Mechanisms for Inter-Domain QoS Routing in Differentiated Service Networks [1]

Peng Zhang, Raimo Kantola

Laboratory of Telecommunication Technology,
Helsinki University of Technology
Otakaari 5A, Espoo, FIN 02015, Finland
Email: {pgzhang@tct.hut.fi, raimo.kantola@tct.hut.fi}

Abstract. In order to provide various services with different quality requirements, the current Internet is expected to turn into a QoS based Internet under the Differentiated Service (DiffServ) architecture. A variety of works have been done in the field of *constraint based routing* to provide QoS guaranteed or assured services by developing novel routing protocols and algorithms. However, most of these efforts focus on intra-domain routing rather than inter-domain routing. In this paper, we discuss issues of finding routes with QoS requirements among multiple domains, called *inter-domain QoS routing*. We first investigate the needs and problems faced when introducing inter-domain QoS routing into the Internet. Then, we present a model for inter-domain QoS routing and describe its building blocks. Finally, we present five mechanisms for operating inter-domain QoS routing in DiffServ networks.

1 Introduction

Today's Internet consists of domains also called Autonomous Systems (ASs). An AS is usually a set of routers under a single administration, using an intra-domain routing protocol and common metrics to route packets within the AS while using an inter-domain routing protocol to route packets to other ASs. The overall Internet topology may be viewed as an arbitrary interconnection of ASs. With the marvelous success of Internet in recent years, Border Gateway Protocol (BGP) has become the *de facto* inter-domain routing protocol in the Internet. BGP shows distinguished flexibility and robustness in connecting ASs. However, BGP does not provide any exact QoS support of traffic flows.

On the other hand, the current Internet is expected to become a QoS based Internet in which various services with QoS requirements will be provided easily. How to provide QoS support is becoming one of the hottest topics in the Internet community at present. Numerous works have been done in various aspects including traffic engineering and network management [1], [2]. Among them, constraint based routing is gradually becoming an essential mechanism for selecting routes with requirements for additional routing metrics, e.g., delay and available bandwidth, or administrative policies [3], [4]. An objective of constraint based routing is to aid in managing the

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traffic and the efficient utilization of network resources by improving the total network throughput. Moreover, constraint based routing provides flexibility in support of various services.

Meanwhile, a demand exists for establishing connections with QoS requirements of specific flows, or even building QoS based networks among multiple ASs. For example, a large QoS based virtual private network (VPN) for a worldwide company might be built up in an efficient and economical way through cooperation of several network operators, each of which might manage a separate AS. Therefore, issues of constraint based routing over multiple domains naturally come into being and call for solutions. Unfortunately, most of previous works on constraint based routing are limited within the scope of intra-domain routing.

In this paper, we investigate the issues of inter-domain QoS routing. In particular, we present five mechanisms for operating inter-domain QoS routing in DiffServ networks. These mechanisms can be directly used in DiffServ IP networks with several existing inter-domain routing protocols (e.g., BGP, IDRP) after possibly minor modifications in those protocols.

The remainder of this paper is structured as follows. In section 2, we give the general background information on the traditional inter-domain routing protocols and present the goals and criteria for inter-domain QoS routing in section 3. In section 4, we discuss problems faced when introducing inter-domain QoS routing into the Internet. We present and describe a model for inter-domain QoS routing and its building blocks in section 5. In section 6, we present five mechanisms for operating inter-domain QoS routing in DiffServ networks. In section 7, we briefly describe our works on the development of a routing simulator for investigating these mechanisms. Some conclusions and future works are given in the final section.

2 Background on Inter-Domain Routing

The first inter-domain routing protocol, i.e., Exterior Gateway Protocol (EGP), appeared in the 80s. EGP introduced the concept of AS and supported the exchanging of network reachability information between ASs. As the Internet grew in the 90s, EGP was replaced by BGP because EGP only supported the backbone-centered tree topology. BGP uses the path vector approach for loop avoidance. BGP is capable of supporting interconnections of heterogeneous networks with arbitrary topologies. As a result, BGP has become the most widely used inter-domain routing protocol in the Internet. The latest version of BGP is BGP-4, which introduces support of the Classless Inter-Domain Routing (CIDR). CIDR was developed as an immediate solution to the problems caused by the rapid growth of Internet, e.g., Class B exhaustion and routing table explosion.

Unlike interior routing protocols such as RIP and OSPF using a single criteria for route selection, i.e., the shortest path, routing in BGP is policy driven. Policy routing refers to any form of routing that is influenced by factors other than merely picking the shortest path. Each AS is free to choose its own set of policies, which will allow or not allow transit data from and to other ASs. These polices possibly include several items, such as Acceptable-Use policies (AUP), the selection of providers and even a particular quality of service.

Meanwhile, several other advanced inter-domain routing protocols proposed recently can provide better support of policy constraints and scalability: Inter-Domain Policy Routing (IDPR) protocol uses the link-state approach, domain-level source routing and superdomains [5]; Viewserver Hierarchy Query Protocol (VHQP) combines domain-level view with a novel hierarchical scheme, that is, domain-level views are not maintained by every router but by special nodes called *viewservers* [6]; Source Demand Routing Protocol (SDRP) provides a mechanism for route selection to support "*provider selection*" and "*quality of service selection*" [7].

The policy constraints supported by the above protocols could naturally be incorporated into the requirements of traffic flows. Thus, it is possible to develop new inter-domain QoS routing protocols on the basis of the traditional inter-domain routing protocols.

3 Goals and Criteria

In general, Inter-domain QoS routing aims to improve the interoperability of networks through providing efficient routes for various services with simple methods, and to increase the efficient utilization of limited network resources.

To achieve this goal, inter-domain QoS routing should cooperate with other QoS related works, e.g., traffic engineering mechanisms and signaling protocols, which are all devoted to realize a QoS based Internet [1], [3].

The current Internet is a very large scale network containing tens of thousands of ASs, which are arbitrarily connected using inter-domain routing protocols. Therefore, introducing QoS constraints into inter-domain routing must obey the following criteria:

– Compatibility

Inter-domain QoS routing protocols must be compatible with the inter-domain routing protocols currently used in the Internet, e.g., BGP. They should also support policy routing and be capable of exchanging and understanding the route information of BGP or other inter-domain routing protocols.

We suggest to develop a new inter-domain QoS routing protocol on the basis of several (best effort) inter-domain routing protocols, e.g., BGP, IDPR, SDRP, etc. For example, it is possible to combine IDPR with SDRP for selecting a path with QoS constraints and forwarding data traffic along the path. Here, IDPR is expanded to accommodate exact QoS parameters for specific data flows.

– Scalability

Inter-domain QoS routing must be capable of scaling up to very large networks, i.e., with a very large number of domains. In order to achieve scalability, several technologies such as hierarchy and flow aggregation are likely to be used.

– Flexibility

The current Internet incorporates diverse heterogeneous networks with arbitrary size, topology and management policies. Inter-domain QoS routing protocols must be flexible enough to accommodate these networks.

– Robustness

Inter-domain QoS routing protocols must automatically adapt to resource changes, and keep stable and robust against accidents, e.g., links or nodes failures, etc.

– Feasibility

Feasibility refers to all factors that affect the development of inter-domain QoS routing. In general, inter-domain QoS routing introduces a tradeoff between performance improvement and complexity of implementation and management and the tradeoff drives the decision of when, where and how to adopt inter-domain QoS routing.

4 Problems faced when introducing inter-domain QoS routing

In this section, we present and discuss the problems faced when introducing inter-domain QoS routing into the Internet, and their possible solutions.

Problem 1: What kinds of QoS metrics might be used?

Usually, a traffic flow could be characterized by a number of QoS metrics, e.g., *bandwidth*, *delay*, *delay variation* and *data loss*, etc. However, more than one metric used may lead to significant computation complexity, i.e., finding a route with two constraints is usually a NP-hard problem [3]. Therefore, only one metric (i.e., *bandwidth*) is preferably used because of simplicity. It is noticed that QOSPF adopts *bandwidth* as the only QoS metric [4].

On the other hand, requirements for QoS do not contradict other policy controls on route selection. For example, the best route might be selected from several QoS guaranteed or assured routes according to administrative policies.

Problem 2: How is the resource information distributed and updated?

Resource information of an AS usually include such items as the *available bandwidth* and the *remaining buffer memory*. Each AS monitors variations of available resources, and sends/receives resource information to/from other ASs. Several current inter-domain routing protocols might be used for this task. For example, based on the link state approach as in IDPR, resource information together with domain policies can be distributed and updated across domains.

On the other hand, it is neither strictly required nor necessarily desirable for Inter-domain QoS routing to distribute and update resource information. This is because, first, although suitable inter-domain routing protocols (e.g., IDPR) have been presented for several years, they are not widely deployed in the practical networks yet; Second, with variations of available resources, distributing resource information across multiple domains might significantly increase the transmission overhead especially in a very large network; Third, with the increase of ASs, it becomes more difficult to keep a consistent link state database and make consistent decisions on route generation and selection among ASs.

Therefore, we present three of five mechanisms in section 6, i.e., mechanism 1, 2 and 3, which can avoid distributing and updating resource information. To some extent, in these algorithms the function of distributing and updating resource information is carried out by signaling protocols.

Problem 3: What algorithms might be used for computing routes?

Routing algorithms for finding the shortest path might be also used in inter-domain QoS routing, e.g., Bellman Ford and Dijkstra or their modified versions. Moreover, a number of QoS routing algorithms presented recently are also possibly used if their computation complexity are acceptable in some cases[3].

Problem 4: What sorts of policy controls may be exerted on path computation and selection?

Each AS sets its own routing polices such as access authentication, QoS and so on. These policies are mostly used in inter-domain QoS routing, too.

Problem 5: How is the external routing information represented within an AS?

For further study. We also need to understand how external information can be aggregated and how the frequency of resource availability changes can best be controlled so that the signaling overhead and the possibility of routing loops is minimized.

Problem 6: How is the resource information stored?

Resource information might be locally stored in each exterior gateway or globally stored in a *routing agent* of a number of exterior gateways. Either each gateway or an agent's topology database could possibly be enhanced to accommodate resource information of ASs. In order to achieve scalability, resource information in low-level ASs need to be aggregated to high-level ASs.

Problem 7: What routing capabilities are needed (e.g., source routing, on-demand path computation)?

When implementing an inter-domain QoS routing protocol, there are a number of options for computing routes, e.g., source routing vs. distributed routing, on-demand computation vs. pre-computation, etc. Source routing determines routes by the source AS while distributed routing computes routes by many ASs. For source routing the source AS should have the knowledge of topology and other global information. Distributed routing requires ASs to adopt the same routing algorithm. Both source routing and distributed routing need to keep the consistency of topology databases of different nodes. Otherwise, any discrepancy is likely to result in incorrect route computation and even in loops.

Routes might be computed on demand or in advance, i.e., pre-computation. On-demand computation can obtain better efficiency in light-load requests and worse efficiency in case of heavy-load requests than pre-computation. In practice, QoS route requests must be limited to a very low level in order to keep the network stable, especially considering the whole Internet.

Problem 8: How is resource availability measured?

If applications are adaptive, they tend to use whatever resources are available and as a consequence, congestion is the normal state of the network and normally no resources are available. We may try to measure how many users are creating the load.

If it is only a few, under the assumption of adaptive applications, we can deduce that still a lot of resources are available. If the congestion is created by many users, we must assume that the congestion is real.

5 An Inter-Domain QoS routing Model

In this section, we present a model for inter-domain QoS routing and describe its building blocks.

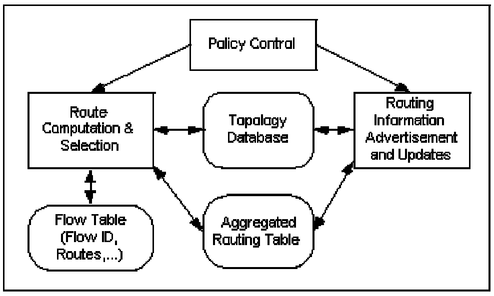

Fig. 1. An inter-domain QoS routing model

As shown in Figure 1, this model is composed of three functional blocks (i.e., Policy Control, Route Computation & Selection, and Routing Information Advertisement and Update) and three tables (i.e., topology database, flow table, and aggregated routing table). Policy Control exerts specified policies on finding routes and exchanging routing information. It might include *source policies* and *transit policies*, which are specified by the AS administrator. Moreover, these policies might be described by using the Routing Policy Specification Language (RPSL) to achieve a stable and analyzable internet routing [8].

Route Computation & Selection determines routes based on the knowledge of topology information and policy constraints. Routes are computed and saved into flow table for data forwarding. The flow table is used to store information related to specific flows, in terms of traffic parameters, requirements for QoS, etc.

Routing Information Advertisement and Update is in charge of broadcasting routing information (e.g., resource information, policy constraints, routes selected, etc) and updating the local database when receiving routing information from other ASs. It is also responsible for broadcasting external routes to the interior routers and for aggregating routes.

6 Mechanisms for operating Inter-Domain QoS routing in DiffServ Networks

As discussed in previous sections, introducing inter-domain QoS routing into the Internet might meet a number of problems. In this section, we present five mechanisms which will facilitate the development and deployment of inter-domain QoS routing. This work should be considered in connection with other works devoted to a QoS based Internet, that is, Differentiated Service, traffic engineering, etc.

Differentiated Services is an architecture for building up a QoS based Internet. It is designed to offer QoS assurances without losing scalability. Meanwhile, Multi Protocol Label Switching (MPLS), which is regarded as one of the core switching technologies for the future Internet backbone, provides mechanisms for traffic engineering. The future IP networks are possibly DiffServ MPLS networks. On the other hand, with the enlargement of MPLS networks, it becomes necessary to consider routing among multiple domains. We present the DiffServ architecture with inter-domain QoS routing in the following subsection.

6.1 DiffServ Architecture with Inter-domain QoS Routing

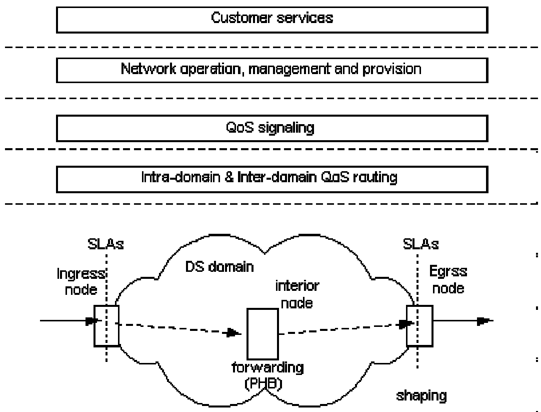

Fig. 2. DiffServ architecture with inter-domain QoS routing

Figure 2 shows the DiffServ architecture. Requirements from customer services are clarified first using a number of QoS metrics. Then, network provider will provision the network resource for supporting these services. To maintain reliability and usability of the network, the network provider must perform network operation, management and provision. QoS signaling protocol[2] is needed to broadcast control

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[2] Currently, there are two candidates for signaling protocols in the Internet, i.e., Constraint based Routing – Label Distribution Protocol (CR-LDP) [9] and Extended Resource Reservation (ERSVP) [10].

messages from network manager or to exchange interoperation information between network nodes. Intra-domain & inter-domain QoS routing selects routes for data transfer within and outside the DS domain. Data packets are classified and forwarded to the destination by the network nodes.

In order to achieve consistent support of QoS, service level agreements (SLAs) should be achieved in advance. SLAs depict the agreements on flow specifications and QoS support between adjacent domains.

6.2 Design Assumptions and Main Functions

In this subsection, we first present some general assumptions:

- A network node is a router;
- A DS domain is an AS;
- Intra-domain & inter-domain QoS routing computes routes for specific flows on-demand;
- Intra-domain & inter-domain QoS routing protocols provide routes for best effort services in the same way as intra-domain & inter-domain routing protocols.

Figure 3 illustrates the main functions and the procedures for setting up paths across domains. Signaling entity (SE) is a signaling agent of a DS domain, while routing entity (RE) is a routing agent of a DS domain running inter-domain QoS routing protocols. SE's functions include outgoing and incoming parts. The outgoing part collects QoS requests from interior routers and determine to initiate path setup requests; The incoming part processes path setup requests from other SEs. SE queries its local RE for external routes, and RE replies SE with next hops or whole routes. Note that the *path setup request* message usually contains the specifications of the flow and the requirements for QoS.

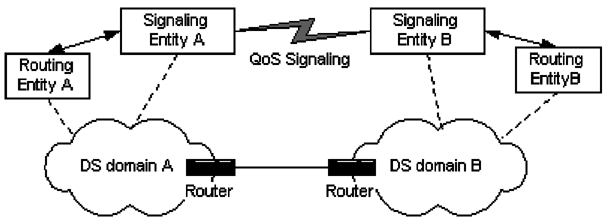

Fig. 3. Setting up paths across domains

6.3 Mechanisms for Operating Inter-Domain QoS Routing in DiffServ Networks

First, we should note that the following mechanisms mostly omit the part of route computation (e.g., how to compute next hops or whole routes and how to distribute resource information, etc). Instead, these mechanisms mainly focus on the functions of SEs related to REs. This is because of the fact that at present no inter-domain QoS routing protocol is available and the implementation of such protocol is unclear yet.

Next, we present five mechanisms by using pseudo-codes.

Mechanism 1: SE based - crankback

The pseudo-code of this mechanism is given in Figure 4. For simplicity, we just describe the procedures and interactions between SE and RE in transit domains.

```
Mechanism 1: SE based - crankback

If SE receives a path setup request message from upstream SE
    SE queries its local RE for next hop;
    if RE replies a blank next hop
        SE sends a path setup failure message to upstream SE;
    else
        SE checks its local resource information database;
        if there is enough avaliable resource to that hop
            SE adds itself to the route list of the path and
            sends the path setup request message downstream;
        else
            if SE has queried RE for K times for setting up this path
                SE sends apath setup failure message to upstream SE;
            else
                SE queries its local RE for next hop again;
            endif
        endif
    endif
else
    if SE receive a path setup failure message from downstream SE
        if SE has queried RE for K times for setting up this path
            SE sends a path setup failure message to upstream SE;
        else
            SE queries its local RE for next hop again;
        endif
    endif
endif
```

Fig. 4. Mechanism 1: SE based - crankback

When SE receives a *path setup request* message from an upstream SE, it first requests its local RE for next hop. If RE replies a non-blank next hop, SE checks if there is enough available resource on the link to that hop. If yes, SE adds itself to route list of the path and sends a request to that hop. If no, it requests the local RE for next hop again. If SE has queried RE for *K* times, SE sends a *path setup failure* message upstream. Here, *K* is a given constant. If SE receives a *path setup failure* message from downstream SE, it also requests its local RE for next hop again. A feasible route will be found until the request reaches the destination. In this case, resource reservation is proceeded downstream.

This mechanism does not require RE to understand the global resource information, that is, there is no need for global topology and resource information database. As a result, advertising and updating resource information can be avoided.

The current inter-domain routing protocol (i.e., BGP) can be directly introduced into the DiffServ networks, except minor modifications on interface with SE.

On the other hand, this mechanism has a few obvious disadvantages. For example, it might take a long time to find feasible routes because of crankback. This method also increases the overhead of SE, i.e., processing and transmission of signaling messages.

Mechanism 2: SE based – flooding

This mechanism is a modified version of the first mechanism. It is designed to shorten the time for searching feasible routes by using flooding. That is, RE replies SE with all possible next hops and SE then floods requests to all possible next hops after checking its local resource information database. It should be noted that SEs do not need to reply the previous SE whether they find next hops or not. If some SEs fail finding feasible next hops, they just simply discard requests. A feasible route will be found until the request reaches the destination. However, if the destination SE receives multiple requests with various routes from the same source SE, it is responsible for selecting only one route and discard others. Then, it sends reply message and proceed resource reservation upstream.

Also, this mechanism does not require each node to maintain a global topology and resource information database.

The pseudo-code for SE in transit domains is given in Figure 5.

```
Mechanism 2: SE based - flooding

If SE receives a path setup request message from upstream SE
        SE queries its local RE for all possible next hops;
        if RE replies a blank next hop
              return;
        else
              SE checks its local resource information database,
              if there is enough avaliable resource to any of these hops
                  SE adds itself to the route lists of the path and
                  floodsthe path setup request messages to each of these possible hops;
              endif
         endif
endif
```

Fig. 5. Mechanism 2: SE based – flooding

This algorithm is expected to improve routing efficiency with the tradeoff on increasing signaling overhead.

Mechanism 3: Cache based Routing

This mechanism is an enhancement to the above two mechanisms. Figure 6 shows its pseudo-code.

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Mechanism 3: Cache based routing

If SE needs to setup a path
      SE looks up routing cache first
      if there are availabe routes in the cache
            SE checks their feasiblity and updates the cache;
            if there is any feasible route,
                  use the route;
            else
                  SE queries RE for routes and updates the cache;
            endif
      else
            SE queries RE for routes and updates the cache;
      endif
endif
```

Fig. 6. Mechanism 3: Cache based

SE caches success and failure information on next hops. Therefore, subsequent requests adopt previously successful routes and avoid previously unsuccessful routes.

Mechanism 4: *D*-hop resource routing

As shown in Figure 7, REs advertise resource availability information with TTL (Time To Live) set to *D* –depth of resource availability dissemination, where *D* is a small integer indicating the maximum number of hops resource availability information is distributed. Each node calculates only the next hop taking into account not only the local resource availability information but also information until the depth of *D*. Path vector information is used for loop avoidance. The parameter *L* in this mechanism limits the attempting times for searching feasible next hops.

```
Mechanism 4: D-hop resource routing

If SE receives a path setup request message from upstream SE
      do while next hop in Path-so-far and tries < L
            SE queries local RE for path using resource info until D increment tries
      enddo
endif
```

Fig. 7. Mechanism 4: *D*-hop resource routing

This mechanism could also be combined with Cache based QoS routing in mechanism 3.

There are issues with this algorithm including

- the frequency of resource availability information updates and consequently frequency of recalculations of the routing tables;
- how to measure resource availability.

Regarding the last bullet, we suggest to measure only the use of resources by one or two highest traffic classes. If applications have fixed resource requirements, this algorithm should give a good spread of high quality traffic across the network and should help to avoid creating hot spots of traffic in the network. If the applications that require using a high traffic precedence class are elastic, measuring resource usage becomes more complicated and a more intelligent measurement and filtering mechanism is required.

Mechanism 5: RE based source routing

In this mechanism, source SE requests its local RE for whole routes to destination.

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Mechanism 5: RE based source routing

If source SE decides to setup a path
      SE queries its local RE for the whole route.
endif
```

Fig. 8. Mechanism 5: RE based source routing

This mechanism is suitable in case of using IDPR. However, the current IDPR should be extended to accommodate broadcasting resource information and updating global topology database.

6.4 Considerations on deployment

As described above, the first three mechanisms have less requirements for routing protocols. These mechanisms do not care about the detailed implementation of routing computation, so that they can transparently support the mostly widely used inter-domain routing protocol, i.e., BGP. In these mechanisms, the QoS routing decisions are made by SEs instead of REs. Since SEs naturally provide functions related to support of QoS, the first three mechanisms can greatly facilitate the deployment of routing across multiple domains and next improve the support of QoS.

On the contrary, the last two mechanisms, especially mechanism 5 likely rely on the development of inter-domain QoS routing itself. IDPR is a candidate of inter-domain QoS routing. The inter-domain QoS routing protocol is responsible for advertising resource information and determining routes mostly according to the network resource information and QoS requirements. These two algorithms possibly provide better support of QoS through directly finding QoS based routes.

Whatever, the efficiency of the five mechanisms needs for careful verifications.

7 Simulator

In order to study constraint based routing as well as the mechanisms presented in the paper, we are currently devoted to developing a new routing simulator – Extended QoS based Routing Simulator (EQRS)[11]. It is designed on the basis of DiffServ architecture, which consists of essential QoS related components, e.g., network management, signaling protocol, routing protocol, etc. Mechanisms presented in this paper are expectedly implemented into EQRS. EQRS allows users to configure parameters of DiffServ MPLS networks, where the dynamics of constraint based routing algorithms as well as traffic engineering mechanisms can be investigated. With the help of EQRS, our future works can focus on investigation and verification of these mechanisms. Also, this simulator is suitable for modeling, designing and evaluating DiffServ MPLS networks.

8 Conclusions

With the rapid growth of the Internet, inter-domain QoS routing is becoming an important topic for developing large QoS based IP networks. In this paper, we investigate problems faced when introducing inter-domain QoS routing into the Internet. We also present an inter-domain QoS routing model and five mechanisms for operating inter-domain QoS routing in DiffServ networks. These mechanisms are suitable for using the current inter-domain routing protocols into DiffServ networks.

On the other hand, there are still a large number of open research problems concerning QoS routing across domains, e.g., methods of flow aggregation, algorithms of advertising and updating resource information, etc. Our near future work will focus on design and implementation of the mechanisms presented in this paper. Our far future works will be devoted to studying those problems.

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