Charging and Revenue Estimation for the WiMAX System

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ABSTRACT

In the near future it is foreseen that a genuine multimedia service over the WiMAX system is provided in a worldwide manner by exploiting the QoS technologies introduced in the wireless and wired broadband network. In this work we propose a pricing scheme for the multimedia service over the generic WiMAX system that supports a full QoS functionality. We assume real-time services such as the voice and video as well as the nonreal-time service such as the conventional high-speed data, and we propose a pricing and charging scheme for those services by investigating the inherent characteristics of those services and the multiple-class of QoS-service provided to them. After that we propose a method to compute expected revenue that is obtained from the WiMAX system by using an analytic method to estimate the usage of the bandwidth resources for the different class of services. Via numerical experiment, we verify the implication of the work.

Keywords : WiMAX system, Multimedia service, QoS guarantee, Pricing, Charging, Revenue estimation

Ⅰ. Introduction

Mobile multimedia service is recognized as one of the most promising business models in the near future. WiMAX (Worldwide interoperability for microwave access) service is one of the complementary solutions that can replace an ADSL in a dense urban area by offering mobility as well as broadband bandwidth connectivity to users that require the broadband wireless access networks. WiMAX service is based on an IP-based IEEE802.16 standard, and it will provide the users with a high-quality multimedia service by using QoS (Quality of Service) technologies and mobility management. WiMAX service will prevail in the near future as it is determined as an international standard by ITU-T in the October 2007 meeting.

On the other hand, the current WiMAX system is operated in a best-effort manner, the main reason for this is two: First, there is no incentive in adopting the technologies for the QoS guarantee under the current flat pricing. Currently, the market for the ISPs (Internet service providers) is very competitive and ISPs are struggling for the market share by discounting the charge without specific technological differentiation. Second, by maintaining the best effort service, ISPs can save the cost of the additional network design as well as escaping the complexity of the network operation. As such charging is determined almost in a flat rate manner. For example, a company currently suggests a Wibro (Wireless Broadband) services with the following charging policy: The basic menu is a monthly charge of 10$ with basic data volume of 1Gigabyte and 2.5 Cents per additional usage of 1Megabytes[1]. Note that this is basically a flat rate charging if a user abides by the basic usage, whereas if a user overuses the service in excess of the basic usage it is a hybrid of flat and volume charging. A detailed description on the architecture of current pricing for the Wibro service is given in [2]. Note that this basic service menu has a few drawbacks. First, it is not friendly to the light users, since no incentive is given to them for not using the allocated volume. Second, it does not take into account the QoS guarantee (alias, service differentiation) in the charging policy. It just concerns the byte count, which is not faithful to the generic attributes of

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Paper number : KICS2008-11-504, Manuscript received : 2008년 11월 14일, Final manuscript received : 2009년 3월 3일

WiMAX system where guarantee of QoS is one of the major attributes of the system.

However, if a realistic multimedia service is provided by the WiMAX network, different kinds of media requires different levels of QoS along the end-to-end path of the network. To that purpose all the nodes composing the path have to employ a packet scheduling scheme, which will be based on the DiffServ (Differentiated service) architecture of the Internet. This motivated a necessity for a new pricing scheme that takes into account the QoS differentiation.

Now let us summarize the basic principle for the WiMAX services, from which we argue that a new pricing scheme has to be devised for more efficient operation of the WiMAX network. First, let us review the generic philosophy for the pricing. The pricing model affects the behaviors of users: when the price is high, users refrain from using the network, and vice versa. This implies that a well-established pricing model affects the behavior of users in the amount of consumed bandwidth, via which it can be used as a measure for controlling network congestion by discouraging the users from overloading the network. This in turn increases the revenue of the ISPs because they can accommodate more users if every user refrains from overloading of the network bandwidth.

Pricing for the Internet service has been an active research topic. There exists lots of literature for the Internet pricing, thus we do not intend to cover all the research work here. Instead, we touch a few works that is most related to our work. In the initial stage of Internet, flat pricing and usage-based pricing have been widely used. When it comes to the pricing of wireline Internet, almost all the Internet services are based on flat pricing. As to the usage-based pricing, pricing is purely based on the usage of the bandwidth, and one can find related works at [3,4,5,6].

Recently, the focus on the Internet pricing is given to the QoS-enabled networks services. As such there exists lots of literature that deals with the incentive of provisioning the QoS in Internet pricing. On the other hand, when it comes to the mobile Internet services, pricing is usually based on the usage basis, e.g., per-packet charging. The main reason for this disparity comes from the scarcity of the wireless frequency.

Now let us consider the pricing scheme from a different point of view. When the bandwidth is demanded by a connection in an inelastic manner, such as the voice channel of PSTN or cellular phone, the ideal pricing scheme is to charge the call by a fixed and flat rate pricing that levies a fixed amount of charge to a peak rate, and the total charge is computed as a time charge which computes the time duration during which a connection is held.

On the other hand, when the bandwidth is demanded by a connection in an elastic manner, the ideal pricing scheme is to charge the call by a versatile pricing scheme such as the volume pricing or sustained bandwidth pricing[7], where price is levied to a connection based on the volume of the data or the amount of bandwidth that is sustained to a connection.

Note that the above works are established over a wired Internet. Also, the main issue for those schemes lies in the determination of the tariff function by investigating the value or utility of the service provided by the network. When it comes to a QoS-pricing per se, there are diverse ranges of literature that focuses on the guarantee of QoS itself as well as the prevention of congestion. A discussion for the congestion avoidance is evolved to the pricing the QoS network with the adoption of CAC (connection admission control), via which the QoS of existing flows can be consolidated. Li et al. summarized that the main purposes of the ISPs for introducing the pricing scheme for the QoS-enabled networks is categorized into three areas: achieving economic efficiency and optimality of the network, providing better QoS guarantee to the customers, and implementing simple and scalable pricing machine[8].

Now let us investigate the pros and cons of those three purposes. The first purpose is known to be hard to be realized or even impossible to achieve as the scale of the problem is large, and so Li et al.

argue that maximal simplicity is often more important than maximal efficiency. Our opinion from the past experience is that the price of network service is determined not by system optimality but by the policy of the ISP, which is similar to Li et al.'s argument.

The second purpose is actively discussed in the academia by coupling the problem of QoS guarantee and corresponding pricing scheme. Two main examples are pricing for the IntServ and DiffServ networks. The former assumes per-flow pricing for the guarantee of deterministic QoS, which is carried out at the edge of the network, which is categorized as an edge pricing[9]. Note that pricing for the IntServ network has a scalability problem due to hugh number of flow state. The latter assumes the guarantee of statistical QoS to aggregated packets, which is carried out at the core of the network. Note that the provision of QoS at the DiffServ network is realized for the aggregated traffic. As such the target of the pricing is aimed at the aggregated traffic. By pricing the DiffServ network based on the QoS for the aggregated traffic ISP can avoid the complexity of the implementation, because it does not require fine granularity in the calculation of the usage of the individual flow. It is usual that a pricing scheme for the aggregated traffic uses per bandwidth accounting instead of the per packet accounting, and so this is suitable to the enterprise users. However, this scheme can not charge an individual flow.

Finally, the third purpose is born from the limits of those two purposes mentioned above. Shenker et al. suggest an edge pricing for a flow by using the information for the path and transmission rate of a flow, which is connection-oriented[9]. This is feasible because the scale of users in a single edge node is not so big. Odlyzko proposes a PMP (Paris Metro Pricing) scheme where the network resource is partitioned into several logical subnetworks, and different price is levied to each subnetwork[10]. Ozianyi et al. argue that this scheme assumes non-sharable network resources between different logical subnetworks, so that it is not adaptive to congestion inside the individual subnetwork[11]. Also, it has low utilization when there is an unbalance in the traffic volume between the different classes.

However, we argue that the capacity of the future Internet is growing fast, and we will gain much from the advantage of simplicity in the implementation at the expense of maximal efficiency in the network capacity. From this fact, it is known that research focus for the pricing has shifted to the simplicity and scalability issues[8].

Now let us return to the discussion of the WiMAX system. Contrary to the proliferation of discussion about WiMAX service itself, little work is done about the pricing scheme for this service. In [12] we can find several schemes for the pricing the third generation (3G) mobile services, from which a direction to the pricing of WiMAX service can be deduced. However, they did not give a detailed method about charging multiple classes of services. Ozianyi et al. suggest a pricing scheme for the three-class DiffServ services on the setting of 3G services[11]. They classified the DiffServ services into platinum, gold, and silver service. And, they propose tariff formulas for the platinum and gold services, which are based primarily on the demand for the bandwidth of each class. However, contrary to their assumption on the setting of 3G services, we could not find the attributes of the network services specific to 3G networks.

Kannisto et al. propose an adaptive scheduling method for the WiMAX system[13], where they argue that the revenue increases linearly as a function of the perceived QoS such as the delay and loss. They assume a WRR (Weighted round robin) scheduler for the general number of service classes, and they suggest a pricing function as a function of expected delay. By using the revenue maximization algorithm, they obtained a mathematical formula for the upper bound of revenue. However, we argue that it is not simple to connect the delay performance of the WiMAX network to a pricing function if we have no solid basis for the mapping between the NP (Network Performance) and QoE (Quality of Experience) felt by a user, which is actually not established, yet.

As an alternative way for pricing the QoS-based WiMAX service, we proposed a universal framework for pricing the WiMAX service[2], where the price is based on the attributes of each service class of the WiMAX system such as the unsolicited granted service, polling service, and best effort service. The proposed scheme incorporates the generic principle of the WiMAX system such that unsolicited granted service is charged by peak rate, polling service is charged by statistical rate, and BE (Best Effort) service is charged by actual usage.

Recently, we found that we have to redefine the service class in more detail such that polling service is subdivided into real-time and nonreal-time. We also argue that BE services may be exempted from usage-based charging, because they receive no QoS service from the network. We also found that the work in [2] did not present a method to compute revenue that can be obtained from provisioning of multiple classes of service in the WiMAX services, which is very important in the design and operation of the WiMAX network.

Bearing in mind those facts, this work extends the work proposed in [2] toward charging and revenue estimation for the realistic multiple classes of services provided by a WiMAX system. To that purpose, let us propose a method to compute the expected revenue seen from the service provider by estimating the usage of each class of service in the WiMAX system. To the best of authors' knowledge, this is the first attempt to establish a framework for estimating the price and revenue for the multiple classes of services for the genuine WiMAX system.

This work is composed as follows: In Chapter II we propose a framework for pricing the genuine WiMAX service that incorporates multiple service classes. In Chapter III we present a pricing function for different types of service. In Chapter IV we present an analytic model to estimate the revenue that is expected from accommodating the customers. In Chapter V we present numerical results. Finally, in Chapter VI, we summarize our work.

Ⅱ. Pricing the WiMAX service

2.1 WiMAX system and class of services

First let us describe the basic framework for the WiMAX system, which is composed of a convergence of the wired and wireless networks. Strictly speaking, only the link between the end users and base station is wireless, and all the other elements are based on the wired network. It is usually known that the backbone network of the WiMAX services is constructed by an MPLS-enabled IP network. Therefore, a reliable path with guaranteed QoS is set between edges of the backbone. When the current IP network is used as a backbone, it is sufficiently over-provisioned with utilization no greater than 0.5. For example, less than 10 percent of the links in the backbone experience utilization higher than 50 percent[14]. Therefore, little concern about QoS has been given to the backbone, and this is one of the reasons a QoS-free flat pricing scheme is used for the current WiMAX services.

On the other hand, when it comes to the wireless part of the network, the most severe environment for QoS is the area between the end users and base station. Finally, the area between the base station and the edge of the QoS-enhanced IP network is looked upon as an aggregation / distribution region, and it is also a wired network.

There exist diverse service menus in the WiMAX system: conventional voice calls, mobile Internet, video/music download, on-line gaming, M2M (Machine-to-Machine) communications etc. We think that all of these services will be provided by the WiMAX system in the near future. In WiMAX service, guarantee of different QoSs to different services is assumed to provide QoS-aware transmission for various applications, and usually there are three service classes: UGS (Unsolicited Granted Service), PS (Polling Service), and BE (Best Effort) service[15].

First, UGS is defined to require absolute and strict (hard) guarantee of bandwidth to a connection in an end-to-end manner so that strict delay requirement of real-time service is guaranteed. Voice over IP application without silence suppression belongs to this class. This class is analogous to a constant bit rate (CBR) service of the ATM network or expedited forwarding (EF) service of the IP network. Therefore, a fixed size of grant is allocated to this class irrespective of the state of the network.

Second, PS includes traffic generated from bursty applications with soft QoS requirements. There exist two kinds of service for this class: PS for real-time service (rt-PS) and PS for non-real-time service (nrt-PS). Real-time service requires strict delay guarantee, example for which includes VoIP, video streaming, and interactive real-time game service. This class is analogous to a real-time variable bit rate (rt-VBR) service of the ATM network or assured forwarding service of the IP network. The applications for the rt-PS require a variable grant size (contrary to the minimum size for the nrt-PS) per cycle from the system, since those services generate packets in a periodic manner throughout the flow connection. Non-real-time service can tolerate a certain amount of delay for the packet, but tolerance for the packet loss has to be kept to a certain level. Examples for this class include web browsing, e-commerce, ftp and HTTP, which require guarantee of a minimum amount of bandwidth throughout the connection holding time. This class is analogous to a non-real-time variable bit rate (nrt-VBR) service of the ATM network or assured forwarding (AF) service (with lower subclass) of the IP network. The applications for the nrt-PS require a minimum size of grant per cycle from the system, since those services generate packets in a stochastic manner throughout the flow connection.

Finally, BE service requires no delay/loss QoS guarantee as well as no data rate to an individual flow. E-mail belongs to this service class. This class is analogous to an unspecified bit rate (UBR) service of the ATM network or best effort service of the IP network. As such no pricing related to the provision of QoS may be levied to a flow.

As one can find from this classification of the service class of the WiMAX service, each class of service requires different treatment of the packet. There exist lots of schemes that deal with the provision of QoS in the WiMAX network: scheduling of packets at the MAC (media access control) layer, resource management at the packet and flow level, CAC at the flow level, etc. Among them, the resource allocation may act as a major role in the pricing of the multimedia services over the WiMAX system. This is because the limited bandwidth resource for the up and down link of the WiMAX system is divided into different service classes, and the reward for the provision of QoS is determined from this policy.

When it comes to the allocation of bandwidth to each class, there exist lots of policies such as complete partition, partial sharing, and complete sharing, etc. Among them, it is envisaged that an adaptive channel allocation is most suitable to the WiMAX system since it can reflect the dynamic behavior of the number of users in a realistic manner.

When it comes to the revenue maximization problem for the multi-class wireless network, there exist many literature (See [16] and the references therein), and it is out of the focus of this work. Instead, this work assume that the total bandwidth resource for the WiMAX system is divided into two typical ways. First, a bandwidth is divided into uplink and down link. Second, the uplink is divided into three logical channels for the UGS, rt-PS, and nrt-PS, which is denoted as C_U, C_{rtPS}, and C_{nrtPS}, respectively. Note that no bandwidth is allocated to the BE service. BE service uses bandwidth that is unused by other classes in a best effort manner.

A method to physically partition each bandwidth area is implicitly implemented by a bandwidth allocation scheme as well as the packet scheduling algorithm in the system. But, this is optional to the system maker, and we do not specify a special scheme in this work.

2.2 Pricing scheme for the WiMAX services

Now let us turn to the pricing scheme, and let us investigate the problem inherent in the current volume-only pricing scheme seen from the attributes of the WiMAX service, which lies in the ignorance of service class and incentives accompanied by the support of QoS for different service classes. We argue that different classes of service have to be treated in different manners by way of the service scheme introduced in the WiMAX service, via which different rewards are brought to the ISPs so that the price has to be levied according to the difference in the QoS. This motivated our proposition of a new pricing scheme for the WiMAX system.

There exist lots of schemes in pricing Internet service, typical of which includes fixed and flat pricing (FP), volume pricing (VP), committed rate pricing (CRP), etc. FP levies a charge to a user irrespective of the usage of the network resource, which can be found in the current ADSL (Asymmetric digital subscriber line) service, where a user is charged by a fixed amount of monthly fee to the always-connected Internet service. VP levies a charge to a user based purely on the usage of the network resource, which can be found in a data service over the cellular phone, where the charge is levied for the number of packets or messages. CRP levies a charge to a user for the rate that is committed to a certain size of the network resource, which can be found in the VPN (Virtual private network) service, where a fixed amount of charge is levied to an enterprise user by guaranteeing a certain amount of bandwidth for a specified period (e.g., month, year, etc.) exclusively to the company.

When it comes to Internet services such as file transfer and e-mail, some users prefer VP to FP. This scheme may be preferred by light users who use small amount of bandwidth. On the other hand, some users may want flat pricing because they do not want to mind the price every time they send packets to the network. Recently, it is known in the field of wired network that a sustained rate pricing (SRP) is considered to be suitable to the flows that transmit bursty traffic[7]. SRP levies a charge to a user based on the guarantee of a certain amount of bandwidth with probability. Note that this complies with the pricing of effective bandwidth at the ATM/IP network.

However, to the best of our knowledge, we could find no explicit pricing function that faithfully incorporates the service class of the WiMAX service, yet. So, let us propose a new pricing scheme for the WiMAX service that takes into account different QoS-service classes such as UGS, rt-PS, and nrt-PS classes. To that purpose, let us develop a framework for the pricing of WiMAX service, which is given in three generic attributes: First, Pricing for each connection is based on the guarantee of bandwidth. For example, $f(x)$\$ is levied to each connection for the use of x bps, so that each connection is charged by a unit of bandwidth provided to it.

Second, a total charge is computed by the time duration, so that $f(x) \times \tau$\$ is levied to a connection if it consumes x bps for τ seconds. Finally, pricing for the guarantee of QoS is based on the class of service that is defined by a WiMAX system. A premium service such as UGS is charged by a CRP that takes into account the hard QoS, which is represented by hard guarantee of bandwidth resources. As to a sub-premium service such as rt-PS and nrt-PS, it is charged by an SRP that takes into account the soft QoS, which is represented by statistical guarantee of bandwidth resources. Finally, as to the BE service, it is not charged for the use of bandwidth, because no QoS is provided to that service. Instead, a basic subscription charge is levied to the user.

2.2.1. CRP for the UGS class

The basic principle behind the CRP is its simplicity in the pricing architecture by reserving peak bandwidth, say $\triangle$bps, to the connection and levies a fixed amount of price to the connection. In CRP, users can use a bandwidth resource up to the preset limit $\triangle$bps during the contraction period. ISP does not mind whether the user is actually using the bandwidth up to $\triangle$bps or not, so that ISP does not measure the usage of bandwidth except measurement of the duration of a connection. The main advantage for this scheme is that it is simple to the users as well as to the network operators.

2.2.2. SRP for the PS class

In SRP, the user and ISP exchange a service contraction concerning the required bandwidth for the connection in a statistical manner. Allocation of bandwidth in a statistical manner implies a probability to the guarantee of QoS to a user, so that a probabilistic guarantee of bandwidth is promised rather than an absolute guarantee of bandwidth. There exist two different types of SRP for the PS class: One is for rt-PS class, and the other is for nrt-PS class, which will be described in more detail.

2.2.2.1 SRP for rt-PS class (rt-SRP)

To support a connection of an rt-PS class, network has to provide the connection with at least Λbps of bandwidth throughout the connection holding time. Since the frequency resource of wireless network is versatile, we have to model such a requirement in a stochastic manner such that guarantee of bandwidth resource is provided with probability up to ϕ per cent. This implies that Λbps of bandwidth is sustained to the connection with maximum probability of ϕ per cent. To do that, the network operator has to monitor the usage of the user in a statistical manner, which is depicted in the following discussion.

Starting from the initiation of the packet transmission, the network operator maintains a trace for the user's usage by a sampled measurement of the usage history. The sampling frequency is determined appropriately by a network operator (typical sampling interval is 1 or 10ms) and a fixed-period packet sampling is sufficient to be used in estimating the transmission rate of a flow[17].

The basis for the pricing is given for the two cases:

Case 1 (Contraction kept) : When ISP finds that more than Λbps is consumed by a connection no more than ϕ per cent of the observation time, the network operator charges a fixed amount of money, say $g(\Lambda)$ \$ per second, where $g(\Lambda)$ is determined by a market force. Here, user may transmit bursty traffic up to the peak rate upon which the user is subscribed to the network, which is usually greater than Λbps, during the connection time without extra charge if and only if the contraction is not violated. On the other hand, when a user does not use the negotiated amount of bandwidth, no redemption is done.

Case 2 (Contraction violated) : If, at the end of the transmission, it is found that more than Λbps is consumed by a connection for more than ϕ percent of the observation time, a maximum charge of $g(M)$ \$ per second is charged to the user, where M is the maximum link capacity of the user.

2.2.2.2 SRP for nrt-PS class (nrt-SRP)

To support a connection of an nrt-PS class, network provides the connection with a minimum of Γbps of bandwidth throughout the connection holding time. Even though the frequency resource of wireless network is versatile, ISP has to guarantee a minimum bandwidth resource to each flow. As such, no precise monitoring of the detailed usage of the bandwidth is carried out in this class. ISP monitors the duration of the flow, via which a total charge is computed.

Summarizing the attributes of the WiMAX service and corresponding pricing schemes, we can obtain the following table.

2.3 Overhead in the measurement

As we have discussed in the above subsections, each pricing scheme has different overhead in the measurement of the data for the pricing. First, let us consider the CRP. CRP permits free use of bandwidth up to the preset limit, and ISP does not mind whether the flow actually uses the bandwidth or not. Price is computed in the unit of the duration of the flow.

Therefore, ISP monitors the flow duration time only, which is simply obtained by the log data of the control signal in the session initiation protocol that is used in the initiation and termination of the connection. Computational complexity of the CRP is

Table1. Attributes of WiMAX service and pricing

Service class		QoS	Bandwidth allocation	Pricing
UGS		Strict delay, jitter, loss	Reservation-based peak rate	CRP
PS	rt-PS	Delay sensitive	Sharing-based sustained rate	rt-SRP
	nrt-PS	Loss sensitive	Sharing-based minimum rate	nrt-PS
BE		Not applied	Residual rate, but bandwidth is not allocated	Not applied

just a single addition (in fact minus operation) throughout the flow duration.

Next, let us consider the rt-SRP. The usage of the bandwidth is monitored in a statistical manner and in a periodic time interval such as 1 second or 10 ms throughout the flow duration. The flow duration is obtained in the same way as that of CRP. Computational complexity of the rt-SRP is *O(m)* additions, where m is the number of samples, and a single multiplication.

Finally, for nrt-SRP, flow duration is monitored. Therefore, the overhead is the same as that of CRP.

Ⅲ. Pricing functions

Let us define the pricing function for each service type. In order to compute the price for the flow, let us define a flow and a method to measure parameters from the flow. Flow is identified by generic flow identifiers such as the source/destination IP address, source/destination port number, and protocol field. The flow duration is measured by the start time and end time for each flow, which can be computed by observing the time stamps between the packets with SYN and FIN flags. The flow size is calculated by summing up the packet length field in the packet, from which the data rate can be computed.

Price for each class of service is charged to a flow by one of the following schemes.

3.1 CRP

Following the basic principle for the CRP, ISP levies price to a connection by a function of the committed bandwidth Δbps, which is given by $f(\Delta)$ \$ per second. The function $f(\Delta)$ can be determined by considering various parameters concerning the service, which will be illustrated in the numerical experiment.

When the duration of a connection with committed rate of Δbps is *T*, the charge for a connection is given as follows:

$$\psi^{CRP} = f(\triangle) \times T[unit: \$] \qquad (1)$$

Note that the charge is levied to a connection even though the connection does not use the reserved bandwidth of Δbps.

3.2 SRP

As we have described before, we have two methods for the allocation of bandwidth and corresponding pricing for the PS class: rt-PS and nrt-PS.

3.2.1. SRP for rt-PS class (rt-SRP)

Following the basic principle for SRP, the price is determined as follows: ISP levies price by a function of the sustained bandwidth to the connection, which is given by $g(\Lambda)$ \$ per Λbps, where Λ is the amount of bandwidth sustained to the connection during its connection duration. The sustainment of the bandwidth is defined by a probability, which is represented as follows: When the instantaneous rate of a flow is $a(t)$, and if the duration of a flow with sustained rate of Λ bps is *S*, the charge [unit:\$] for a flow is given as follows:

$$\psi^{SRP}_{rt-PS} = \begin{cases} g(\Lambda) \times S, \text{if } P(a(t) > \Lambda) \le \phi \\ g(M) \times S, else \end{cases} \qquad (2)$$

where M is the maximum link speed that is allowed to a flow. Note that a fixed price $g(\Lambda)$ is levied to a flow even though the flow does not send packets to the network during its connection time, which is similar to CRP. Instead, no extra price is charged to a connection for the excess use of the bandwidth which exceeds Λbps if and only if the percentile of $a(t)$ that exceeds Λbps is less than ϕ.

Note that we can practically measure $a(t)$, and let us also assume that it is normally distributed with mean m and variances σ^2. Then we can obtain the following relation, which is obtained by normalization operation for condition in the upper part of eq.(2)[18]:

$$Q\left(\frac{\Lambda - m}{\sigma}\right) \le \phi \qquad (3)$$

In (2) $Q(x)$ is a Gaussian error integral, which is usually known as a Q-function. Note that our purpose is to get a formula for Λ, which is obtained from the inverse operation of inequality (3), and it is given as follows:

$$\Lambda = m + \sigma \times Q^{-1}(\phi) \tag{4}$$

Note that we can compute Λ if we have information about the attributes of the source traffic profile as well as the target value ϕ.

3.2.2. SRP for nrt-PS class (nrt-SRP)

The price for the nrt-PS class is determined in a different way compared to that of rt-PS class, which is given as follows: ISP guarantees a minimum bandwidth Γ bps to an nrt-PS flow and levies price by a function of the sustained minimum bandwidth to the connection, which is given by $h(\Gamma)$ \$ per Γ bps, during its connection duration. Because the probability of guaranteeing a minimum bandwidth is almost sure, no probability is introduced in this class. Therefore, this scheme corresponds to a CRP scheme.

Note that a fixed price of $h(\Gamma)$ \$ is charged to a flow even though the flow does not send packets to the network during its connection time, and instead no extra price is charged to a connection for the temporary excess use of the bandwidth which exceeds Γ bps. Note, however, that the network does not allow excess bandwidth (in terms of the average rate) other than the minimum bandwidth Γ bps to the nrt-PS class by using a bandwidth allocation scheme inherent in the WiMAX system.

Ⅳ. Estimation of revenue

In section III we have determined the price of using the bandwidth by a single connection. ISPs can collect charges from all the users that had been engaged in the transfer of data through the network, which is called the revenue. In order to estimate the revenue of the ISP one has to know the usage of the bandwidth consumed by customers in the WiMAX system. A WiMAX system can accommodate multiple types of service such as voice and video as well as data. As we have mentioned before, we can map each application service (voice, video, and data) into each QoS class (UGS, rt-PS, nrt-PS or BE service), respectively.

Bearing in mind this fact, we argue that the bandwidth resource of the WiMAX system can be looked upon as a Russian doll. The concept of Russian doll model is first argued at the IETF as a means to allocate a limited bandwidth resource of IP network into a number of logical groups, which is based on the concept of DiffServ QoS classes[19]. Let us assume that the total bandwidth capacity of a WiMAX system is C [unit: Mbps]. Four generic QoS classes such as UGS, rt-PS, nrt-PS, and BE share and compete for the access of the bandwidth C according to a bandwidth allocation scheme, which is realized by packet scheduling scheme in the MAC layer. The packet scheduling scheme for the WiMAX system is assumed as a proprietary of venders. From the generic attributes of the WiMAX system the following packet scheduling schemes may be used: Strict priority (SP) scheduling[20], WRR[21] or a variation of those schemes[22].

Jin et al. suggest either SP or dynamic weight scheduler for the DiffServ scheduling scheme[23]. Via numerical experiments, they argue that both schemes work well in the DiffServ networks. But, we need some network mechanism that can limit the flow rates into each class so that minimum QoS is to be provided to a class (especially, to a higher class) or among the different classes[23]. Note, however, this is not the main focus of this work, and it will be remained as a future work. Instead, let us adopt the following approach.

Note that the bandwidth for the UGS class is absolutely guaranteed at any situation in the system, which necessitates the use of any form of SP scheduling scheme for the UGS class. Yamauchi et al. argue that SP scheme acts almost in the same manner as that of a dedicated link to voice packets [24]. But, if one use an SP scheme, connections of type UGS can monopolize the bandwidth capacity C with absolutely high priority over the other classes. This presents a starvation problem for the lower classes. However, it is usual that a CAC scheme is introduced in the multi-service networks, so that there is an upper limit in the number of flows for the highest class, which acts as a delimiter of bandwidth in the system. In fact, it is known in [20] that the starvation problem is not so evident for the broadband networks if the offered load of the highest class traffic is kept to a certain level. We adopt this concept to the UGS class.

Second, connections of the remaining classes use the remaining bandwidth capacity that has not been consumed by UGS connections. Now the rt-PS and nrt-PS compete for the access of bandwidth that is remained in the system. As we have mentioned before, the QoS class of the WiMAX system can be mapped to that of DiffServ network such that UGS, PS, and BE class is mapped to EF, AF, and BE service, respectively.

The PS class corresponds to AF class. Note that the AF class can be further classified to Gold, silver, and copper subclass, and they are served by a WRR scheduling scheme. In the previous work, we have presented such a scheme for the DiffServ setting in [22]. As such PS can be mapped to two of those subclasses, and rt-PS and nrt-PS can be served by WRR scheme.

Finally, BE connections use the remaining bandwidth capacity that has not been used by connections from UGS and PS.

In the generic WiMAX system, the bandwidth capacity for the UGS is reserved for the deterministic guarantee of QoS, which is denoted by $\overline{C_U}$.

Therefore, the bandwidth compatible to $\overline{C_U}$ is looked upon as a logically separated bandwidth from the total bandwidth capacity C even though one applies a packet scheduling scheme such as SP. Let the residual bandwidth $C-\overline{C_U}$ is denoted by C_R. Again, we can allocate C_R into two logical bandwidth for rt-PS and nrt-PS class, respectively, and let us call it $\overline{C_R^{rtPS}}$ and $\overline{C_R^{nrtPS}}$, respectively.

Summarizing the above-mentioned bandwidth allocation algorithm, we obtain the following result: First, estimate the average bandwidth that is reserved for the UGS class, $\overline{C_U}$. Second, estimate the average bandwidth for the rt-PS class, $\overline{C_R^{rtPS}}$. Then, the average bandwidth for the nrt-PS class is $\overline{C_R^{nrtPS}} = C - \overline{C_U} - \overline{C_R^{rtPS}}$.

Note that the remaining bandwidth resource that is not occupied by the upper classes at every instant of the frame cycle is used by the BE class.

4.1 Revenue from UGS class

In order to estimate revenue obtained from providing the service to the users of UGS class, one has to know the mean usage of bandwidth from those users. Note that, because UGS class recognizes each connection as a logical channel, the bandwidth $\overline{C_U}$ can be mapped to a multiple number of channels with fixed size slot in the frequency spectrum of the WiMAX system. If we assume that the bandwidth requirement of each UGS connection is r_{UGS}, then a maximum of N_{UGS} connections can be accommodated to the system simultaneously, where $N_{UGS} = \left\lceil \frac{\overline{C_U}}{r_{UGS}} \right\rceil$ and $\lceil x \rceil$ is an integer not greater than x.

Now let us assume that UGS class accommodates voice connections, and a WiMAX system with bandwidth capacity $\overline{C_U}$ can accept up to N_{UGS} voice connections. The arrival and service process of the voice connection is characterized by a Poisson and exponential distribution, respectively, with mean arrival rate λ_{UGS} and mean duration $1/\mu_{UGS}$.

Next, we use the M/M/N_{UGS}/N_{UGS} queue model as an abstraction of the voice service over the bandwidth capacity $\overline{C_U}$. Since there are N_{UGS} parallel servers in the system, we can represent the arrival and departure processes with the following parameters:

$$\begin{aligned} &\lambda_n = \lambda_{UGS}, n = 1,2,... \\ &\mu_1 = \mu_{UGS}, \mu_2 = 2\mu_{UGS}, ..., \mu_n = n\mu_{UGS}, ..., \\ &\mu_{N_{UGS}} = N_{UGS}\mu_{UGS} \end{aligned} \tag{5}$$

where n is the number of flow in the system. The offered load to the single server is $\rho_{UGS} = \lambda_{UGS} / \mu_{UGS}$. The probability p_k^{UGS} that there are k connections of UGS class in the system in equilibrium is given by[25]

$$p_k^{UGS} = p_0 \left(\frac{\rho_{UGS}{}^k}{k!} \right), 0 \le k \le N_{UGS} \tag{6}$$

where p_0 is given by

$$p_0 = \frac{1}{\sum_{k=0}^{N_{UGS}} \frac{\rho_{UGS}{}^k}{k!}}.$$

Finally, we obtain the following result for the expected value of the bandwidth from the UGS connections

$$\overline{C_{UGS}} = \Sigma_{k=0}^{N_{UGS}} p_k^{UGS} \times k \times r_{UGS} \tag{7}$$

Once one obtains the mean usage of bandwidth $\overline{C_{UGS}}$ for the users that belong to UGS class, the remained job is to estimate the mean duration of the connection for the UGS service. Finally, the revenue that can be obtained by provision of a voice service to a group of users is given as follows:

$$\Psi_{UGS} = f(\overline{C_{UGS}}) \times 3600 \ [unit : \$] \tag{8}$$

4.2 Revenue from rt-PS class

Let us compute the mean bandwidth that is used by an rt-PS class. As we have mentioned above, the packets generated by a number of flows of an rt-PS class can be served by a bandwidth capacity $\overline{C_R^{rtPS}}$. Let us assume that rt-PS class accommodates a video call that is generated by a Poisson process with the mean arrival rate λ_{rtPS}.

Next, note that the video programs that are produced by a variety of users have a variety of duration times, that is, a video clip lasts only a few minutes, whereas others last a few hours, etc. At present we have no real-field data about the holding time of a video application for a WiMAX service. So, let us assume that the holding time of the video flow follows a general distribution with mean duration $1/\mu_{rtPS}$. Offered load of the system is $\rho_{rtPS} = \lambda_{rtPS} / \mu_{rtPS}$.

Finally, note that the video flows compete for the access of the bandwidth $\overline{C_R^{rtPS}}$ with equal chance. From this argument we can model the video flows to the WiMAX system as an M/G/1 queue with processor sharing service discipline. We have the following formula for the probability p_k^{rtPS} that there are k, $0 \le k \le \infty$, connections of rt-PS class in the system in equilibrium, which is given by.

$$p_k^{rtPS} = (1 - \rho_{rtPS}) \rho_{rtPS}{}^k \tag{9}$$

Finally, we obtain the following formula for the mean of the bandwidth that is actually used by rt-PS class, which we denote by $\overline{C_{\text{rtPS}}}$:

$$\overline{C_{rtPS}} = \Sigma_{k=0}^{\infty} p_k^{rtPS} \times \Lambda_k \tag{10}$$

where $\Lambda_k = k \times m + \sqrt{k} \sigma \times Q^{-1}(\phi)$.

Finally, a revenue that can be obtained by provision of video services to a group of rt-PS users during a busy hour is given as follows:

$$\Psi_{rtPS} = g(\overline{C_{rtPS}}) \times 3600 \ [unit : \$] \tag{11}$$

4.3 Revenue from nrt-PS class

Let us assume that data flows from sufficiently large number of nrt-PS users are generated by a Poisson process with the mean arrival rate λ_{nrtPS}. Let us also assume that the distribution for the size of data file follows a general distribution with the mean service time $1/\mu_{nrtPS}$. Similar to the case of rt-PS flows, we can model the data flows to the WiMAX system as an M/G/1 queue with processor sharing service discipline.

So, we have the following formula for the probability p_k^{nrtPS} that there are k connections of nrt-PS class in the system in equilibrium, which is given by

$$p_k^{nrtPS} = (1-\rho_{nrtPS})\rho_{nrtPS}^{\ k}, 0 \le k \le \infty \qquad (12)$$

where $\rho_{nrtPS} = \lambda_{nrtPS} / \mu_{nrtPS}$.

Finally, we obtain the following formula for the mean bandwidth that is actually occupied by the nrt-PS connections:

$$\overline{C_{nrtPS}} = \Sigma_{k=0}^{\infty} p_k^{nrtPS} \times \Gamma_k \qquad (13)$$

where $\Gamma_k = k \times \Gamma$.

Finally, a revenue that can be obtained by accomodation of nrt-PS class users is given as follows:

$$\Psi_{nrtPS} = h(\overline{C_{nrtPS}}) \times 3600 [unit:\$] \qquad (14)$$

4.4 Revenue from users of BE class

Note that, as we have argued in the above discussion, we do not levy a charge to the BE service class. On the other hand, BE service users pay a fixed monthly charge to ISP for the always-connection fee. The amount of monthly fee is usually determined by a policy of the ISP, and it is out of our discussion

V. Numerical Results

In order to illustrate the implication of the proposed scheme let us investigate two problems: First, let us compute the charge for the individual connection. Second, let us estimate the revenue of an ISP that can be obtained from the WiMAX system, which corresponds to a total charge that can be tolled by a group of users for a defined period of time in the network. The period of time the charging is collected is assumed to be a busy hour. An extension to the charging for the day and month is trivial.

Let us assume that users abide by the service level agreement that is contracted between the user and ISP before receiving the services, so that overcharge due to excess use of the bandwidth is not considered in the experiment.

Note that one may introduce a weighting factor for the unit price of bandwidth between the CRP and SRP. This is because CRP is based on a hard guarantee of reserved bandwidth to a connection, whereas SRP is based on a soft guarantee of statistical bandwidth. Therefore, the value of the reserved bandwidth and the shared one may be different between each other even though the same amount of bandwidth is allocated to a connection. At present we do not have information about the added-value of the dedication over a statistical provisioning for the bandwidth, which is strongly related to the economical aspects of the telecommunication market. Therefore, we assume it as a policy of the ISPs. Instead, let us assume that the added-value of the dedication of a link to a connection relative to a statistical provisioning is *k*, where $k > 1$.

Finally, let us assume that a WiMAX system adopts a linear pricing policy, which is based on the usage 10$ for data volume of 1Gigabytes, which is called the unit-usage price.

5.1 Charge for the individual service

First, let us estimate the price of individual service for the WiMAX system by assuming typical application for each class. We assume phone service, video transmission, and file transfer for the UGS, rt-PS, and nrt-PS service class, respectively.

5.1.1 Charge for the phone service

Let us assume that a phone service is subscribed as a UGS class in the WiMAX system, so that it is levied by CRP. Let us assume that the phone service has the following traffic parameters: Voice call uses ITU-T G.729 voice encoder, which is used as a coding scheme for the cellular phone. The packet length is 76bytes and packet generation period is 20msec. This corresponds to 30.4Kbps of link speed for a connection. Therefore, 30.4Kbps of bandwidth is allocated to a flow as a committed rate throughout the connection holding time. The flow duration *T* is assumed to be 3 minutes. Then, the amount of data is 684Kbytes. Therefore, we obtain *f(30.4Kbps)*=0.68 Cents.

Next, let us assume that *k=2*. Then, a user pays 1.37 Cents to a WiMAX service provider for their 3 minutes voice conversation over a reserved bandwidth of 30.4Kbps of link speed. Note that this is very cheap as compared with current PCS price, where 36 Cents are levied for a call with 3 minutes. This implies that the current price for a voice service has to be reduced to a substantial amount when it is evolved to a future WiMAX service.

5.1.2 Charge for the video transmission

Now let us assume that a video connection is subscribed to the WiMAX system as an rt-PS class, so that it is priced by an rt-SRP scheme. Now let us assume a music video with the following traffic parameters: A video file is in the form of MPEG-1 with pixel size 320×240. The bit rate of the video file has a mean 2Mbps and standard deviation 0.6. The duration of a music video is 9 minutes. The percentile of the sustained rate provided by the ISP is assumed to be 95%.

From these parameters we can compute the sustained rate given by $\Lambda = m + \sigma \times Q^{-1}(\phi) = 2.99$ Mbps.

Then, the amount of consumed bandwidth is 201.8 Megabytes. Using the basic unit-usage price that has been assumed, we can compute the price for the video service given by *g(2.99Mbps)*=0.37Cents.

Finally, one can find that a user has to pay 2.02 Dollars to a WiMAX service provider for enjoying 9 minutes of music video clip over a sustained bandwidth of 2.99 Mbps.

5.1.3 Charge for the file transfer

Now let us assume that a user sends an ftp file to the network, which is classified as an nrt-PS class in the WiMAX system, so that it is priced by an nrt-SRP scheme. Now let us assume the following traffic parameters: An ftp file has a size of 100Mbytes. It is served by a WiMAX system with minimum bandwidth of 1Mbps. From this fact, one can estimate that it takes 800seconds for the flow to finish the transfer of the file through the system. Using the unit-usage price, this implies that 1$ is needed to consume a minimum bandwidth of 1Mbps throughout the flow time. From this result, one can find that *h(1Mbps)*=0.13Cents.

5.1.4 Discussion

From the above three examples, we observed that different service class has different bandwidth price depending on the type of the QoS service that is provided by the WiMAX system. This indicates the value of the guarantee of the differentiated QoS is reflected to the price, which means that the proposed scheme is incentive-compatible.

5.2 Estimation of revenue

Up to now we have investigated the price of QoS service for each class. Now let us investigate the revenue that can be tolled from each service class by accommodating a number of users to the system. In order to estimate the revenue from the WiMAX system, we have to introduce lots of parameters concerning the WiMAX system and services such as the cell size, frequency ranges, the physical attributes of packet scheduler at the MAC layer as well as the user profiles such as the traffic source parameters, the scale of the users, and the combination of the service.

At present, we have no parameters for the WiMAX system that is operating in the real field, because we are now at the beginning phase of the service. From this limitation, let us suggest one of ideal situations for the parameters of WiMAX system that is obtained from our past experience in the conventional networks and services, which is described below.

5.2.1 System parameters

Let us assume an urban indoor with cell size of 1km and the sector throughput (per cell bandwidth) is assumed to be 21Mbps over a 10MHz channel, which is based on the model introduced in [26]. In order this scheme to be practically implemented to the system, let us assume that the maximum bandwidth demand to a WiMAX system from each class is estimated a priori from the user behavior, the percentage of which is given by *UGS:rt-PS:*

nrt-PS:BE=0.1:0.5:0.2:0.2.

As to the source traffic parameters for each type of service, let us use the same values that we have defined in pricing the individual flow. Note that no traffic parameter is defined for the BE class because it requires no QoS specification to the system and so no QoS guarantee is given to this class of service.

From this argument, our experiment proceeds in the following manner: By varying the offered load of each class from zero up to the predefined limit of allocated bandwidth for each class, we can estimate the revenue that is tolled by accommodating the UGS, rt-PS, and nrt-PS classes. As to the flows from the BE class, the packets from those flows will be served by a residual bandwidth that is left after the UGS and PS flows has used, and it is free of charge.

5.2.2 Estimation of revenue

Now let us investigate the expected value for the total revenue that can be obtained from providing the different classes of services to the users. First, let us show the expected revenue from the UGS class service, which is illustrated in Fig. 1.

As we can see from the mathematical model, an ISP can obtain revenue in a linear manner as the offered load increases.

Second, let us show the expected revenue from the rt-PS class service, which is illustrated in Fig. 2.

Note that the expected revenue increases in a nonlinear and convex manner as a function of the offered load. This comes from the non-reservation nature of the PS class, as compared to the reservation nature of the UGS class.

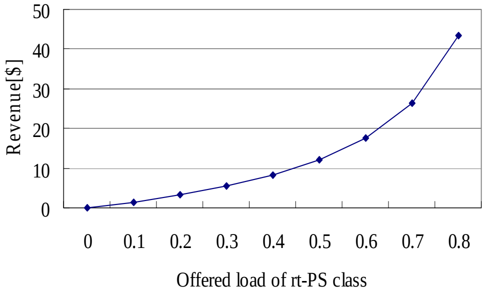

Fig. 2. Expected revenue from rt-PS class

Note in Fig.2 that the maximum offered load of the rt-PS class is 0.8, otherwise the bandwidth requirement exceeds the predefined portion of bandwidth limit that has been set to the rt-PS class.

Finally, let us show the expected revenue that is obtained from the nrt-PS class service, which is illustrated in Fig. 3.

Note that an ISP can obtain revenue in a convex manner, too. Note also that our proposed scheme is straightforward in understanding the relationship between the QoS class of the WiMAX service and the usage of the bandwidth as well as the duration of time. Therefore, we can conclude that the proposed pricing scheme can act as a means for the incentive to the ISP in the provision of QoS to the users, via which they can charge more money to recover the cost of QoS.

On the other hand, users will be benefited from this pricing scheme by refraining from the transfer of unnecessary information to the network, via which they can save the communication fee. This is our main contribution.

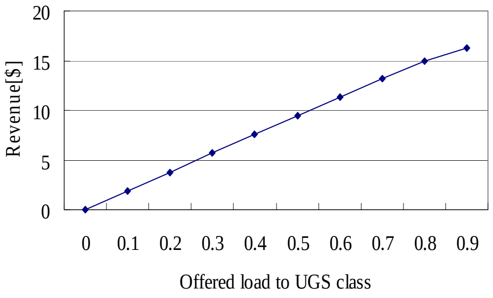

Fig. 1. Expected revenue from UGS class

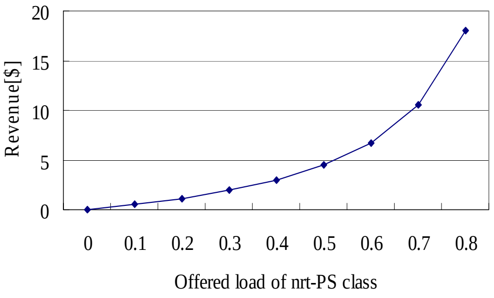

Fig. 3. Expected revenue from nrt-PS class

Ⅵ. Conclusions

In this work, we have proposed a practical pricing scheme for the future WiMAX system in which multiple classes of services are guaranteed. First, we proposed a basic framework for the pricing of the different services in the WiMAX system by taking into account the characteristics of the different service class such as the UGS, PS, and BE classes. After that we proposed a new pricing scheme for the WiMAX service by reflecting the requirements of the different service classes, which is named as CRP and SRP schemes for the UGS and PS class, respectively.

First, we suggested an analytic model for computing the price for an individual service class. After that we proposed an analytic model for estimating the revenues that can be accumulated by providing the multiple classes of services over the WiMAX system. These two results are the main contribution of this work.

From the numerical experiments we found the following facts: First, as to the price of individual service, the current pricing scheme overcharges users by using a flat pricing for the unused bandwidth, whereas the proposed scheme reflects the characteristics of the WiMAX service and charges price for the usage of bandwidth as well as the different service classes in the system. This illustrates the novelty and practicality of this work as compared to current flat pricing scheme.

Our future research work includes the proposition of a more practical pricing scheme that covers a cross-layer performance of the WiMAX system by taking into account the flow-level grade of service such as the flow blocking probability. One more future research includes the optimization for the system with multiple classes of services such as the maximization of revenue or realization of social welfare.

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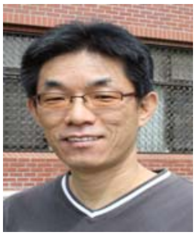

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