國 立 清 華 大 學

碩 士 論 文

題目：政策性頻寬計費系統之研製

The Design and Implementation of

Policy-based Bandwidth Billing System

所別：通訊工程研究所

學號：885601　　　　　姓名：周 照 欽

指導教授：　黃　能　富　教　授

中華民國九十年六月

摘要

隨著網路使用量的劇增以及網路使用人口的快速成長，如何更有效地利用有限的頻寬資源以及對網路服務品質的保證（The guarantee of Quality of Service）成為現今一門重要的課題。現今被網路服務提供者（Internet Service Provider, ISP）所廣泛採用的兩種頻寬計費方式為單一速率計費（flat-rate pricing）和 使用時間計費（Duration-based pricing），而這兩種計費方式都無法應用在提供多種不同服務等級的網路架構上。因此，網路服務提供者急需一個適當的計費機制，而這個機制必須可以依據提供給各個使用者的服務等級和型態做出合理的收費，並且透過這個計費機制可以讓使用者更有效率地使用網路資源，以減少服務提供者不必要的軟硬體支出。這篇論文提出一個新的計費系統：政策性頻寬計費系統（Policy-based Bandwidth Billing System)，這個系統不但能有效地解決上述的頻寬計費問題，同時可以事先或即時地控管使用者的頻寬和傳輸量，提供對網路服務品質的保證。政策性頻寬計費系統採用的新的計費機制：政策性頻寬計費機制（Policy-based Billing Scheme），該機制不但支援傳統的計費方式，更包含了使用量計費（volume-based pricing），服務導向式計費（service-based pricing），時段式計費 (schedule-based pricing)，以及線上即時頻寬計費 (online-bandwidth-based pricing)。政策性頻寬計費系統是架構於政策性頻寬管理系統（Policy-based Network Bandwidth Management System）之上，並根據管理者和使用者所訂定之頻寬計費政策（Policy）來控管網路頻寬和計費。此系統在安裝時不需要更動既有的網路架構和協定，並且可以同時對多個網域做計費和控管。在這篇論文中也實作了這個系統，並做了一個簡單的計費模擬。

The Design and Implementation of Policy-based Bandwidth Billing System

Advisor: Prof. Nen-Fu Huang

Student: Chao-Chin Chou

June 2001

A Thesis Submitted to the
Institute of Communications Engineering
National Tsing Hua University
Hsinchu, Taiwan
Republic of China

In Partial Fulfillment of the Requirements for the
Degree of Master in Communications Engineering

Abstract

The guarantee of Quality of Service (QoS) on the IP network is becoming an important issue in recent years. The pricing schemes currently used by the Internet Service Providers (ISPs) are flat rate pricing and duration-based pricing, and both cannot be applied to the network with multiple service levels. The service providers have an urgent demand for a proper billing system that can charge the users for different service levels provided by the service providers. This paper presents a Policy-based bandwidth billing system (PBBS), which not only bills users for their consumed services and bandwidth resources but also controls and guarantees the QoS classes required by the users over IP networks. The Policy-based pricing scheme adopted by PBBS can be molded into many kinds of pricing schemes such as flat rate pricing, duration-based pricing, volume-based pricing, service-based pricing, schedule-based pricing, or online-bandwidth-based pricing. The PBBS is based on the Policy-based bandwidth management system and achieves the billing and bandwidth controlling according to the Policies made by the network providers and users. The system requires no changes to the existing protocols and applications and can be used to bill and manage multiple domains simultaneously. An implementation of PBBS based on the BandKeeper system is described and indicates that the system is practical.

List of Contents

Index of Figures

1. Introduction

As the Internet population grows up year-by-year in a rapid rate, the problem of sharing the bandwidth and Quality of service (QoS) provisioning has become the focus of much recent research. Even if there will be much more bandwidth in the future, the control of the network resource utilization remains essential for the prevention of the waste on bandwidth and for more efficient using on the important applications which have special demands. Some solutions are proposed to provide multiple levels of services on the network, such as Differentiated Service framework (DiffServ), which provides multiple QoS classes over IP networks [1] , and some solutions aim on the Policy-based Network Management that manages the bandwidth according to the predefined bandwidth policies [2] [3] . Besides, many studies show that pricing on the network services makes the network to be used more efficiently and provides a possibility to control utilization and sharing of network resources [4] [5] [6] .

However, the primary pricing schemes currently offered by both dial-up and broadband Internet Service Providers (ISP) are flat rate pricing and pure duration-based pricing, and each of them is not an ideal pricing scheme. For the flat rate pricing, it causes an inefficient utilization on the bandwidth resource. The reason is that users do not face the true marginal cost of usage and resulting in over-usage and potentially higher than socially optimal levels of infrastructure investment to meet the demand. The high levels of usage under flat-rate unlimited-access service planes have the potential to reduce the overall performance under broadband access technologies [7] . For the duration-based pricing, it is not impartial to apply the same charging scheme on the users even when they have the same connection duration. For example, user A transmits large amount of video clips and MP3 files all the time via Ftp or Http and user B is just idle on the BBS reading his favorite articles via Telnet. Although user A and B have the same duration, user A user much more bandwidth than user B. So it is not fair for user B to apply the same duration-based pricing scheme with user A. The charging schemes on bandwidth should be more precise, make more efficiency on the utilization, reduce the waste of the bandwidth, and follow the principle that how much the user should pay depends on how much bandwidth resource the user has consumed.

There are many pricing architectures been proposed for the DiffServ Network. A pricing scheme based on the cost of providing different levels of quality of service to different classes and on long-term demand is proposed by Xin Wang and Henning Schulzrinne in [6] . In [8] , a policy-based billing architecture of DiffServ is proposed, which allows a service provider to define policies for configuring various processes of a billing system based on the charging and pricing schemes used for individual services. On a multi-domain network, a pricing and accounting architecture based on the network access agent (NAgent) that mediates between users and network providers is proposed in [10] . A congestion-pricing scheme is also proposed in [11] which is to assign each packet entering a switch a price. When a packet traverses several switches on its route, each switch adds its price to the price currently carried by the packet. The price reflects the degree of congestion encountered by the packet and end users are informed of how much they were charged when their packets are acknowledged. Besides, early in 1995 a system for billing users for their TCP traffic is proposed in [10] , which is achieved by delaying the TCP ACK message to postpone the establishment of connections while the user is contacted, verifying in a secure way that they are prepared to pay. It also shows that pricing schemes may be used to control network congestion either by rescheduling time-insensitive traffic to a less expensive time of the day, or by smoothing packet transfers to reduce traffic peaks. In this paper, the *Policy-based Bandwidth Billing System (PBBS)* on a multi-domain network is proposed which is based on the Policy-based Bandwidth Management System (PBMS) proposed in [12] and the policy reference model proposed in [4] . The PBBS requires no change to the existing protocol and applications. It uses the *Policy-based pricing scheme*, which can be molded into only the pricing schemes currently used by most ISPs (flat rate and duration-based pricing) but also the volume-based pricing, service-based pricing, schedule-based pricing, and online-bandwidth-based pricing. The PBBS provides precisely bandwidth pricing and more efficient bandwidth utilization.

The rest of the paper is organized as follows. Section 2 is the overview of the Policy-based Network Bandwidth Management System [12] and the Policy-based accounting architecture proposed in [4] , both are the base of PBBS of this paper. Section 3 describes the system design of the PBBS and the concept of the Policy-based pricing scheme. Section 4 presents the implementations of the charging policy maker and converter in PBBS. Finally, a conclusion and future work is drawn in Section 5.

2. The Preliminary

2.1 Policy-based Network Bandwidth Management System

Although more and more bandwidth will be available in the future, an more efficient usage on bandwidth resource and the QoS guarantees on important applications are still critical issues. Therefore, the Policy-based Network Management becomes a popular issue in recent years since it provides a mechanism for guaranteeing the QoS of each application and gives the MIS a way to control the bandwidth resource via policies. The PBMS proposed in [12] is an implementation based on the architecture of Policy-based Network Management and consists the following components:

- *Policy Management Tools*: or *Policy Maker*, a tool for the MIS to set up the bandwidth policies, to detect the conflict between policies, and to push the policies to the Policy Repository or the Policy Decision Point.
- *Policy Repository*: a directory server or database to store the policies.
- *Policy Decision Point (PDP)*: Get the policies from the Policy Maker or the Repository, translate them to the device configurations and push them to the Policy Enforcement Point to enforce them.
- *Policy Enforcement Point (PEP)*: The place where the policies are enforced.

The architecture of the PBMS is shown as follows:

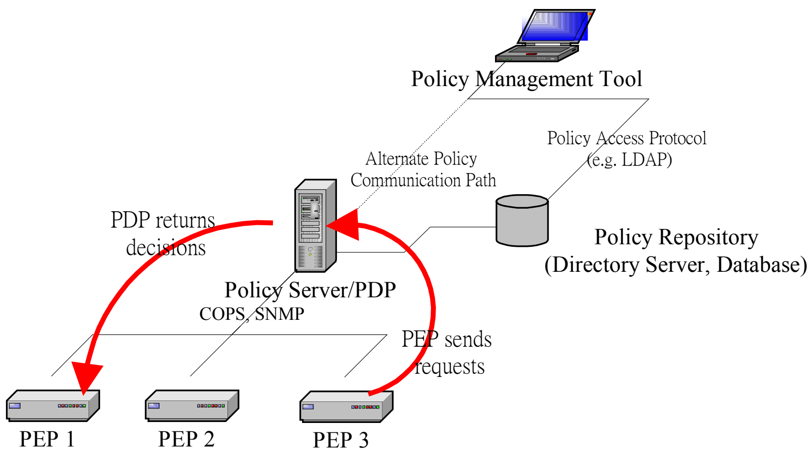

Figure 1 The architecture of Policy-based Network Management System

The PBMS manages the bandwidth resource of the IP network by controlling the TCP connections and UDP streams according to the bandwidth policies, and exports the data of traffic. The PEP first classifies the flows according to the policies (Source IP/Netmask, Destination IP/Netmask, protocol type and service port), and then enforces the QoS settings on these flows.

The billing system should not only do the accounting and pricing jobs by metering and analyzing the connections, but also have to manage and control the bandwidth resource actively to avoid the illegal using without payment and to make more efficiently usage on the bandwidth. Consequently, the PBMS is a good platform for the implementation of billing system.

2.2 Policy-based Accounting

Since the billing system aims to make revenues from the users, the business roles involved in billing and the relations between these roles should be discussed. *Figure 2* depicts the different roles and the business relations proposed in [4] . Here the term "service" is defined as a set of capabilities offered by a provider to a customer. In the definition provider and customer can be one of the business roles in *Figure 2*.

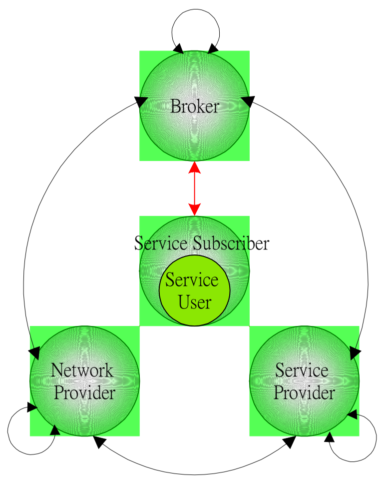

Figure 2 Roles and business relations

The *service subscriber* is the one subscribed to a service and thus has a contractual relationship with the service provider and a network provider who provides the underlying transport service. The service subscriber can control the service usage to each service user or other subscribers based on the contract, thus the service provider can use the billing system to charge the service users. The *service user* is the one uses the service and can be identical with the service subscriber. The *network provider* provides the underlying network infrastructures and the transport services to all the other business roles that are also the billing targets of the network provider. The *service provider* furnishes information services on top of transport services provided by network providers to the subscribers, users and also the other service providers (retailers). The billing system here can be used to charge to service subscribers, users and retailers. Finally the *broker* allows the other roles to access the information controlled by it and provides different information (references) to different business roles.

An accounting policy model developed in [4] provides a clear view of configuration relations between the policies and their target blocks. The PBBS takes advantages of this model and combines with the bandwidth control functions of PBMS to develop a novel policy reference model for the Policy-based pricing scheme. The model is shown in *Figure 3*. The blocks at the right side are layered according to the processing of the data from the bottom level bandwidth controlling via metering up to the final billing process. The block on each layer is configured by the policy shown on the left side. The configuration parameters are extracted from the policy and passed to the corresponding block.

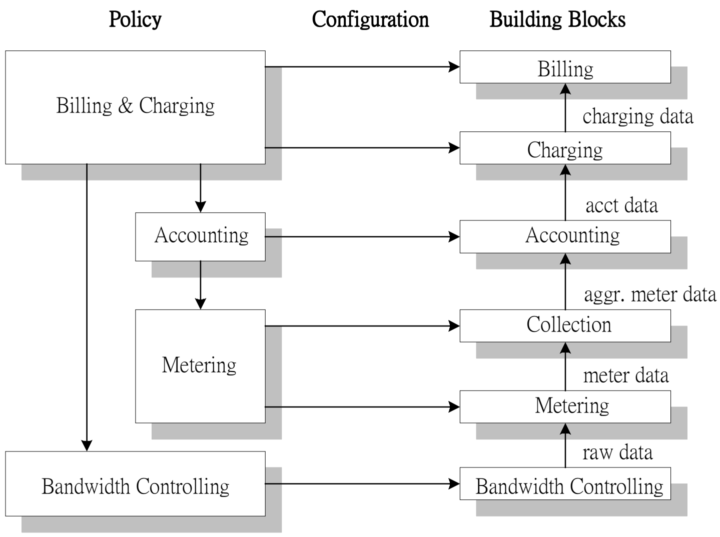

Figure 3 The reference model of Policy-based Accounting with PBMS

The tasks of the different blocks are as follows:

- *Bandwidth Controlling*: Controls the bandwidth according to the bandwidth policies to guarantee the QoS, records and gathers all the data of connections go through it (static metering) and exports the raw data to the metering. The bandwidth policies are derived from the charging policies.

- *Metering*: Meters are needed for capturing data about resource consumption in the network and will probably be placed at the edges of the network. Combined with the PBMS, parts of the metering jobs are done in the bandwidth controlling. As a result the job here is to do the configurable meters on the raw data export by the bandwidth controlling.

- *Collection*: The data gathered by the meters has to be collected for further processing and how the collection and aggregation is done are defined in the metering policies.

- *Accounting*: Accounting describes the collection of data about resource consumption. For subsequent charging, the metered data must be associated with a user that is the initiator of a flow, and a customer (service subscriber) that is responsible for the payment.

- *Charging*: The Charging derives non-monetary costs for accounting data sets based on service and customer specific tariff parameters. Charging policies define the tariffs and parameters that are applied.

- *Billing*: The Billing translates cost calculated by the Charging into monetary units and generates a final bill for the customer. Billing policies define the type, the form of the bill and the time for billing.

3. The Design of Policy-based Billing System

A billing system is a tool to make revenues from the billing targets. As a result, it is an important issue to choose an appropriate pricing scheme. The pricing schemes should be considered with the following principles:

- The pricing schemes should be simple and clear.
- The pricing schemes should be reasonable and equitable to all bandwidth consumers.
- The pricing schemes should be flexible and can cover all kinds of situations.

The Policy-based Billing System uses the *Policy-based pricing scheme*, which charges the users based according to the policies made by the bandwidth provider. Like the schemes of bandwidth controlling in PBMS, the manager makes the *charging policies*, which indicate the reserved bandwidth QoS and the charging formula in the *activated hours* specified in the policies. The charging policies are made from the customer's point of view with the commercial considerations in order to compete against other competitors. That is different from the policies of the Bandwidth Management System, which is made from the MIS's point of view with management considerations.

3.1 Policy-based Pricing Schemes

Based on the Policy-based Bandwidth Management System, many kinds of controlling and metering on the bandwidth can be achieved. As a result, there are plenty of parameters can be used for charging: the parameters on duration-based charging and on volume-based charging, the parameters on charging different QoS of the bandwidth, even the parameters on charging different kind of TCP or UDP services. Since all the parameters are available, the charging scheme becomes more flexible, and relatively, more complex than it is used before (which only takes care of the duration-based charging). The users (who pay the money to buy the bandwidth) should not face the complicated parameters and charging schemes, for that should be the bandwidth provider's duty. To look after both the manager's side (flexible and exact charging) and the user's side (simple and clear choices), the PBBS provides the users a set of *Virtual Lines*, which are pre-allocated virtual channels with predefined bandwidth classes and pricing schemes. These bandwidth class and pricing schemes are specified in the *charging policies* by the *Charging Formula*, which is composed of several pricing parameters. A Virtual Line can be composed of one or more than one charging policies depends on the QoS and pricing schemes in each time period.

3.1.1 Making Charging Policies

A charging policy is composed of three elements: *charging formula*, *QoS specification* and *activated hours* as describes below.

3.1.1.1 Charging formula

The charging formula is constructed by several pricing parameters and is an expression like the following:

$$UC = \Pi D * \Sigma (P_{fee} * P_{scale})$$

Where P_{fee}, P_{scale}, and D are pricing parameters and will be describe later. The charging formula not only indicates the pricing scheme, but also implicates the bandwidth QoS specified in this charging policy. Besides, all the QoS specifications and pricing schemes in this policy will only be effective in the specified activated hours. The following subsection describes the available pricing parameters to set up a charging policy.

To construct a charging formula, all the pricing parameters provided by the PBMS should be considered. The pricing parameters can be roughly classified in three categories: *parameters on fees*, *parameters on scales* and *parameters on discounts,* enumerates as follows:

- **Parameters on fees**:

Case 1: User reserves the same bandwidth for both incoming and outgoing connections:

- Fee for reserving committed bandwidth:

  User can reserve the committed bandwidth for his connections so that the transmission rate will be just exactly the bandwidth settings. Related parameters are charge once (F_{rcombw}), charge by reserved time (F_{rcombw_pret}), charge by consumed time (F_{rcombw_uset}) and charge by consumed octets (F_{rcombw_useo}). Besides, the pricing maybe vary with the time period Ti: F_{rcombw_ti}, $F_{rcombw\_prêt\_ti}$, $F_{rcombw\_uset\_ti}$, $F_{rcombw\_useo\_ti}$.

- Fee for reserving minimal bandwidth:

  User can reserve the minimum bandwidth for his connections so that the transmission rate will be guaranteed to be equal or higher than the bandwidth settings. Related parameters are charge once (F_{rminbw}), charge by reserved time (F_{rminbw_pret}), charge by consumed time (F_{rminbw_uset}) and charge by consumed octets (F_{rminbw_useo}). And the pricing may vary with the time period Ti: F_{rminbw_ti}, $F_{rminbw\_pret\_ti}$, $F_{rminbw\_useo\_ti}$, $F_{rminbw\_uset\_ti}$.

- Fee for online bandwidth (actually used bandwidth):

  The actual online bandwidth of the user's connections may be different from the reserved settings. To charge by the online bandwidth, related parameters are as follows:

  - Default fee for all bandwidth: charge once (F_{bwd}), charge by consumed time (F_{bwd_uset}), and charge by consumed octets (F_{bwd_useo}).

  - Fee for specified bandwidth x: charge once (F_{bwx}), charge by consumed time (F_{bwx_uset}), and charge by consumed octets (F_{bwx_useo}).

  And the pricing may vary with the time period Ti: F_{bwd_ti}, $F_{bwd\_uset\_ti}$, $F_{bwd\_useo\_ti}$, F_{bwx_ti}, $F_{bwx\_uset\_ti}$, $F_{bwx\_useo\_ti}$.

- Fee for exceeded host quota:

  If the maximum host quota is applied to the user's host, the charging on the exceeded transmission is available. Related parameters are charge once (F_{hq}), charge by octet (F_{hq_useo}), and charge by the duration time used for transmitting the exceeded data (F_{hq_uset}). Besides, the host quota may vary with the time period T_i, and the parameters are: F_{hq_ti}, $F_{hq\_useo\_ti}$, $F_{hq\_uset\_ti}$.

- Fee for exceeded incoming/outgoing octets:

  If the limitation of the maximum incoming/outgoing transmission octets is applied to the user's host, the charging on the exceeded transmission is available. Related parameters are charge once (F_{ino} / F_{outo}), charge by exceeded octets (F_{ino_useo} / F_{outo_useo}), and charge by the duration time used for transmitting the exceeded octets (F_{ino_uset} / F_{outo_uset}). Besides, the limitation of octets may vary with the time period T_i, and the parameters are: F_{ino_ti} / $F_{out\_ti\ o}$, $F_{ino\_useo\_ti}$ / $F_{outo\_useo\_ti}$, $F_{ino\_uset\_ti}$ / $F_{outo\_uset\_ti}$.

- Fee for different Service type:

  It is possible to limit the service type of the user's connections to a limited set of TCP or UDP services, and even to have different bandwidth settings on different type of services. Besides, charging on a special service is also available. For example, the parameters for pricing Http services are charge once (F_{serv_http}), charge by consumed time ($F_{serv\_http\_uset}$), and charge by consumed octets ($F_{serv\_http\_useo}$). Besides, pricing on the services may vary with the time period T_i, and the parameters are: $F_{serv\_http\_ti}$, $F_{serv\_http\_uset\_ti}$, $F_{serv\_http\_useo\_ti}$.

Case 2: User reserves different bandwidth for incoming and outgoing connections:

The parameters in this case are the same with those in case 1, but are divided into two sets: parameters for incoming connections and parameters for outgoing connections, shown as follows:

- Fee for reserving committed/minimal bandwidth:

  User can have the following combinations of reservations on their bandwidth:

- Committed bandwidth *cx* for incoming connections and *cy* for outgoing connections.
- Minimum bandwidth *mx* for incoming connections and *my* for outgoing connections.
- Committed bandwidth *cx* for incoming connections and minimum bandwidth *my* for outgoing connections.
- Minimum bandwidth *mx* for incoming connections and committed bandwidth *cy* for outgoing connections.

And the related parameters are:

- Charge once: $F_{rbw\_in\_cx\_ti}$, $F_{rbw\_out\_cy\_ti}$, $F_{rbw\_in\_mx\_ti}$, $F_{rbw\_out\_mx\_ti}$.
- Charge by reserved time: $F_{rbw\_in\_cx\_pret\_ti}$, $F_{rbw\_out\_cy\_pret\_ti}$, $F_{rbw\_in\_mx\_pret\_ti}$, $F_{rbw\_out\_mx\_pret\_ti}$.
- Charge by consumed time: $F_{rbw\_in\_cx\_uset\_ti}$, $F_{rbw\_out\_cy\_uset\_ti}$, $F_{rbw\_in\_mx\_uset\_ti}$, $F_{rbw\_out\_mx\_uset\_ti}$.
- Charge by consumed octets: $F_{rbw\_in\_cx\_useo\_ti}$, $F_{rbw\_out\_cy\_useo\_ti}$, $F_{rbw\_in\_mx\_useo\_ti}$, $F_{rbw\_out\_mx\_useo\_ti}$.

■ Fee for online bandwidth:

The same as the parameters in case 1 but divided into incoming part and outgoing part:

◆ Default fee for all bandwidth: $F_{bwd\_in\_ti}$, $F_{bwd\_out\_ti}$, $F_{bwd\_in\_uset\_ti}$, $F_{bwd\_out\_uset\_ti}$, $F_{bwd\_in\_useo\_ti}$, $F_{bwd\_out\_useo\_ti}$.

◆ Fee for specified bandwidth *x*: $F_{bwx\_in\_ti}$, $F_{bwx\_out\_ti}$, $F_{bwx\_in\_uset\_ti}$, $F_{bwx\_out\_uset\_ti}$, $F_{bwx\_in\_useo\_ti}$, $F_{bwx\_out\_useo\_ti}$.

■ Fee for exceeded host quota: F_{hq_ti}, $F_{hq\_useo\_ti}$, $F_{hq\_uset\_ti}$.

■ Fee for exceeded incoming/outgoing octets: F_{ino_ti}, F_{outo_ti}, $F_{ino\_useo\_ti}$,

$F_{outo\_useo\_ti}$, $F_{ino\_uset\_ti}$, $F_{outo\_uset\_ti}$.

- Fee for different Service type: $F_{serv\_serviceType\_ti}$, $F_{serv\_serviceType\_uset\_ti}$, $F_{serv\_serviceType\_useo\_ti}$.

- **Parameters on discounts**

For the commercial issues, the parameters on discounts are provided by PBBS:

- Discount in special time period: D_{time}
- Discount on special hosts/users: $D_{host/user}$
- Discount on special/limited services: D_{serv}

The manager can define any kind of discount items depends on his commercial policies: D_{new_item}

- **Parameters on scales**:

Scales are the unit for metering in the Billing Module and Reporting Module of PBBS. Appropriate scales collocating with reasonable charging fees make the most benefits for the bandwidth providers.

- Reserved time (T_{pre}), reserved octets (O_{pre})
- Consumed time (T_{use}), consumed octets (O_{use})
- Consumed time on online bandwidth x (T_{use_bwx})
- Consumed octets on online bandwidth x (O_{use_bwx})
- Consumed time on the exceeded octets ($T_{use\_exceedo}$)
- Consumed exceeded octets (O_{exceed})
- Consumed time in the time-period i (T_{i_use})

All the values of the parameters above can be obtained from the data exported by the PBMS. With these pricing parameters, a charging formula can be established by putting the required parameters together with the appropriate operators. Applied to the pricing schemes described before, an example of the flat rate charging formula should be looked like the following:

$UC = F_{rcombw}$ or $UC = F_{rminbw}$

An example of the duration-based charging formula:

$UC = F_{rcombw} * T_{use}$

An example of the volume-based charging formula:

$UC = (F_{bwd\_useo} * O_{use}) + (F_{hq\_useo} * O_{exceed})$

An example of the Service-based charging formula:

$UC = F_{serv\_serviceName} * T_{use\_serviceName}$ or $UC = F_{serv\_serviceName} * O_{use\_serviceName}$

An example of the time-period-based charging formula:

$UC = \Sigma(F_{rcombw\_ti} * T_{i\_use})$

An example of the online-bandwidth-based charging formula (the fee varies with the bandwidth):

$UC = F_{bwd\_uset} * T_{use\_bwd} + \Sigma(F_{bwx\_uset} * T_{use\_bwx})$

The charging formula can be the combinations of several kinds of pricing schemes. An example of the duration-based billing on the committed bandwidth with Service-based billing on Ftp service by transmitted octets is as follows:

$UC = F_{rcombw} * T_{pre} + F_{serv\_ftp} * O_{use\_ftp}$

3.1.1.2 QoS specifications

The QoS specifications of PBBS are inherited from the Policy-based Bandwidth Management System but discard the Connection QoS. The reason is that while charging the users for the consumed bandwidth, there is no need to meter the usage of each connection. All we have to know is how much and how long the user's hosts are used in total, and the Rule QoS is sufficient for this. In fact, the QoS specifications PBBS needs for the charging targets are:

- Maximum, minimum, or committed bandwidth of the incoming/outgoing connections.
- Maximum quota per day of the target hosts.
- Maximum incoming/outgoing octets of all the connections.
- Maximum, minimum, or committed bandwidth of the incoming/outgoing connections with the specially treated Service type.
- Maximum incoming/outgoing transmission octets of the connections with the specially treated Service type.

3.1.1.3 Activated hours

The activated hours of a policy is the hours in a week in which the QoS settings and pricing schemes are effective. The reason to use a week as the scheduling target time period is that it's a working cycle for most of the people in the world. The charging policy does not care about the time longer than a week (a month, a year…) and leaves it to the users while making the *User's Policy* (described in section 3.1.3). A charging policy can be specified to be effective in the whole week, in couples of days, in every night, or only in some hours of important conferences, up to the maker's decision and their commercial considerations. *Figure 4* illustrates the activated hours of Policy 1A and Policy 1B. The row headers indicate the day of week and the column headers indicate the hours of a day. The schedule of Policy 1A is the working hours (from 9 AM to 7 PM, from Monday to Friday), and the schedule of Policy 1B is the night time from 9 PM to 3 AM on working days.

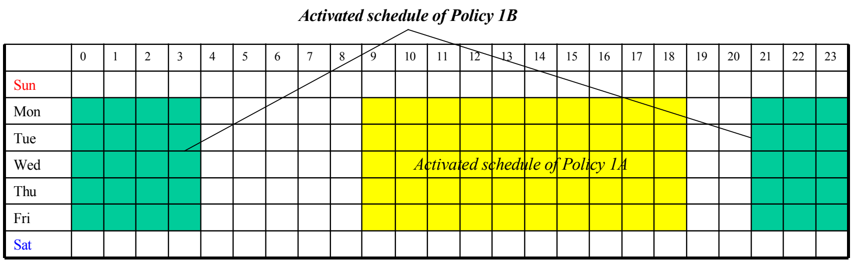

Figure 4 The activated hours of charging policy 1A and 1B.

Now the charging policy 1A and 1B can be specified as follows:

Charging Policy 1A:
Policy Name: Policy 1A
QoS Specifications:
Minimum bandwidth of all incoming connections: 256 kbps
Minimum bandwidth of all outgoing connections: 256 kbps
Maximum bandwidth on Ftp service connections: 64 kbps
Billing Formula: UC = (Frminbw_pret * Tpre)+(Fftp_useo*Ouse_ftp)
Activated Schedule : Monday to Friday, 09:00 to 18:00

Charging Policy 1B:
Policy Name: Policy 1B
QoS Specifications:
Committed bandwidth of all incoming connections: 128 kbps
Committed bandwidth of all outgoing connections: 128 kbps
Available Service type of all connections : Ftp
Billing Formula: UC = Frcombw_uset*Tuse
Activated Schedule : Monday to Friday, 21:00 to 03:00

Figure 5 Charging policy 1A and 1B

3.1.2 Setting up the Virtual Lines

Once the charging policies are ready, the Virtual Lines can be set up by grouping the policies to a “bigger” policy, which takes care of the bandwidth QoS and pricing schemes of a whole week. For example shown in *Figure 6*, Line Class 1 is in fact the Charging Policy 1 which is made by grouping Policy 1A, Policy 1B, Policy 1C and Policy 1D. Policy 1A specifies the working day bandwidth and the pricing may focuses on the Service type of business applications such as Http, SMTP, POP3 and NetBIOS and may be charged by consumed octets. Policy 1B specifies the bandwidth for Servers backup time (since the enterprise usually does their backup job in the midnight) and the pricing may focuses on FTP and the charging maybe by time. Policy 1C is activated in the non-working hours so that the reserved bandwidth in this period maybe zero or lower than usual and the charging maybe free or at a discount. Policy 1D specifies the very important videoconference time with higher bandwidth and more charging on VoIP service. Each policy has its own QoS specification and charging formula, takes care of its own activated hours and specify a part of the

Virtual Line. The Virtual Line can be composed of many policies, or only one policy as shown in *Figure 7*, which is a policy with the whole week as its activated hours.

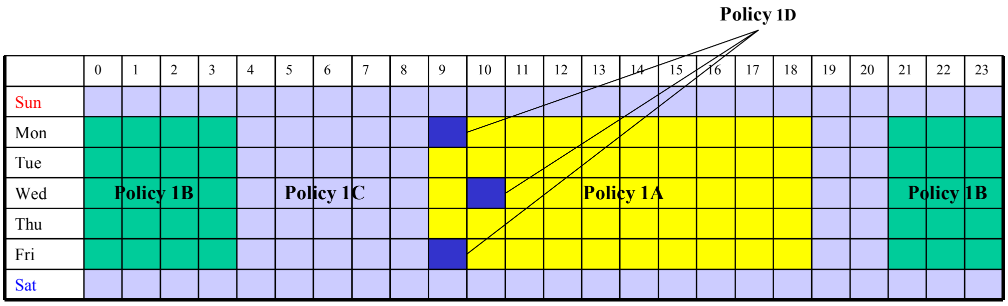

Figure 6 Line Class 1 (Charging Policy 1): composed of Policy 1A, Policy 1B, Policy 1C and Policy 1D.

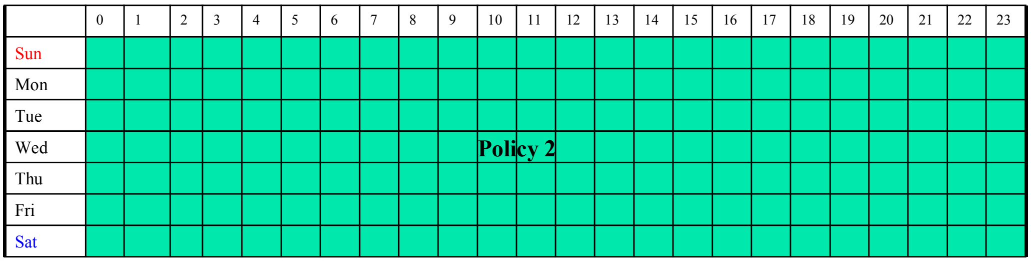

Figure 7 Line Class 2 (Charging Policy 2): composed of only Policy 2.

3.1.3 Making User Policies

One of the features of the Policy-based Billing System is *Customer-based Bandwidth Scheduling*, which means the customer (the bandwidth user) can allocate and schedule his bandwidth to meet his requirement. However, this is a trade off between the flexibility and complexity. To avoid the complexity of scheduling the bandwidth and keep the flexibility and convenience for the user, PBBS leaves only the User Policy to the user and let the manager to take care of the complex part (making charging policies, set up Virtual Lines for users). The elements compose of a User Policy are just the factors the user has to consider: *the user's hosts*, *reserved period of date*, and *reserved Line Classes*.

The user's hosts are the target IPs to be achieved the bandwidth controls and billings. The target can be a single host, a group of hosts (a subnet) or a group of subnets. User has to make choices of the required Lines for his hosts and schedules these Lines to meet his requirement. *Figure 8* illustrates the Line schedule of an example User Policy. In this policy the user reserves the bandwidth from May 7 2001 to July 20 2001 with three classes of Lines. The days marked by indigo color are reserved with Line Class 1, which is set with the bandwidth for working days using (described in section 3.1.2). The days marked by green color are reserved with Line Class 2, which is set for the holidays using.

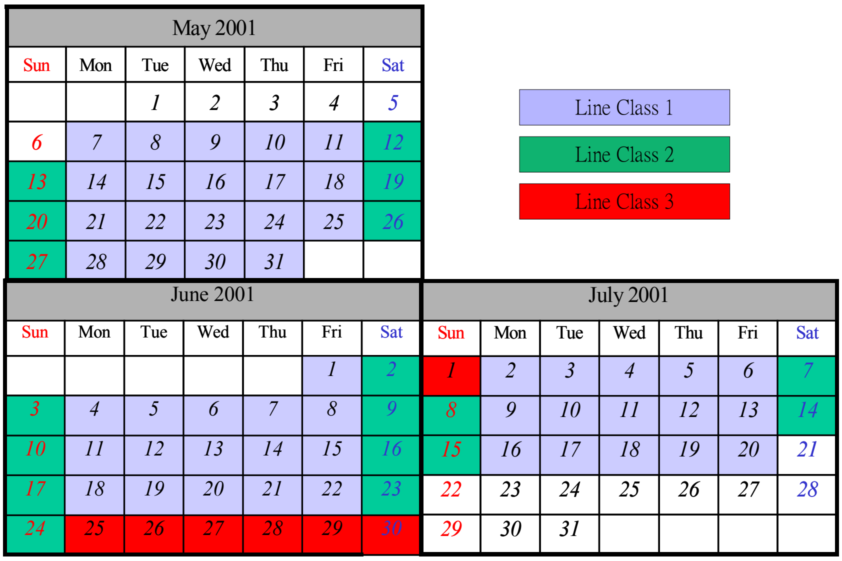

Figure 8 The scheduling of Virtual Lines in a User Policy.

Since there is always more than one customer, the set of Lines predefined by the manager may not be able to fit the demands of all customers. Besides, user may sometimes have an emergency using, for example, more bandwidth for a show in the World Trade Center from June 25 to July 1. The class of Line marked by red color in *Figure 8* is provided to solve this problem. User can specified his requirement to the manager and customize his own Line. At this time, the user has to learn and consider more details of charging and pricing, and how many decisions user can make is left to the contract between the managers.

Suppose the user has a single host with IP 192.168.0.1, now the User Policy for this user can be specified as follows:

User Policy for host 192.168.0.1:
Policy Name: UPolicy 1
Target Host IP: 192.168.0.1
Reserved Lines and Schedules:
Class 1: 5/7-11, 14-18, 21-25, 28-31, 6/1, 6/4-8, 11-15, 18-22, 7/2-6, 9-13, 16-20
Class 2: 5/12, 13, 19, 20, 26, 27, 6/2, 3, 9, 10, 16, 17, 23, 24, 7/7, 8, 14, 15
Class 3: 6/25-7/1

Figure 9 An example of the User Policy

3.2 Policy-Based Bandwidth Billing System

The *Policy-based billing System (PBBS)* is based on the Policy-based Network Bandwidth Management System (PBMS) and is an add-on module of PBMS. It aims on accounting and billing, and control the bandwidth depends on the user's requirement and payment via PBMS. *Figure 10* illustrates the architecture of the Policy-based Bandwidth Management System with the PBBS Module added on it. The Policy Maker of PBMS is replaced with the *Charging Policy Maker* and *User Order/Policy Maker* and the manager does not set the bandwidth policies directly. Instead, the manager set the *charging policies* together with the *User Policies* made by the bandwidth consumers are converted to the Bandwidth Policies by PBBS and are pushed to the PBMS to enforce the QoS settings on bandwidth. The PBBS communicates with the Policy Server, pushes bandwidth policies, and gets required logs of connections for pricing and billing. The billing related policies and logs are stored in the database of the PBBS module. Thus there is no need to change the architecture of the PBMS for adding PBBS.

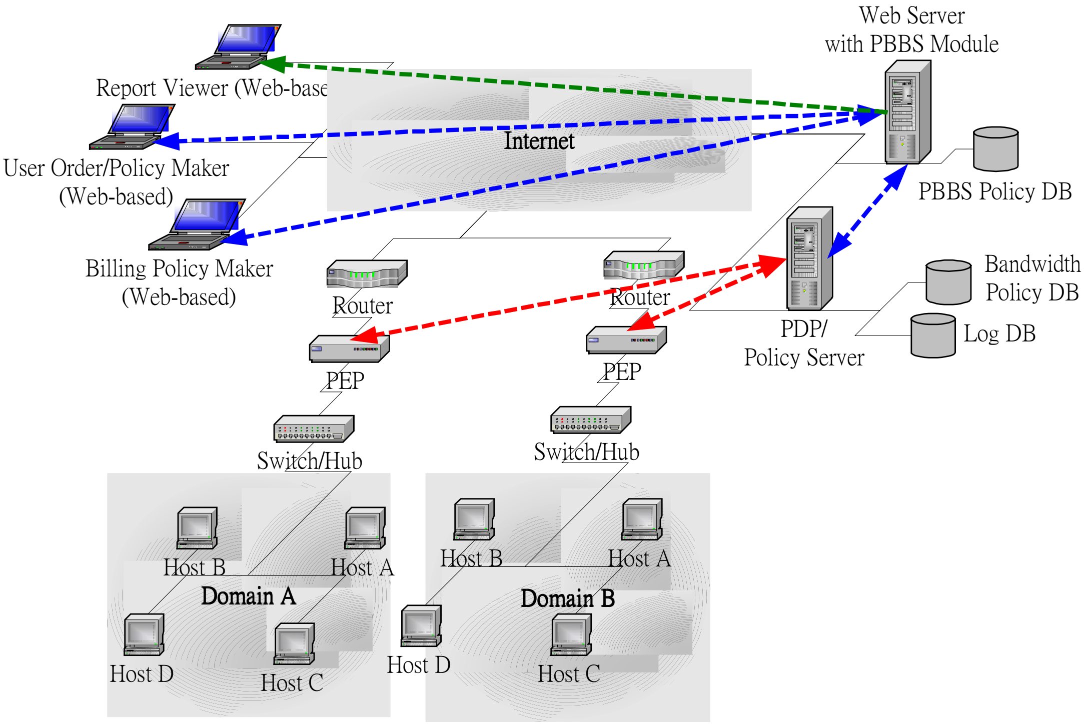

Figure 10 The architecture of PBMS with PBBS.

The features of PBBS are:

- *Supports all kinds of pricing scheme*: PBBS uses the Policy-based pricing scheme, which can be molded into flat rate pricing, duration-based pricing, volume-based pricing, service-based pricing, time-period-based pricing, or online-bandwidth-based pricing by changing the charging formula.

- *Customer-based Bandwidth Scheduling*: User (the bandwidth consumer) can schedule the bandwidth on his own free will. Describes in Section 3.1.3.

- *Web-based management and report*: The Policy Makers and Report Viewers are designed Web-based for the manager to manage the system everywhere.

- *Billing following with controlling*: PBBS not only billing the users by metering their bandwidth usages but can control the usage to avoid the illegal or exceeded using and reduce the waste on bandwidth.

- *Requires no change to existing protocols or applications*: The PBBS is an add-on module on the PBMS and requires no change to existing protocols or applications.

The PBBS is mainly composed of several modules as shown in. The charging policies are made by the PBBS and are converted and pushed to the PBMS. The jobs of the PBMS here is to reserve or control the bandwidth to meet the required QoS according to the converted charging policies. The PBMS also takes care the metering and data collecting of all the connections go through it and exports all the raw data to the PBBS. PBBS then does accounting and billing and exports the reports and bills. Besides, the interface is available for PBBS to communicate with the existing financial system and user management system that are used before the billing system is applied. This is to reduce the add-on efforts to transfer the users' data from the old system to the new one.

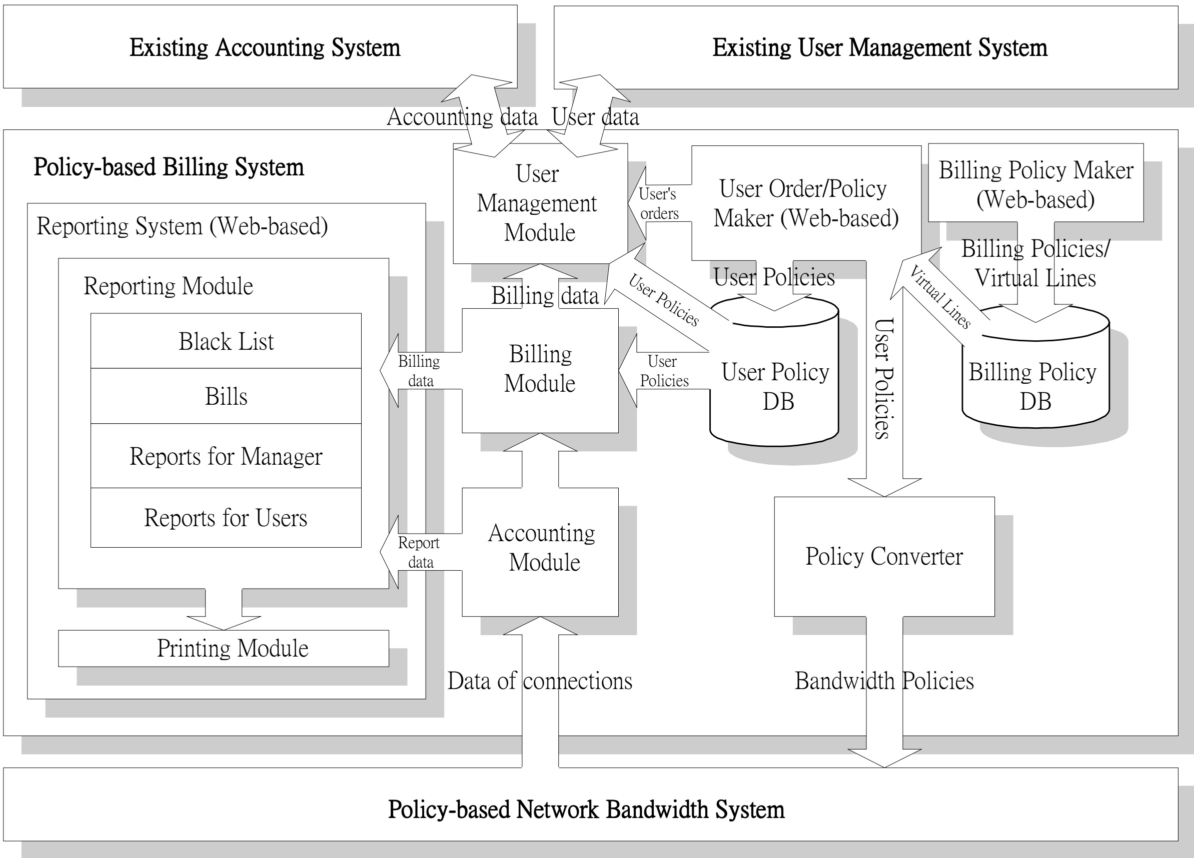

Figure 11 The architecture of the Policy-based Billing System.

The modules compose the PBBS shown in *Figure 11* are described in the follows:

- *Charging Policy Maker*: A web-based GUI for the manager to conveniently set up the charging policies (described in section 3.1.1) and the Virtual Lines (described in section 3.1.2).
- *Charging Policy DB*: The database for keeping the charging policies.
- *User Order/Policy Maker*: A web-based GUI for the users (or customers) to reserve the Lines they need, the time period to allocate and to make the related orders and contracts with the manager (the bandwidth provider).
- *User Policy DB*: The database for keeping the policies made by the users.
- *Policy Converter*: Convert the User's Policies to the Bandwidth Policies of the PBMS and pushes them to the PBMS.
- *User Management Module*: Manages the user's information and orders, takes care of the details of users' accounts, and provides the interface to communicate with the external accounting system and other user management systems.
- *Billing Module*: Evaluates the charges of the users according to the User Policies and the accounting data exported by the *Accounting Module*, and generates the bills and related reports to the manager and users.
- *Accounting Module*: Collects the data about resource usage from the raw data exported by the PBMS and associates them to each user, generate the reports of the bandwidth usage to the manager and user, and exports the pricing-related information to the *Billing Module*.
- *Reporting System*: The most important and valuable part of the PBBS (from the economics point of view), contains the following sub-modules:
  - *Reporting Module*: Generates the reports for the manager (bandwidth usage,

network performance monitoring, the status of the accomplishment of the policies…) and the users (the user's own bandwidth usage, achieved QoS, billing details…), the bill of every user, black list of users (the users who owe the payment), and so on.

- *Printing Module*: The module for printing jobs.

3.3 Converting User Policies to Bandwidth Policies

Because the PBBS is designed as an add-on module works on the Policy-based Bandwidth Management System, all the policies of PBBS have to be converted to the bandwidth policies that are acceptable by the PBMS. The job of the Policy Converter Module in PBBS is to pick out the QoS part of the User's Policies and recombine them to the bandwidth policies, leaving the pricing part to the Billing Module.

A Bandwidth Policy is composed of the *Conditions* and *Actions*.

- *Conditions*: Source IP/Netmask, Destination IP/Netmask, Service type, and Schedule.

- *Actions*: specified by *Rule QoS* and *Connection QoS*. The Rule QoS specifies the total QoS of all the connections satisfy the Condition, and the Connection QoS specifies the individual QoS of each connection satisfy the Condition. Both contain the following elements: maximum rate, committed rate, minimum rate, maximum octets, maximum host quota and connection duration time.

A User Policy in PBBS is in fact a combination of a set of IPs, a set of charging policies (the Virtual Line) and the schedule times. Since the IPs can be converted directly to the Condition of a Bandwidth Policy, the most efforts of the Converter Module are focus on the charging policies and the schedule times. To describe how the policies are converted, let's see the example shown in *Figure 9*. In this example, the QoS settings are described in the user reserved Lines, which are specified by sets of charging policies. As a result, the converting should be start from extracting the QoS settings from these charging policies.

The User Policy shown in *Figure 9* can be extends according to its schedules as shown in follows:

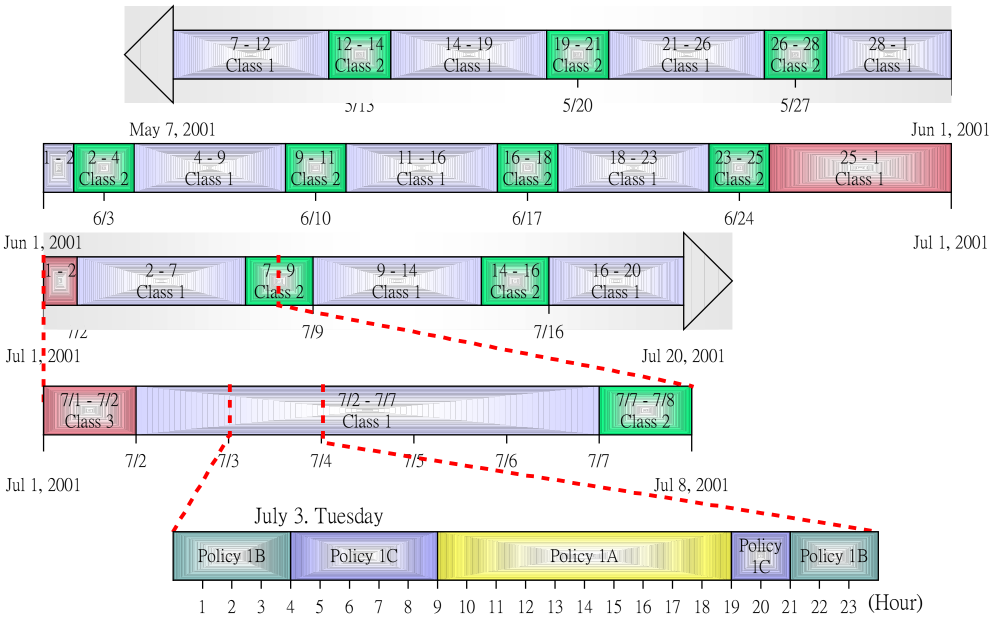

Figure 12 The User Policy extended by the schedule.

Figure 12 illustrates that the User Policy is in fact the combination of a sequence of charging policies arranged by their schedules in Line and in the User Policy. Each charging policy presents a set of Bandwidth Policies. The QoS settings of the Bandwidth Policy can be obtained from the charging policy, and its schedule is the intersection of the schedule in virtual line and in charging policy as shown in the following figure.

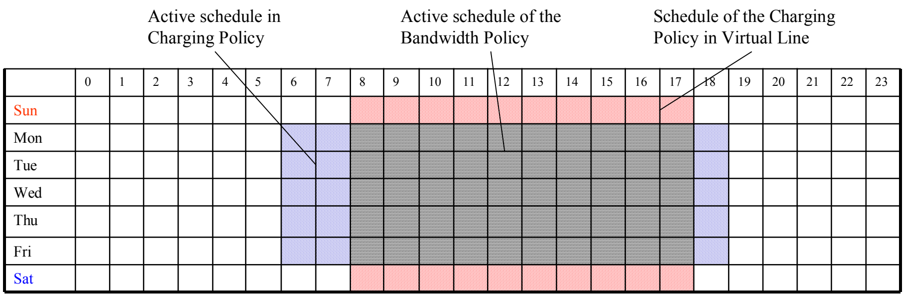

Figure 13 The schedule of the Bandwidth Policy is the intersection of the active schedule in Charging Policy and the schedule of the Charging Policy in Virtual Line.

In this example, the Bandwidth Policies obtained from Charging Policy 1A are as follows:

Bandwidth Policy 1:
Condition:
Source IP = 192.168.0.1
Source Netmask = 255.255.255.255
Destination IP = ANY
Destination Netmask = 255.255.255.255
Protocol = ANY
Service = ANY
Schedule = From 5/7 to 7/6, Monday to Friday, 09:00 to 18:00
Action: Rule QoS :
Minimum incoming bandwidth: 256 kbps
Minimum outgoing bandwidth: 256 kbps

Bandwidth Policy 2:
Condition:
Source IP = 192.168.0.1
Source Netmask = 255.255.255.255
Destination IP = ANY
Destination Netmask = 255.255.255.255
Protocol = TCP
Service = FTP
Schedule = From 5/7 to 7/6, Monday to Friday, 09:00 to 18:00
Action: Rule QoS :
Maximum incoming bandwidth: 64 kbps
Maximum outgoing bandwidth: 64 kbps

Figure 14 Bandwidth Policies obtained from Charging Policy 1A

Notice of that the schedules in Bandwidth Policy 1 and Bandwidth Policy 2 are not identical to the schedule of Charging Policy 1A since the actually activated hours should be obtained from the intersection of the schedules in Charging Policy, in Virtual Line, and in the User Policy.

4. Implementation

To demostration the practicality of PBBS, an implementation is presented in this chapter. It takes BandKeeper system as its bandwidth management and metering system. The BandKeeper[12] is a policy-based network bandwidth management device with the following features:

- The controls on the bandwidth of the incoming (remote to local) and outgoing (local to remote) connections which go through it.
- The controls on the maximum quota of the hosts resident in the local end.
- Supports IP/Mac pair filtering function.
- Records the detail of every TCP connection and UDP stream goes through it. These data are valuable for the PBBS on accounting and billing.
- Cross-platform management tools and report viewer designed with Java.
- Dynamically changing on bandwidth policies without interrupting the existing alive connections.

In order to have no modification on the BandKeeper system, the implementatoin of the PBBS are designed as an add-on module of the BandKeeper and use the PBBS Policy Maker instead of the BandKeeper Policy Maker. And the implementation demostrates making policies (charging policies, virtual lines and the user policies), and the bills.

4.1 System Architecture

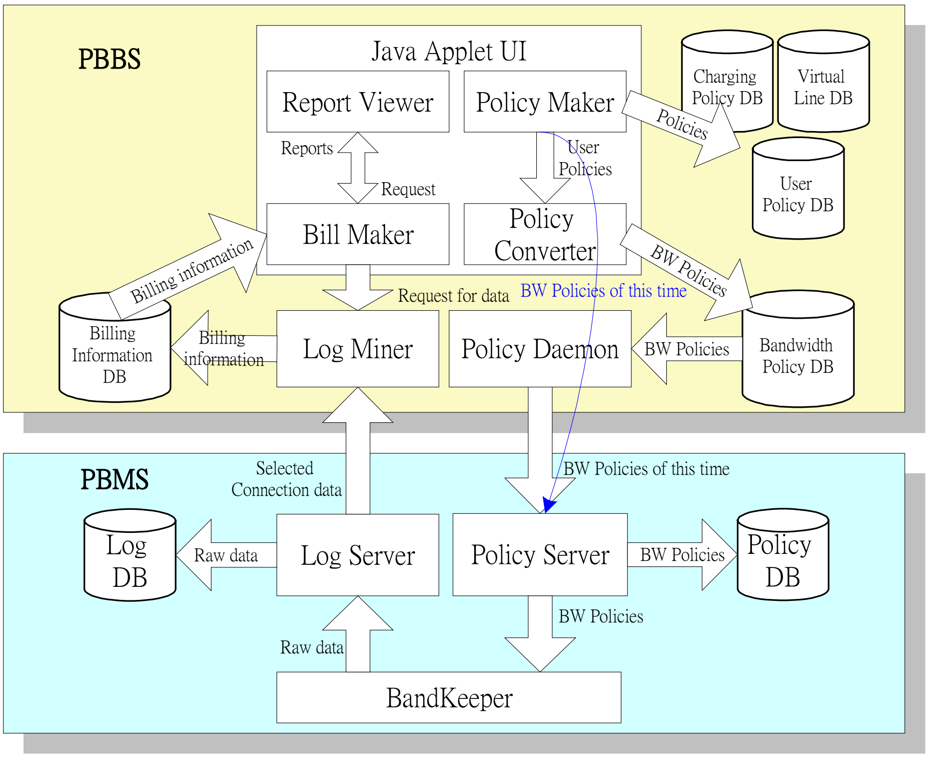

Figure 15 The architecture of the implementation of PBBS

Figure 15 shows the architecture of the implementation of PBBS. The Charging Policies, Virtual Lines and User Policies are made at the *Policy Maker*, which is a Java Applet running on the browser. All the policies are stored in the database and then are pushed to the *Policy Converter*. The Policy Converter is designed as part of the Policy Maker in order to integrate with the BandKeeper system without modification. It derives the QoS settings from the PBBS policies and translates them into the bandwidth policies that are recognizable by the BandKeeper. The bandwidth policies may be different on different days according to the line schedules specified in the User Policies. As a result, the bandwidth policies are arranged by their active dates, and are pushed to the bandwidth policies database if they are active later, or are pushed directly to the *Policy Server* if the policies are activated right now. The *Policy Daemon* is a daemon program, which wakes up every hour to check the bandwidth policies and the active dates related to these policies to decide whether or not to update the policies to the Policy Server. The Policy Server is the Policy Decision Point of the BandKeeper system and is a centralized controlling server which can manage up to 32 BandKeepers simultaneously. It receive the bandwidth policies from the policy maker and push them to the the BandKeepers. The Policy Server also monitors the status of each BandKeepers and reports the status (via Email or log event viewer) to the manager. The *BandKeeper* is the Policy Enforcemnet Point where the bandwidth policies are enforced. It also records all the connection data go through it for the later metering and accounting. The *Log Server* takes care of the metering and accounting jobs of PBBS and PBMS. It receives the raw data of connections exported by the BandKeeper, aggregates and translates the data to the valuable information readable for managers and users. Two different models of obtaining the connection data can be differentiated: *push* and *pull* model. In the push model the connection data are exported from the BandKeepers periodically to the Log Server. These data are usually used for the long–term reports. In the pull model, the Log Server sends requests to the BandKeepers to ask for required data. The required data are usually for the interim accounting and on-line monitoring requrests from the Report Viewer. In the case of PBBS only the data of the billing targets are needed, as a result the job of the *Log Miner* is to ask the Log Server for data according to the requirements of the *Billing Maker*. The Billing Maker does the scheduled billing jobs and takes care of the real time billing requests from the Report Viewer. The *Report Viewer* is a Java Applet and is an extension of the PBMS report viewer and can read the reports from the BandKeepers (the connection states, charts of the bandwidth utilization, top talkers/listeners, etc) and the reports from the Billing Maker (the bills and bandwidth utilization of each user).

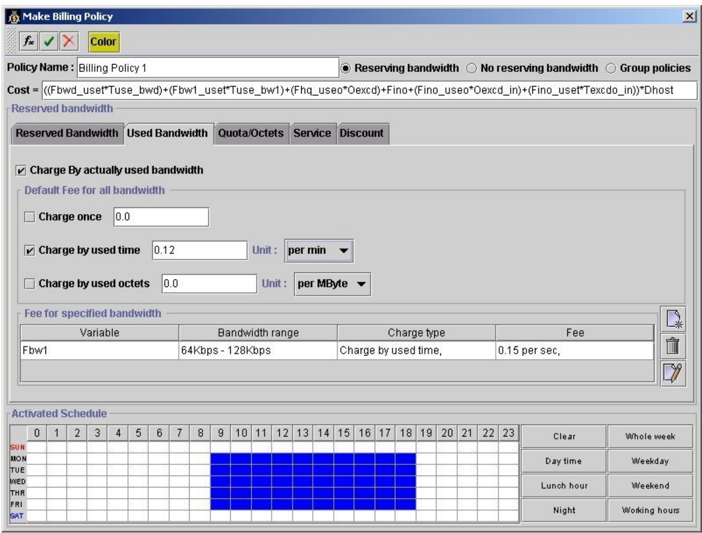

Figure 16 A snapshot of the Charging Policy Maker

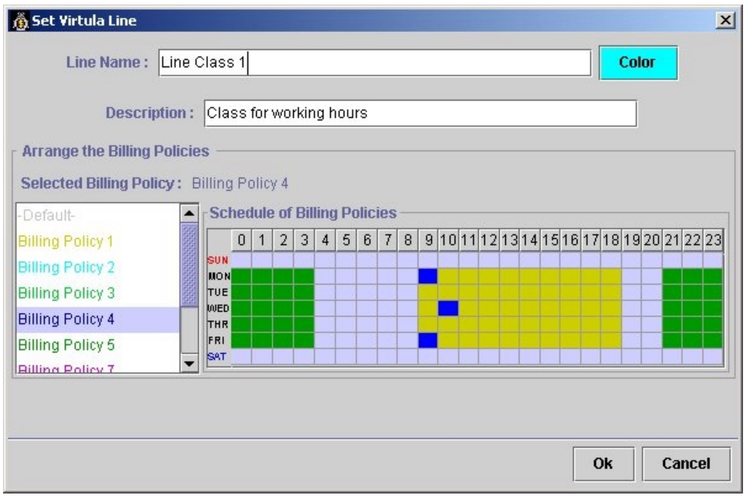

Figure 17 A snapshot of the Virtual Line Maker

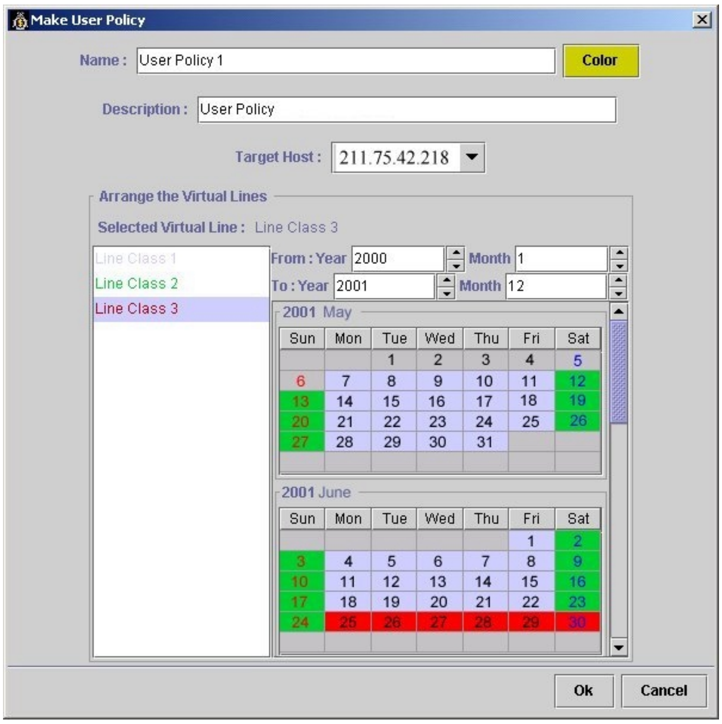

Figure 18 A snapshot of the User Policy Maker

4.2 Simulation Environment

In the simulation presents a contrast between five different pricing schemes: flat rate pricing, duration-based pricing, volume-based pricing, service-based pricing and online-bandwidth-based pricing. Each scheme is applied to a single billing target. All the targets reserved the same bandwidth, and are controlled as possible as we can to have the same transmission time and octets. The simulation environment is shown in *Figure 19*. Here the Apache Web Server is used to be the codebase of the PBBS Policy Maker (together with the Policy Converter) and Report Viewer (including user report, manager report and bills generator). The reason to use Apache as the web server in this implementation is that it's easier to config (compared to the IIS of Microsoft) and supports the platforms of both Windows and Linux. Besides, it's free.

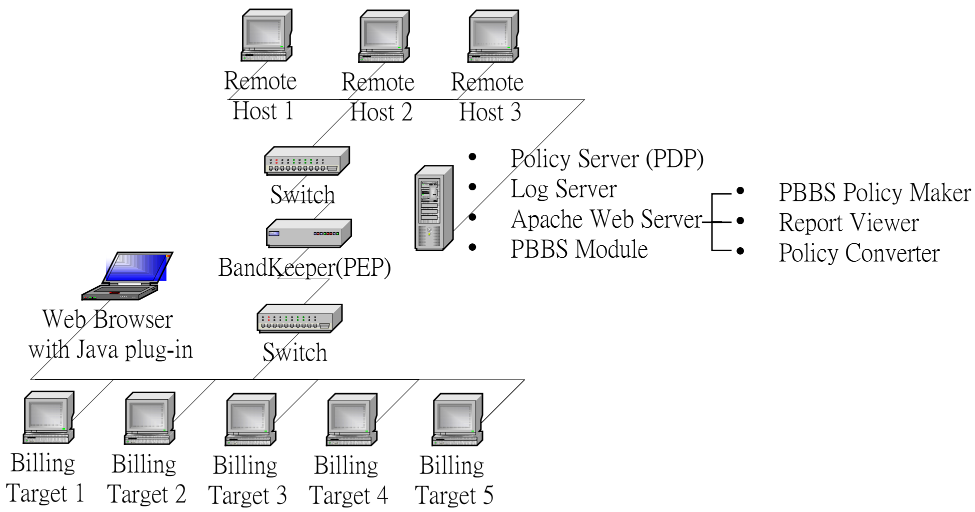

Figure 19 The environment of the implementation of PBBS

The Pricing scheme and charging formula for each billing target is shown in *Figure 20*. Target 1 and 2 are applied with the pricing schemes mostly used new by the ISPs (flat rate pricing and duration-based pricing). Target 3 is applied with the volume-based pricing and the host quota is limitted to 1 Gbytes at most. Target 4 is applied with service-based pricing and the Ftp service is charged with higher price than other services. Target 5 is applied with online-bandwidth pricing. The fee for consumed bandwidth lower than or equal to 256 kbps is 0.5 dollars per minute (the default fee), and for bandwidth higher than 256 is 1.5 dollars per minute.

The bandwidth of all the targets are committed 512 kbps, which is specified in the charging policies. To generate identical and stable traffics for each billing target, a traffic generation tool called *Catapult* is used. The Catapult can build the required connections between two hosts according to the specified protocol type (TCP or UDP), service port and data size. The traffic test patterns for the targets are shown in *Figure 21* and the result of simulation is shown in *Figure 23*.

The simulation shows that the total cost varies greatly between different pricing schemes. In this case the volume-based pricing produced the largest cost far away than all other pricing schemes. To decide a reasonable charging method, many comercial issues and trade off between users and service providers have to be taken care, and is beyond the scope of this paper.

Billing Targets	**Pricing Scheme**	**Charging Formula ($: NT)**
Target 1	Flat rate	*UC = Frcombw, Frcombw = 500*
Target 2	Duration-based	*UC = Frcombw * Tuse, Frcombw =0 5/min*
Target 3	Volume-based	*UC = (Fbwd_useo * Ouse)+ (Fhq_useo * Oexceed), Fbwd_useo=1.0/MB, Fhq_useo=2.0/MB*
Target 4	Service-based	*UC = (Fserv_ftp * Tuse_ftp) + (Fserv_other * Tuse_other), Fserv_ftp=1.5/min, Fserv_other=0.5/min*
Target 5	Online-bandwidth based	*UC = Fbwd_uset * Tuse_bwd + FbwOver256_uset * Tuse_bwOver256, Fbwd_uset=0.5/min, FbwOver256_uset=1.5/min*

Figure 20 Pricing scheme for each billing target

Protocol Type	**Port**	**Duration Time (min)**	**Date Size (Kbyte)**	**Source**	**Destination**
TCP	23 (Telnet)	10	307200	Billing Targets	Remote Host 1
TCP	20 (Ftp data)	60	1843200	Remote Host 2	Billing Targets
TCP	80 (Http)	30	921600	Billing Targets	Remote Host 3
TCP	110 (POP3)	10	307200	Billing Targets	Remote Host 1
UDP	161 (Snmp)	10	307200	Billing Targets	Remote Host 1

Figure 21 Traffic test patterns

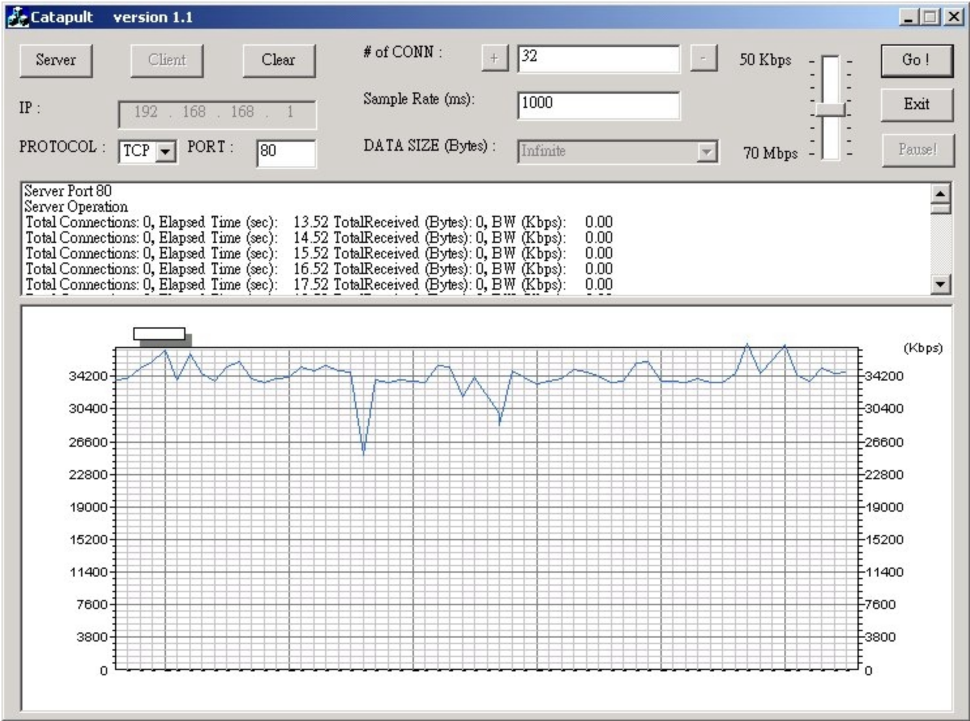

Figure 22 Catapult, the traffic generation tool.

Billing System

Duration: 2001/5/26~2001/6/2

User Policy : UPolicy1

Summary Result on May 27 2001 00:00:00

Date	Host IP	Virtual Line	Total Tx (bytes)	Total Rx (bytes)	Total Time (sec.)	Fee (NT.)
May 26 2001 00:00:00	192.168.168.1	Line1	1887437120	1887440103	7205	500.0
May 26 2001 00:00:00	192.168.168.2	Line2	1887442310	1887436872	7198	59.9
May 26 2001 00:00:00	192.168.168.3	Line3	1887437223	1887436995	7203	3104.0
May 26 2001 00:00:00	192.168.168.4	Line4	1887441237	1887438731	7256	120.7
May 26 2001 00:00:00	192.168.168.5	Line5	1887439963	1887447218	7212	179.3

Figure 23 A snapshot of the bill.

5. Conclusion

As the network provider's trend is to provide leveled services and guaranteed QoS to the users, a mechanism to charge for the services and bill the users becomes an important issue both from the commercial point of view and the management point of view. This paper proposes the Policy-based Bandwidth Billing System and the Policy-based pricing scheme that can handle all kinds of pricing situations and can meet most network providers' requirements. It can be applied to a campus, a high building, the intranet of an enterprise, an ISP, or other IP based networks to construct a service-guaranteed network environment. The users can decide to have better QoS and more bandwidth with higher payment, or the normal QoS and bandwidth with less cost.

The PBBS is currently based on the BandKeeper that is already a commercial product and is been widely used. However, there are still many kinds of policy-based network management system available and with the similar functions. A billing system had better not be restricted to a specific bandwidth management system and should take advantage of the existing one. A common interface and secure communications between the billing system and the bandwidth management system is further issues to be studied. Furthermore, when the Service Level Agreements (SLAs) is applied, the decision and making on the charging policies and bandwidth policies should have some adjustments according to the contracts between providers and consumers. It remains an interesting open issue about the integrating of the policy-based billing and the SLA.

References

[1] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang, and W. Weiss. "*An architecture for differentiated services*," RFC 2475, Network Working Group, Dec 1998.

[2] M. Stevens, W. Weiss, H. Mahon, B. Moore, J. Strassner, G. Waters, A. Westerinen, and J. Wheeler, "*Policy Framework*," draft-ietfpolicy -framework-00.txt, Internet Draft, September 1999.

[3] Hugh Mahon, Yoram Bernet, Shai Herzog, "*Requirements for a Policy Management System,*" IETF Internet Draft, October 22 1999.

[4] G. Carle, S. Zander, and T. Zseby "*Policy-based Accounting,*" draft-irtf-aaaarch-pol-acct-02.txt, Internet-Draft, March 2001.

[5] R.J. Edell, N. McKeown and P.P. Varaiya, "*Billing Users and Pricing for TCP*," IEEE JSAC, Sept. 1995, vol. 13, no. 7

[6] Xin Wang and Henning Schulzrinne "*Pricing Network Resources for Adaptive Applications in a Differentiated Services Network,*" In Proc. IEEE INFOCOM 2001.

[7] Jörn Altmann and Karyen Chu "A Proposal for a Flexible Service Plan that is Attractive to Users and Internet Service Providers" In Proc. IEEE INFOCOM 2001.

[8] F. Hartanto and G. Carle. "*Policy-based Billing Architecture for Internet Differentiated Services,*" Proc. of BC'99, Hong Kong, November 1999.

[9] J. Vollbrecht, P. Calhoun, S. Farrell, L. Gommans, G. Gross, B. de Bruijn, C. deLaat, M. Holdrege, D. Spence, "*AAA Authorization Framework*," Informational RFC 2904, October 2000.

[10] Misuhiro NAKAMURA, Masakazu SATO and Takeo HAMADA "*A Pricing and Accounting Architecture for QoS Guaranteed Services on a Multi-Domain Network,*" Globecom'99.

[11] Ayalvadi Ganesh, Koenraad Laevens and Richard Steinberg "*Congestion pricing and user adaptation,*" IEEE Infocom 2001.

[12] Nen-Fu Huang, Chuan-Pwu Wang, Chien-Yu Yeh and Ru-Lin Tsai "*The Design and Implementation of Policy-based Network Bandwidth Management System,*" Journal of Internet Technology, July 2000.