Enabling Dynamic Market-Managed QoS Interconnection in the Next Generation Internet by a Modified BGP Mechanism

Junseok Hwang[1], Jörn Altmann, Huw Oliver, Alfonso Suárez
Mobile and Media Systems Laboratory
HP Laboratories Bristol
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E-mail: jshwang@syr.edu, joralt,heo, Alfonso_Sanchez-Beato@hplb.hpl.hp.com

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We propose a market-managed QoS (Quality of Service) interconnection model for heterogeneous networking environments. The deployment of this model will help autonomous systems to reduce the cost of their network services as well as increase social welfare. We describe a technical solution for a next generation Internet, where networks are managed based on either technology requirements (QoS networks) or market principles (market-managed networks). Our solution requires two technologies: BMP (Bandwidth Management Point) and a modified version of BGP (Border Gateway Protocol). The modified version of BGP, as proposed in this paper, provides additional routing exchange information such as price and QoS level specifications. Both technologies are discussed with regard to the impact on routing, QoS provisioning, and charging. In order to show the benefit of our approach for inter-domain routing and interconnection, we present some analytical and simulation results, showing the significant increase in network service revenue as well as the increase in social welfare. These results draw important implications for designing the next generation Internet with regard to investment in QoS networks.

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[1] School of Information Studies, Syracuse University, Syracuse, NY 13244-4100, USA
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Junseok Hwang
School of Information Studies, Syracuse University
Syracuse, NY 13244-4100, U.S.A.
Email: jshwang@syr.edu

Jörn Altmann, Huw Oliver, Alfonso Suárez
Hewlett Packard Laboratories
Bristol, BS34 8QZ, U.K.
Email: joralt,heo,Alfonso_Sanchez-Beato@hplb.hpl.hp.com

***Abstract*— We propose a market-managed QoS (Quality of Service) interconnection model for heterogeneous networking environments. The deployment of this model will help autonomous systems to reduce the cost of their network services as well as increase social welfare. We describe a technical solution for a next generation Internet, where networks are managed based on either technology requirements (QoS networks) or market principles (market-managed networks). Our solution requires two technologies: BMP (Bandwidth Management Point) and a modified version of BGP (Border Gateway Protocol). The modified version of BGP, as proposed in this paper, provides additional routing exchange information such as price and QoS level specifications. Both technologies are discussed with regard to the impact on routing, QoS provisioning, and charging. In order to show the benefit of our approach for inter-domain routing and interconnection, we present some analytical and simulation results, showing the significant increase in network service revenue as well as the increase in social welfare. These results draw important implications for designing the next generation Internet with regard to investment in QoS networks.**

I. Introduction

The future Internet will be a network of networks, having various QoS mechanisms, associated management techniques, and business models in place. Moreover, the management has to occur in a business environment, where business relationships between ISPs can be established and canceled at any time. Therefore, mechanisms for future network interconnections have to consider not only connectivity but also dynamic interconnection. Dynamic network interconnection requires QoS control, traffic engineering, charging, and QoS service coordination. However, no such system exists in the current Internet.

Little research has addressed these issues of how to set prices of network services in order to support QoS service, as well as how to allocate resources among those involved in network access and interconnection. Mackie-Mason [6] presented a general optimization model for resource allocation as a network planning problem. The study proposed a "smart market" mechanism for solving the problem. The smart market assumes efficient routing and bandwidth allocation for network resource reservations made in advance. Hwang et al. [4] modeled a market-based profit maximization model for interconnecting networks under various settlement conditions and showed numerical results concerning different QoS services and their demand conditions. To prove the concept of the market-managed Internet, M3I [7] is being conducted as a European Union funded research project. One of the approaches within this project has Internet users that can choose a QoS level based on their perceived QoS and value of task in hand [2]. As a result of experiments and tests, market-managed principles for end-user QoS control have been introduced [1] [8].

The research cited above has been conducted under the assumption that interconnection service provisioning, charging, quality selection, and bandwidth allocation can be done in dynamic ways at both the user and network levels. But, this is not reality yet. To deploy these technologies, supporting mechanisms and protocols such as inter-domain QoS routing are necessary. Only two studies [5] [10] have been conducted to address the issue of inter-domain QoS routing and dynamic routing mechanisms. Based on these studies, we will introduce a modified version of BGP and BMP, which is flexible enough to support market-managed QoS network interconnections in dynamic interconnection environments. Through the support of QoS routing for end-users, network service providers can maximize the network utilization and, therefore, increase revenue.

The next section describes the proposed network architecture in general and its different components. Section III explains the QoS interconnection mechanisms such as modified BGP and BMP. After discussing analytical and simulation results gained from our model in Section IV, we conclude the paper with the implication of our results for the next-generation Internet infrastructure in Section V.

II. Proposed Network Architecture

Since competition is one of the key requirements for the correct operation of a market-managed approach in network interconnection, we take a modified BGP approach (rather than a global coordination approach), limiting routing information distribution. We propose using BMPs (Bandwidth Management Points) to support QoS, routing control, and route charging for such market-managed interconnection environments.

The key components of the proposed interconnection network architecture (see Figure 1) include *market-managed QoS networks*, *market- managed QoS network users*, *modified BGP (Border Gateway Protocol)* and *BMP (Bandwidth Management Points)*.

Market-managed QoS networks is based on the concept of differentiated services and price schedules similar to the architecture proposed in [3]. They can be based on a dynamic DSCP (Differentiated Service Code Point) host marking concept with flexible user price selection [2]. However the network architecture does not need to be limited to DSCP and PHB (Per Hop Behavior) implementations as proposed in [3] because market-managed networks enable to support relative quality of service

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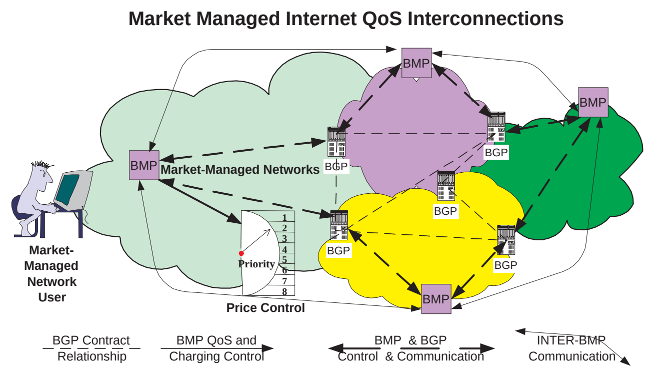

Fig. 1. Market-Managed Internet Interconnection

for any service priority selection [2]. This in turn enables network service providers to customize their service through flexible QoS and price selections for their network interconnections.

Market-managed QoS network end-users need to have controls over their service and charging selections for their network usage. One fundamental feature of the market-managed QoS network is that market-managed networks allow their users to choose relatively different levels of statistical QoS (but not guaranteed) at a static price. An end-user's benefits from such a market-managed approach are the decision and control flexibility for QoS and related pricing plans.

Modified BGP (Border Gateway Protocol) is required for inter-domain provisioning and for interconnecting market-managed networks. BGP is used to distribute the inter-domain route information between network service provider. BGP messages carry routing information between peer routers across the domains. Additional BGP objects are proposed to provide the functionality to carry information about charging and QoS selection. Modified BGP propagates such information to other domains differently depending on their interconnection settlements.

The Bandwidth Management Point (BMP) [4], which is based on the concept of the Bandwidth Broker [9], allocates and controls the bandwidth shared between different interconnected networks, and calculates current service demands, and manages available network resources. In particular, the BMP makes decisions or sets a policy for interconnection routing, network resource provisioning, and SLS (Service Level Specification) configuration. The price and QoS information of intra- and inter-domain network services are used to manage the resources in the domain and are communicated to peer BMPs. With the aid of BMP, BGP will perform the routing updates according to the coordinated QoS allocation and charging arrangement.

III. Interconnection Mechanisms

In this section, we present the concept of QoS interconnection control mechanisms for the market-managed interconnection architecture.

A. Modified BGP UPDATE Message

In the current BGP protocol operation, the routing and interconnection information are exchanged via TCP connection by OPEN, UPDATE, KEEPALIVE, and NOTIFICATION messages. The optional parameters in the OPEN message are used for information about authentication, routing capabilities, and roles of BGP speakers.

Since the exchange of QoS information among different Networks, which are considered autonomous systems (AS), is essential, we use NLRI (Network Layer Reachability Information) in BGP UPDATE message for QoS information (also proposed in [5]). In our architecture, we propose two new attributes, *QoS* and *Price*, which enable the market-managed QoS interconnection. These attributes apply to all NLRI information contained inside the UPDATE message. These attributes will be optional, variable length, and non-transitive (not being forwarded to third party ASs). The BGP nodes exchange information about QoS interconnection and prices in addition to network topology information. These QoS and Price attributes are used to set the routing policy decision.

The *QoS* attribute for interconnections has the following fields:

- *Interconnection Layer Identification*: This field identifies the type of the interconnection such as IP, packet switching, optical cross connect, etc. This allows the network layer reachability information to be used for various types of interconnection implementations.
- *QoS Identification*: This field carries the identification about the network level QoS (e.g. DiffServ, IntServ) for the interconnection layer as specified in the Interconnection-Layer-Identification field.
- *QoS Types*: The QoS terms identified in the previous field can have various types (e.g. jitter, delay, packet loss rate). This field specifies those types.
- *QoS Values*: The values for those QoS types will be carried in this field.

The *Price* attribute for interconnections comprises the following fields:

- *Settlement Types*: The types of interconnection settlements such as SKA-peering, bilateral, multilateral, transit and access are expressed here in a service level agreement (SLA).
- *Interconnection Layer Identification*: The same information from the QoS attribute fields. This is necessary in order to make the *Price* and *QoS* attributes independent.
- *Service Identification*: This field carries the information about the interconnection services supported by the interconnection layer specified in the previous field.
- *Payee Identification*: Identify the criteria involved in the issues who pays whom among interconnecting networks.
- *Pricing Plan*: Specifies the pricing type for the interconnection type (e.g., per-packet pricing, per-minute pricing, etc).
- *Price*: The values for the types identified in the previous field.

B. Routing Update Algorithms

The BMP of an AS domain needs algorithms to use these attributes to decide and implement the optimal policy for its interconnections.

Whenever an AS receives the UPDATE message with those QoS and Price attributes, those messages will be checked by the BMP for their authentication, SLA, and routing policy confirmation. The sharing of BGP routing information and update

```
BMP AND BGP UPDATE:
Receive UPDATE;
IF (authentication, SLA and Policy confirmed)
THEN Check Interconnection Layer, QoS
   and Price Identifiers;
   Hold Types of QoS and Price;
   Send CONFIRMATION;
   Wait DONE;
   Update BMP POLICY
ELSE Return NOTIFICATION(Reason Code);

BMP AND BGP DONE:
Send UPDATE;
Wait CONFIRMATION or NOTIFICATION;
IF (authentication, SLA and Policy confirmed)
   Receive CONFIRMATION;
THEN Setup Interconnection Identifiers;
   Set QoS and Price values;
   Send DONE;
ELSE
   Receive NOTIFICATION(Reason Code)

BMP POLICY:
IF (authentication, SLA and Policy confirmed)
THEN Check QoS mapping;
   Set Charge = min(QoS price offers);
   Set Next Hope
   Update BGP ROUTING;
ELSE authentication check request;

BGP ROUTING:
IF(Types of QoS and Price) THEN
   Get Routing table;
   Set QoS and Price values;
   Set Route = (Next Hop);
ELSE
   Set Route = (Empty Hop);
return KEEPALIVE;
```

Fig. 2. Summary of the Routing Update Algorithms

will be specified within the SLA, which will be defined as part of the settlements between AS domains. For those authorized messages of UPDATE, the BMP will check Interconnection Layer identifiers, QoS attributes, and Price attributes in order to compare this update with current or alternative routing policies. If the BMP decides to implement the received UPDATE as the AS's routing policy, it holds the types and values of QoS and Price attributes and sends the CONFIRMATION of the update to the originating AS domain. Then, the BMP will wait for the DONE message from the BMP of the originating domain. If BMP receives the DONE message, the BMP will update its routing policy by setting the QoS and Price values with the new Next Hop information. As it is explained above, any charging and QoS control for updated information will not be applied to the routing policy until the updating domain is acknowledged about the update confirmation from the updated networks via three way hand shaking. This algorithm and further algorithms for BMP and BGP interconnection routing control are summarized in Figure 2.

The AS domain who sent the new UPDATE message with new QoS and Price attributes will wait for the confirmation from the updated domain before it actually implements the charging for the specified domains. Once the originating BMP implements its charging policy, it will send the final acknowledgement DONE to the associated AS's BMP. Otherwise, the originating BMP will send the NOTIFICATION message to the associated AS domain with Reason Codes (i.e. predefined codes for no confirmation, etc.).

If an actual decision is made for the associated routing information and the DONE message is received, the associated AS's routing table entry will be located and the next hop information will be updated with those new QoS and Price values. Otherwise, the new information will not be activated as the new policy. BGP will continue to exchange KEEPLIVE messages with its current BGP routing peers.

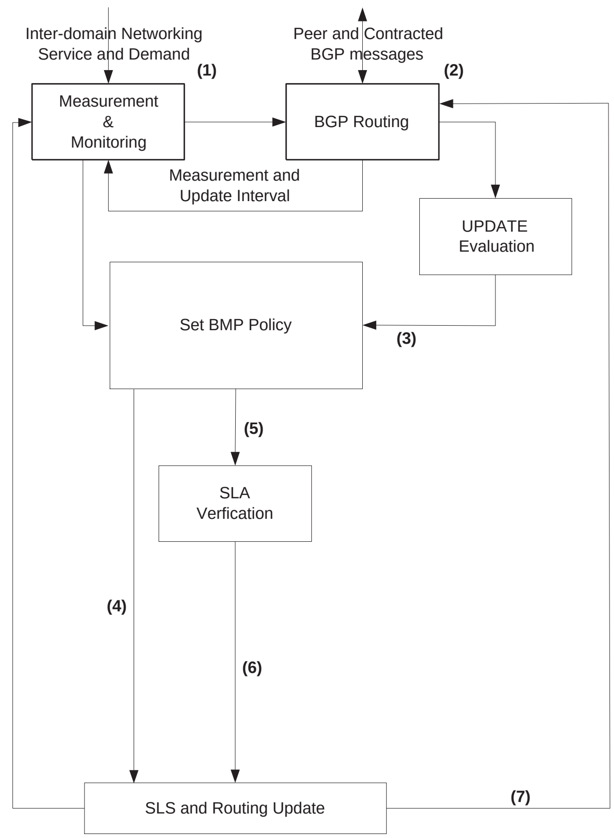

Fig. 3. BMP Control Mechanisms

C. *BMP Control Mechanisms*

The messages of OPEN and UPDATE of BGP speakers are managed and configured according to the routing and interconnection management policy set by the BMP. Regarding the market-managed routing policy of the BMP for inter-domain QoS interconnection connectivity, new decision goals have to be considered. Those goals of the BMP's interdomain routing policy are:

- Connectivity
- QoS Support
- Minimum Cost Transit

In order to find and maintain the connectivity with optimal interconnecting networks, the BGP table in a domain needs to be updated with the QoS and pricing information for market-managed networks. These functions allow the market-managed networks and the interconnecting networks to provide the service and quality that end-users choose, especially if multiple networks are interconnected to provide the service.

Figure 3 illustrates the mechanism of BMP control. The BMPs of market-managed networks are responsible for QoS mapping and monitoring to see whether the network's interconnection performance is consistently managed with QoS selection across interconnecting networks. To compare different offers and updates from different QoS interconnection networks, the BMP needs to be able to compare them through QoS mapping. If the BMP has the capability to map the QoS identifier for its interconnection, then the values from the new QoS and price identifiers will be considered and compared. If the BMP does not have the capability to map specific types of QoS identifiers, then those offers should not be considered for the updates. QoS demand and performance changes can initiate the change of inter-domain routing policy ((1) in Figure 3) in addition to the BGP UPDATE messages from other domains ((2) in Figure 3). As we mention previously, the external routing UPDATE request will be evaluated and the BMP will make new policy decision based on their routing strategy algorithms ((3) in Figure 3).

Those BMPs who are updating their interconnection routing policy might propagate their updated QoS and charging schedule to their interconnecting networks and update their SLSs ((4) in Figure 3). Those BMPs who change their routing and interconnection policy based on new UPDATE messages will reselect their choice of QoS and pricing schedule and reconfigure their routing policy tables that will be verified with the SLA ((5) in Figure 3).

Finally, the BMP's AS's inter-domain routing and SLS policy will be finally updated ((6) in Figure 3). Also, this can initiate the process for sending the UPDATE information to those interconnecting networks who will be affected and related by this update ((7) in Figure 3).

IV. System Analysis

We show that there is a significant revenue increase for backbone service provider (tier-1 ISPs) by offering differentiated services. The analysis will focus on a two priority interconnection system. The price scheme between ISPs is edge pricing in which only adjacent ISPs charge each other. The analysis is based on a model representing a market-managed network, where service QoS is offered by a priority scheme and service priority is chosen based on the expected residual utility that would be gained for each of the priorities. The testbed and software developed in the Hewlett Packard Labs was used for this numerical analysis.

In addition to this, we assume an interconnection market as currently existing where a tier-2 ISP pays for the interconnection service usage to the tier-1 ISPs. The demand of a tier-2 ISP can be considered as the sum of all demand of its customers. In order to provide its customers with the required QoS the tier-2 ISP has to purchase different QoS capacities from tier-1 ISPs.

The numerical analysis results are based on a Markov model in which service request from all customers of the tier-2 ISP arrive with exponential inter-arrival distribution. The service rate of the system is $\mu = 1.25$. Additionally, we are assuming an exponential distribution for the length of the jobs. Only services of the same priority occupy the processor at a given time. We use pre-emptive priority scheduling (higher priority jobs get executed first) and processor sharing (for services with the same priority). The customer decides which priority to choose (job priority level) or not to start the service execution at all. We have two different levels of QoS. Depending on that choice, the quality of service and the residual utility of the customer of the tier-2 ISP will be different. The calculations behind this selection process are illustrated in Figure 4. If the slope of the utility function is less than the slope of the cost function, the user will choose low priority. If the slope is greater, the user will choose high priority. If both slopes are equal, either choice is optimal.

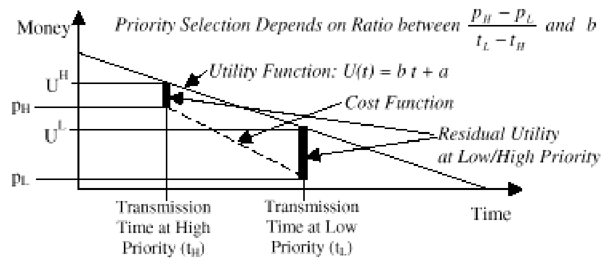

Fig. 4. Selection of Network Priority

The analysis comprises the comparison between the revenue and costs of a best-effort network (without the implementation of the proposed interconnection mechanisms) and the two-priority system with the proposed mechanisms. Figure 5 shows the social welfare, the revenue of the tier-1 ISP, as well as the overall residual utility of all the customers of the tier-2 ISP. The tier-2 ISP makes a profit, if it adds a mark up for the usage of its service to the service price charged by the tier-1 ISP. Consequently, the overall residual utility of all the customers (as shown in the figure) would be reduced by the amount of the profit. We analyzed a system where the tier-1 ISP charges $p_L = 3$ for the low priority service and $p_H = 7$ for the high priority service. The price for the best-effort system is $p_L = 3$. We further assume that the tier-2 ISP provides service to two kind of user groups, both described with two different linear utility functions ($U_1(t) = 10 - 2t$ and $U_2(t) = 5 - t$).

Figure 5 demonstrates that the revenue of tier-1 ISP is significantly higher in the two priority support interconnection system than in the no priority interconnection system. Furthermore, the revenue of the tier-1 ISPs increased strongly, although the residual utility of tier-2 ISP did not reduce that much. An even more important fact is that the social welfare of the two ISPs increased by offering a two quality of service level interconnection system.

Since ISPs run the network at 60% utilitzation in order to get the optimal throughput of the system, the arrival rate, at which the system has a utilization of 60%, is most important. Within Figure 5, this point relates to an arrival rate of 0.8. Even at this point, we see an increase in revenue of tier-1 ISP as well as an increase of social welfare. Basically, this shows that the increased costs to tier-2 ISP could be subsidized by the revenue increase for selling the better quality service to its customers.

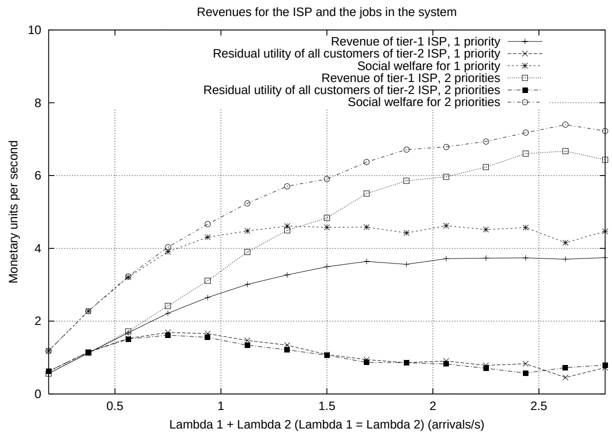

Fig. 5. Social Benefit Analysis of Market-Managed Interconnections

V. Summary, Implications and Future works

As the Internet evolves toward a network of QoS networks, it is not hard to imagine that inter-domain QoS interconnection will become one of the critical factors in the next generation Internet. Current technical and business models are not ready for supporting the next generation Internet with QoS interconnection. Current interconnection technologies (e.g. inter-domain routing for the best-effort Internet) only take connectivity into account. Because of these and the fact that the number of private peering interconnections in the Internet is continuously growing, it is necessary to establish a distributed system of policies for inter-domain interconnection and associated inter-domain routing, which supports QoS interconnections. Therefore, it should be possible to specify pricing policies for peering and client relationships differently for different network services among interconnecting QoS networks.

In this paper, we propose an inter-domain market-managed interconnection management mechanism, which exactly fullfills these requirements. It supports QoS, routing, and price selection while assuming limited coordinated operations of heterogeneous autonomous systems. In particular, using the price and QoS attributes in the BGP UPDATE message as proposed in this paper, the exchanged information can be used by the BMPs to manage and control routing policy for many different types of interconnection settlements.

The results of the analysis show that market-managed interconnection and support of inter-domain QoS routing with charging capability can increase the overall welfare of users and services providers of the internetworking services better than without such QoS support. The implication of the results is that it would be especially beneficial for tier-1 backbone providers. Such effects would minimize the potential threats of balkanization, QoS free-riding, and refusal for the next generation Internet interconnections. These initial results from this paper suggest that the next generation Internet infrastructure will require more control over QoS selection and inter-domain routing. Our study supports for the architecture of overlay networks of BMPs for such tasks over TCP/IP Internet. In addition, intelligent overlay networks will support more robust and efficient connectivity in the Internet than currently existing BGP inter-domain routing.

There are several issues to be investigated with regard to the proposed Market-managed interconnection mechanisms for the next generation Internet. In our analysis, we only considered the interconnection scenarios of tier-1 and tier-2 where tier-2 pays for the interconnection service usage to the tier-1 ISPs. Various other settlement scenarios will be tested in future experiments. The performance and scalability comparison of the modified BGP with other routing schemes is another important area of future research.

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