean of the data rate due to the increase of the traffic. A clever priority-queue based packet dispatcher may make the over-reserved bandwidth available to other data streams, but no QoS guarantee could be made.

VN providers may want to provision the bandwidth and buffer accurately at the start of each user traffic stream. However, the users could not specify their traffic accurately in the service level agreement. Therefore, finer levels of dynamic control to achieve the maximum efficiency need the admission control and traffic provisioning. To make more bandwidth available to QoS traffic, we can resize the QoS link based on the history and predicted future value of the traffic rate. If we could adjust the reserved bandwidth to handle the fluctuation of the incoming traffic rate, the mean of reserved bandwidth will be lower than that of the static provisioning substantially. Link sharing [9] or hose interface [10] allow the VPN providers to share an access link by multiple VPN streams to make a gain from multiplexing. Dynamic link resizing will also help to enhance

multiplexing gain. Other works related to traffic engineering, dynamic resource allocation include [11,12,13].

It is well-known that packet traffic on high-speed links exhibit data characteristics consistent with long-range dependence and self-similarity. To explain the possible mechanisms behind this behavior, various network traffic models have been developed where these features arise as heavy-tailed phenomena. Among QoS services, traffic of singel traffic is expected to be a significant part of the traffic in today and future packet networks. Therefore our paper works on traffic modeling, Forecasting and bandwidth allocation based on single service traffic from O. Rose. [14]. In a bandwidth allocation scheme, accurate predicting of the network load is important. A dynamic bandwidth allocation scheme for VBR traffic based on linear Forecasting was proposed [9]. But recent real traffic measurements show the coexistence of long range and short range dependence in video traffic traces [14]. However, our modeling and network control are considering short range dependence.

One important model with this capability is the On/Off model. It is the view of packet traffic composed of a large number of aggregated streams where each source alternates between an active on state transmitting data and an inactive off-state. The traffic streams generate on average a given mean-rate traffic, they have stationary increments and they are considered statistically independent. So based on experience an On/Off model Forecasting based bandwidth allocation scheme for virtual network is proposed in this paper.

II. TRAFFIC MODELING AND FORECASTING USING ON/OFF MODELS

Let $X_{on}, X_1, X_2, \dots$ be non-negative random variables with distribution F_{on} representing the lengths of on-periods. Similarly let $Y_{off}, Y_1, Y_2, \dots$ be non-negative random variables with distribution F_{off} representing the lengths of off-periods. The X - and Y - sequences are supposed to be independent. For any distribution function F we write $F' = I - F$ for the right tail. [22]

We fix two parameters, α_{on} and α_{off} , such that $1 \leq \alpha_{on} \leq \alpha_{off} < 2$, and assume that

$$F'_{on}(x) = x^{-\alpha_{on}} L_{on}(x) \text{ and } F'_{off}(x) = x^{-\alpha_{off}} L_{off}(x), \quad x \rightarrow \infty,$$

with L_{on}, L_{off} arbitrary functions slowly varying at infinity. Hence both distributions F_{on} and F_{off} have finite mean values μ_{on} and μ_{off} but their variances are infinite. However, thanks to a simple symmetry argument, we can also cover the case $\alpha_{on} > \alpha_{off}$. The case $\alpha_{on} = \alpha_{off}$, for which the on-off process is an alternating renewal process, falls outside of the class of processes we are able to study within the methodology developed here.

We consider the renewal sequence generated by alternating on- and off-periods. For the purpose of stationarity we introduce random variables (X_0, Y_0) representing the initial on and off-periods as follows: let B ,

X_{on}^{eq}, Y_{on}^{eq} be independent random variables, independent of $\{X_{on}, X_n, Y_{off}, Y_n\}$, and such that B is Bernoulli with $P(B = 1) = 1 - P(B = 0) = \mu_{on}/\mu$,

and X_{on}^{eq} and Y_{on}^{eq} have distribution functions

$$F_{on}^{eq}(x) = \frac{1}{\mu_{on}} \int_0^x F'_{on}(s) ds$$

and

$$F_{off}^{eq}(x) = \frac{1}{\mu_{off}} \int_0^x F'_{off}(s) ds$$

Suppose we are monitoring a VN link running video traffic, and calculating the mean of traffic data rate (bits/s) for every time interval $[t_1; t_2], [t_2; t_3], \dots$, where $t_{i+1} - t_i = dt$ is the size of the observing window, then we can get a time series of traffic rate $R_1; R_2; \dots; R_p; \dots$. With the assumption that no stationary traffic will be address later, we could apply a linear predictor on that time series.

Based on the correlation structures of the time series, a linear predictor $P_t R_{t+h}$ predicts the future value R_{t+h} of a time series $R_{(t)}$ according to its history $R_1; R_2; \dots; R_t$.

III. BANDWIDTH ALLOCATION WITH TRAFFIC FORECASTING

In a virtual network, Route computing with bandwidth allocation can be considered as a resource mapping problem, which can be reduced to the Multi-commodity Flow Problem (MFP), which can be solved in polynomial time. And a prediction based resource allocation scheme can be used for virtual network topology restructure (mainly link bandwidth adjustment).

Multi-path achieves better resource utilization by making use of the thin pieces of available bandwidth, by which the virtual network can accept more service requests. Furthermore, flexible multi-path makes the resource mapping problem computationally tractable. A request with some bandwidth constraint is mapped into multiple paths in the virtual network, such that the sum of reserved end-to-end bandwidth along the multiple paths is equal to the constraint. The division of traffic over the paths is specified as a splitting ratio.

However, some failure in the MFP computation implies that one or more links do not have enough available capacity, which violates the linear constraints on the commodities for each link when modeling MFP. To avoid producing bottleneck links, we employed traffic predictor. On one hand, MFP solver makes better resource utilization by making use of the thin pieces of available bandwidth, by which the virtual network can accept more service requests. On the other hand, the traffic predictor adjusts the link with the largest occupation (bottleneck link) by periodically monitoring the traffic rate of a user link and adjusting the reserved bandwidth based on the Forecasting made from the traffic history.

The experiment is implemented in NS-2 environment, which consists of seven nodes as in Fig 1. Service requests arriving at some S-D node pair follow a On/Off model. Total S-D node pairs: $n*(n-1)/2=28$.

So we generated 28 arrays (each 120) of On/Off model random numbers with MATLAB. ($n*p=3$), and even distribution in each interval (unit time).

Then we get the statistic of traffic every 3 minutes on each link, 15 links at last we have 15 time-series each with 40 values.

Fig.1 architecture of the experiment network

Algorithm 1 Algorithm for traffic Forecasting

For each link,

Step 1. Get the history series $y_1, y_2 \dots y_{40}$

Step 2. Determine the order of differential transform d .

suppose $\nabla_{dyt}=zt$ is a stationary series

Step 3. Make zt zero mean value, $wt=zt-\text{avr}(z)$

Step 4. Get the pk , akk of wt

Step 5. Determine if the model is AR, MA or ARMA, else go to 2 and increase d .

Step 6. Get the predictive value with the model

We describe the route computing and bandwidth allocation with traffic Forecasting to enable efficient solutions in Algorithm 2.

When received request, the server could use the algorithm to find a route which subject to the user's bandwidth constrain, in the remained available resources.

Algorithm 2 Algorithm for bandwidth allocation

Bandwidth utilization Forecasting

Step 1. predict traffic with Algorithm 1, and compute bandwidth utilization on each link. And the reciprocal of utilization is the links' priority when being selected in the following steps.

Compute shortest single-path:

Step 2. For new-coming request, compute a shortest single-path in the remaining topology with sufficient bandwidth using Dijkstra algorithm.

Step 3. If Step2 feasible, stop.

Solving MFP and update all the routes:

Step 4. If Step2 infeasible, for all requests with bandwidth constraint, construct linear constraint on the commodities and solve MFP (Multi-commodity Flow Problem).

Step 5. If Step 4 feasible, update all the routes with the result in Step 4.

Step 6. If Step 4 infeasible, refuse the latest request.

IV. PERFORMANCE EVALUATION

We evaluate the design with NS2. Two networks are configured to simulate the virtual networks in our evaluation, and the Forecasting algorithm and non-Forecasting algorithm are used for computing respectively. The dynamics of bandwidth utilization on each link and the mean package delay are studied.

Our evaluation focuses primarily on bandwidth utilization, throughput and packet loss rate as the requests increasing in each network. Fig.2 shows the utilization of bandwidth on each link. Algorithm with traffic Forecasting achieves a better load balancing.

Fig.2 the utilization of bandwidth on each link.

Tab. 1 shows the bandwidth utilization, throughput and packet loss rate on each link, when 100 requests being served. In the OSPF network, some key links is heavy loaded, which causes the low bandwidth utilization, low throughput and high loss tolerance.

$$\text{bandwidth utilization} = \frac{\sum_{t=1}^{t_{\max}} \sum_{k=1}^{15} bw_{kt}}{t_{\max}}$$

By using On/Off model, the Forecasting based dynamic bandwidth allocation, network can provide better quality of service and decrease the requirement of resources. After reducing queue length and buffer size requirement, this bandwidth allocation scheme also results in lower network delay and higher resource utilization.

Tab. 1 Comparison of bandwidth utilization, throughput and packet loss rate

	On/Off-model	Poisson-model
bandwidth utilization	86.6%	76.6%
throughput	108.2 Mbps	100 Mbps
packet loss rate	11.1%	13.2%

V. CONCLUSIONS

In this paper, we make the traffic Model and Forecasting using on/off Models for VN dynamic link resizing. Based on the experiments with linear and Gaussian predictors, We employ a new predictor to improve the response time of the linear predictor to the increase of the traffic.

Our simulation showed that the predictor can improve the response time of linear predictors. In a VN environment, Forecasting based bandwidth resizing will provide multiplexing gain without the degradation of QoS.

Our simulation experiments show a better load balancing with low loss average delay with traffic Forecasting, compared with the On/Off model based Forecasting routing.

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