Merging of Integrated and Differentiated Services

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***Abstract*— This paper investigates the possibilities of merging the two fundamentally different concepts for quality of service assurance in IP networks - Differentiated Services (DS) and Integrated Services (IS). First we study the basic properties of both and then present a table with quick comparison of their most important properties. We emphasize the advantages and disadvantages of IS followed by the same for DS and give the main reasons for merging. Then we describe the network topology and its elements on which we derive our new concept of a merged two-stage network with Differentiated and Integrated Services (DIS). Next we set the method of merging DS and IS that preserves most of the advantages and eliminates most of the disadvantages of IS and DS. The explanation is followed by an example of operation of DIS network and the proposal for the configuration of DIS network devices. Finally we identify possible problems that arise with the merger and propose solutions to them.**

I. Introduction

Introduction of different levels of Quality of Service (QoS) into public IP networks is slower than anticipated. A single solution, such as Differentiated Services (DS) and Integrated Services (IS), can not satisfy all possible demands, do not offer desired QoS functions and do not have all the necessary QoS properties. Each one of them has its advantages and disadvantages. In this paper we introduce a new concept of merging of DS and IS into a new network with Differentiated and Integrated Services (DIS). The proposed DIS network preserves most of the advantages of both DS and IS and suppresses most of their disadvantages.

II. Basic Properties of Integrated Services

The concept of IS has been under development since the early 90's and has been put forward especially with the IETF recommendation RFC 1633 [4]. Network resource reservation is based on flows. Every traffic flow has to reserve the resources separately in each network device on its transmission path. IS offer three main QoS levels (classes): Guaranteed Services, Controlled Load Service and Best-effort Services [8]-[9].

Guaranteed Services offers hard guarantees of transmission parameters (delay, jitter, etc.) for the agreed amount of traffic. This service is suitable for demanding applications which, for instance, require real-time transmission. Controlled Load Service does not give hard guarantees about transmission parameters, the service parameters resemble the behavior of a lightly loaded network. This service is suitable for applications that require better performance than those offered by Best-Effort, that resembles the properties of today's Internet that gives no guarantees.

For the resource reservation across the network some sort of control and signaling protocol is needed. This protocol is not specified by RFC, but RSVP is used almost exclusively for that purpose [5]-[6].

Let us emphasize that IS and RSVP are complementary but independent technologies. IS is merely using the services of RSVP to support its three classes of service.

III. Basic Properties of Differentiated Services

DS differentiate traffic based on service classes. The information about the class, that one packet belongs to, is included in the existing IP header fields. For the purpose of DS their meaning has been changed in order to reflect the level of QoS demanded by that packet.

This approach is much more simple to implement because network devices do no have to spend resources on each traffic flow and there is also no need of control and signaling protocol. Network devices classify each packet into predefined traffic classes based solely on the information in packet header.

The downside of this approach is that network can offer only relative QoS guarantees (no hard guarantees of transmission parameters). QoS level of each class is relative to QoS levels of other classes. More about DS can be found in [12]-[18].

IV. A Quick Comparison of IS and DS

The differences of the most important parameters of both concepts are listed in table I [18]. As one can see, properties of both concepts are practically opposite.

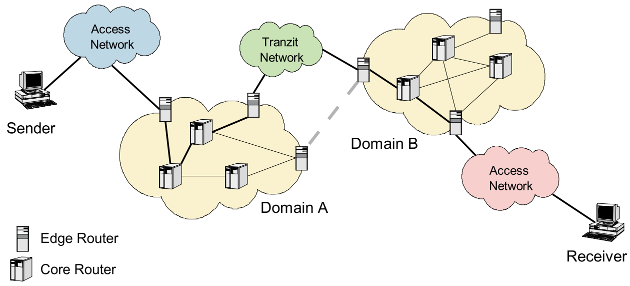

Fig. 1. Referential DIS network topology

Advantages of IS are:

- end-to-end QoS that is based on deterministic (Guaranteed Services) or statistic (Controlled Load) assurances,
- isolation of flows - the flows can not influence each other,
- good service access control and detailed billing possibility.

Disadvantages of IS are:

- high network resource demands (per flow),
- mandatory signaling protocol, that imposed additional network load and complexity,
- scalability issue - network resource demand rises proportionally to number of flows (traffic dependent).

Advantages of DS are:

- low network resource demands (per class),
- no need of signaling protocol,
- scalability is not an issue - network resource demand rises proportionally to number of classes (not traffic dependent).

Disadvantages of DS are:

- QoS is relative and is valid only within DS domain,
- flow isolation is not feasible - flows can influence each other,
- detailed service access and billing not feasible.

Due to mostly opposite properties of IS and DS, the total use of advantages and total suppression of disadvantages of both is not possible. At least not for all of the traffic. Our idea is to use advantages of both concepts in a way to benefit the highest possible share of network traffic. Since our proposal exploits the best of both worlds, the network has to support the functionality of both IS and DS.

V. Referential Network Topology

The functionality of our proposal can best be described by using the example of network topology in figure 1. Its elements are described below.

Communication end-points are users or devices, which exchange data. Such communication is denoted as end-to-end communication and can span over more than one logical network. An example of such communication is depicted in figure 1, where users communicate over domains A and B and transit network.

Domain is a part of a network. It is based on a single technology and owned by one service provider. A domain is therefore a part of a network where the same rules apply and the same services are offered. On a border between domains this rules, services and levels of QoS can change.

Access network is a part of the transmission path over which a user connects to the network (Ethernet, xDSL, dial-up, cable). Our proposal implicates an access network with full IS/RSVP capabilities that can offer the desired QoS, does not reject RSVP connection, and has no scalability problems. We presume that access network has no scalability problems since it has limited number of users.

Transit network is a part of the transmission path of which we have no knowledge. It is not desired and has been introduced into the model for generality purposes. Domains A and B can be linked directly as indicates the dashed line in figure 1.

Edge router is a network device that connects the domain with other parts of the network. Edge router takes care of the traffic that is entering or leaving the domain. Edge router would, in the context of merging IS and DS, have to handle a broad range of tasks and have total control of inbound and outbound traffic flows.

Core router is a network device that takes care of the traffic inside the domain. Since it is only a switching/routing device, it can handle much more traffic than edge routers with the same processing power. The main task of a core router is quick and efficient data transfer between two edge routers of its domain.

VI. Why and How to Merge DS and IS

From figure 1 it can be seen that an end-to-end communication can traverse more than one domain. If these domains use DS with relative QoS, assuring the same level of QoS across the entire transmission path can be extremely difficult, if not impossible, task. Domains can be owned by different operators, they can be based on different technologies, and they most probably offer incompatible QoS levels. A user that has some sort of service level agreement with his service provider (lets say in Domain A) can not expect to get the same service over the entire network. A negative role can be played by business competitiveness and unloyal competition between service providers.

The problem can be elegantly solved by using IS where a user requests a certain service at the communication setup. If the network can not satisfy user demands on the

	Integrated Services	Differentiated services
Differentiation of services	Flow based	Class based
Network resource demands	Per flow	Per class
Traffic classification is based on	Combination of IP header fields	DS field in IP header
Transmission parameters assurance	Deterministic or statistic	Relative
Service access control	Demanded	Not required
Signaling protocol	Demanded (RSVP)	Not required
Differentiation span	End-to-end	Within DS domain
Scalability limited by	No. of flows	No. of classes
Traffic billing	Flow based	Class based
Network management	Like connection oriented networks	Like IP networks

TABLE I

COMPARISON OF THE MOST IMPORTANT PROPERTIES OF IS AND DS

entire transmission path, the request is denied. Otherwise the user gets the requested service across the entire transmission path, even if it traverses different domains.

As it is too optimistic to presume that all advantages of DS and IS could be used, let us define the minimum set of conditions a merged network would have to satisfy.

Such a network would have to offer a deterministic (hard) level of services and a possibility of traffic flow isolation from possible harmful effects of other flows on the same transmission path (or part of it). To ensure this, some sort of control and signaling protocol will have to be present on the network (like RSVP). In this way we preserve most of the advantages of IS and suppress some disadvantages of DS. To ensure scalability and decrease the need for network resources, solutions from DS will also have to be used. In this way we preserve most of the advantages of DS and suppress some disadvantages of IS.

VII. MERGING OF DIFFERENTIATED AND INTEGRATED SERVICES

In this section we propose a new way of merging DS and IS. The new, merged network, is called a network with Differentiated and Integrated Services (DIS) [1].

In a DIS network the type of traffic is recognised and processed accordingly to its QoS demands. Some packets will be switched/routed without detailed examination; other packets will be examined in greater detail and then switched/routed, yet another packets will be examined in greater detail, changed accordingly to defined rules and then switched/routed.

At the first glance, our proposed DIS network would work like a DS network, meaning that the traffic differentiation would be based on traffic classes. Packets would be processed according to the values DS fields in IP header. This mechanism would introduce relative levels of QoS. Since it is anticipated, that for some time the majority of traffic on public IP network would require only relative QoS, the advantages of DS could be exploited.

But for the minority of traffic with more complex and stringent QoS demands a few service classes would be defined. Those classes would receive better service with more processing, similar to IS. RSVP flows could be classified as traffic with complex demands and real-time voice transfer as traffic with stringent demands. In addition to higher demands, such traffic would also use more network resources. This kind of traffic would have to exploit advantages of IS concept. And since it is anticipated that it will only be a small part of the total traffic, disadvantages of IS should not come out. At the same time (at least for this traffic) disadvantages of DS would be eliminated.

At this point it should be stressed, that this is not some sort of ”IS over DS”, but merging of both concepts. In the first stage the network works similar to a DS network. But in the second stage, only for the traffic of certain service classes, the network works similar to an IS network.

The operation of DIS network is easiest presented through example. Let us define 6 service classes denoted with letter A to F, with properties listed in table II. In a DS network each of these service classes would be represented with a certain value in IP header DS field.

Class	Name	Comment	Network
A	Guaranteed service	Deterministic QoS	IS
B	Controlled service	Statistical QoS	IS
C	Signaling protocols	For example: RSVP	IS/DS
D	Precedence traffic	Important traffic	DS
E	Best-effort	Ordinary traffic	DS
F	Background traffic	Less important data	DS

TABLE II

AN ILLUSTRATIVE EXAMPLE OF SERVICE CLASSES

When a packet travels through a network, each network device on its path checks its service class and acts accordingly. Packets from classes D to F are placed in the appropriate queue based only on their service class without further processing. The class is determined by the DS field in the packet header. Class C packets belong to a signaling protocol and must be examined in more detail in each network device. Class A and B packets are also examined, processed and put into appropriate queue.

It can be said that packets of classes D to F receive only one-stage processing (based on a DS field), while packets from classes A, B and C receive two-stage processing.

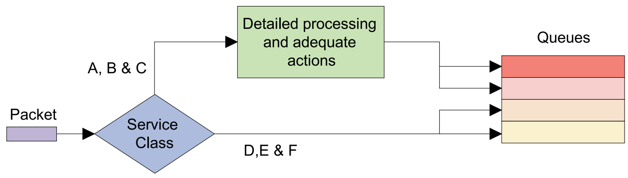

Fig. 2. A simplified packet processing flow in a proposed DIS network

The first stage is based on their DS field in IP header, where it is determined that they need more detailed processing of the second stage. A simplified processing flow for this example is depicted in figure 2. In our case the traffic of classes A to C requires IS functionality, while for classes D to F the DS functionality suffice. Our proposal is certainly reasonable when classes A and B (and consequently also class C) traffic share is low comparing to class D, E and F traffic. Merging of DS and IS is therefore reasonable.

VIII. Possible Problems in Merging DS and IS

All of the above proposals and solutions are based on the presumption that the share of traffic requiring IS functionality is low comparing to traffic requiring DS functionality. In this way the problem of scalability is avoided. The problem occurs when a rising number of traffic flows would require more network resources (especially processing power and memory space in network devices) than available.

To avoid such situations this problem should be addressed and solved. The obvious solution is flow merging (i.e. RSVP). In this way the required network resources can be considerably reduced. In [19]-[22] some proposals with its advantages and disadvantages are listed. In [2] we can find our own proposal for RSVP flow merging. It exploits the possibilities offered by two-stage processing, and is therefore optimal for DIS network.

IX. Other proposals of Merging DS and IS

In [19] RSVP is reintroduced into DS network as an important element of QoS assurance. That was done after the recognition that DS networks, if not over dimensioned, can not assure the desired levels of QoS. DS networks have problems with expected traffic shares for each of the service classes. Therefore it is almost impossible to get an optimal bandwidth share settings for all service classes. When trying to solve this problem with dynamic bandwidth allocation, additional complexity and costs are introduced into the network. That reduces the advantages of DS to a great extent. The use of combination of DS/RSVP, is proposed in [19], where RSVP would be used for dynamic traffic admission and control for service classes and not for separate flows. One example is when RSVP is used as DS network admission mechanism (see figure 3). Separate flows on an access network still use RSVP, but on a core network (DS domain) RSVP is used only by edge routers for admission control. Disadvantages of the approach in [19] are inability to reserve resources for separate flows and with that their isolation from possible misbehaving flows inside the same service class. It is also not possible to give any firm QoS assurances as the core network is still working as a DS network.

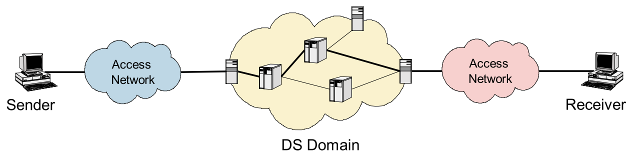

Fig. 3. A network with a DS domain

The idea from [19] is further developed in [20] and [21], but the principle remains the same. The transmission path is divided into three parts (see Figure 3) where access networks are IS/RSVP capable. The proposal mentions two possible configurations of a DS domain. The first configuration presumes that DS domain does not include any RSVP capable devices and therefore network resources inside it are statically allocated (not optimal). Edge routers perform only admission control for separate flows. The core network follows the DS functionality. The second configuration presumes that there are at least some devices inside the DS domain that are RSVP capable. Such devices can take part in RSVP signaling, but the traffic itself is still following the DS principle. The advantage of this approach is the possibility of dynamic resource allocation. Although this proposal eliminates some of the disadvantages from [19] it still can not give hard QoS assurances for separate flows. Resource allocation control is improved, but the traffic itself is still forwarded using DS principles.

Our proposal goes one step forward from [20] and [21]. It presumes that devices in DIS domains are RSVP capable and that they can support IS. The DIS network works in two stages: on the first stage as a DS network and on the second stage, only for certain flows with higher QoS demands, as an IS network. DIS network also supports RSVP flow merging.

The main advantage of our proposed DIS network is the possibility of assured QoS through RSVP and resource reservation on the entire transmission path, without scalability problems. That is achieved with exploitation of advantages of DS and IS networks.

X. Proposed configuration and control of DIS network devices

DIS network devices can be divided into: end devices, edge routers and core routers. **End devices** on the senders side must perform functions of access control and traffic shaping and control. It is presumed that QoS scheduling in end devices is not a problem. **Edge routers** have the hardest job. They must perform all functions: access control, traffic classification, shaping and control, buffer and queue management, scheduling. The main task of **core routers** is appropriate queue control and management, that can offer agreed QoS guarantees.

Documents that define DS and IS do not specify mechanisms that should be used. This gives us freedom with scheduler selection as far as it satisfies all the DS and/or IS demands. From the network device's point of view it is best to select schedulers with low complexity. The disadvantage of such schedulers is that they are usually unfair and that they have high latency.

Since our DIS network introduces two-stage packet processing, let us configure queues in the same manner. This also implies two-stage scheduling. The first scheduling stage should assure different levels of QoS between existing service classes, and the second stage should, when necessary, assure fairness and isolation between flows within the same service class. Based on above conditions, we propose the use of Strict Priority scheduling on the first stage and the use of Deficit Round Robin (DRR) scheduling on the second stage. The justification for this is:

- Both schedulers have complexity of $O(1)$.
- **Strict Priority scheduling** assures relative QoS levels between service classes. Referring to the example in section VII, we conclude that class A has the highest priority and class F the lowest priority. According to properties of Strict Priority scheduling, class A packets see the entire link bandwidth, class B packets essentially share bandwidth only with class A packets, and so on till class F packets. Since Class A and B traffic is limited, it should not happen that their packets use entire link bandwidth and in that way starve lower class packets.
- **DRR** scheduling assures fairness and isolation between flows within each service class, meaning that in long term none of the active flows can get more resources than their reservation. Second stage scheduling is reasonable only for high priority service classes like A (guaranteed service) and B (controlled-load service) in our example.

The detailed analytical and simulation analysis of two-stage network operation with two-stage scheduling is presented in [1].

XI. Conclusion

Merging the two concepts that are so different gives interesting solutions. Especially, if we can exploit most of their advantages, and get best from both. With two-stage operation of DIS network and two-stage scheduling we are given a lot of combinations and possibilities to tailor the network to our needs. Analytical and simulation results have confirmed our presumptions and statements. Recent network devices support both IS and DS, so not a lot of effort and resources is needed to use them optimally.

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