Dynamic Management for End-to-end IP QoS: from Requirements to Offers

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Abstract

The recent propositions made for supporting QoS in IP networks contain several interesting mechanisms that act on a packet or a set of packets basis. As mastery of the end-to-end QoS requires considering each individual host-to-host service, it is of interest to study how these mechanisms can be efficiently assembled and complemented to meet the end-to-end goal without having to overhead each of the participating nodes.

In this paper, we analyze the expression of end-to-end requirements and propose a QoS dynamic management architecture based on DiffServ domains interconnecting units. The proposition relies on a discussion of a set of generic QoS-enabling components that we arrange according to both the time scales axis and the execution planes axis. This reveals the relevant areas to focus on to ensure end-to-end QoS and maintain its conformity to requirements.

1. Introduction

When dealing with the issue of end-to-end QoS in IP networks, distinction should be made between two important aspects: requirements and offers.

1.1 Expression of requirements

The best-effort nature of the Internet forwarding service has made IP networks for longtime unsuitable to support neither multimedia applications as telephony over IP, nor even some purely data applications but of critical importance to customers. Meeting the requirements of such applications was achieved thanks to specialized connection-oriented networks (e.g. PSTN for telephony, X25 for data transmissions). As the QoS (Quality of Service) these networks perform is fixed (i.e. not negotiable), they could rarely suit non-native applications.

Today, service providers and corporate administrators are in need of simple and comprehensive mechanisms to deliver multiple services in accordance with the Service Level Agreements (SLAs). Internet popularity as well as the simplicity of its connectionless mode are driving market demand for integrated services IP networks that make it possible to cohabit classical web browsing applications, multimedia applications, as well as mission critical transactional ones. To do this, the network should first be able to *differentiate* the various *kinds* of data being forwarded. *Flows* differentiation criteria becomes then a key issue as QoS, which is the result of an SLA between a service provider and a service user, will be associated to the end-to-end service guarantees a flow requests.

1.2 Expression of offers

Proposed solutions to differentiate QoS in IP networks include IP-over-ATM, the Multi-Protocol Label Switching (MPLS) technique, the Integrated Services model (IntServ), and the Differentiated Services model (DiffServ).

- ATM networks are already subject to some service differentiation (CBR, rt-VBR, nrt-VBR, ABR, UBR, and ABT services). When ATM is used as an underlying infrastructure for IP networks (Overlay model, Peer model), it can in principle serve as a supporting architecture for IP QoS, provided that QoS could be expressed at IP level and adequately associated to the ATM level.
- In MPLS [6 and 7], traffic aggregates of varying granularity are associated with a label-switched-path (LSP) at an ingress node. Packets within each label switched path are marked with a forwarding label that is used to lookup the next-hop node, the per-hop-forwarding behavior, and the replacement label at each hop. MPLS can enhance the overall quality of service in an IP network, by accelerating the forwarding states in routers and by balancing traffic load according to multiple constraints. However, the amount of forwarding state maintained at each node may be prohibitive (can proportionally scale from the number of nodes to the square of the number of edge nodes [18]).
- In the IntServ approach [5], applications use explicit signaling (RSVP) to request a specific kind of service before transmitting their data. If the available network

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resources allow it, the network agrees to meet the QoS requirements. It fulfills its commitment by queuing separately the packets of each service and managing intelligently the forwarding of different service streams [2]. With IntServ, all nodes have to be IntServ compliant. The amount of state information increases proportionally with the number of flows, leading possibly to a huge storage and processing overheads in routers.

- In the DiffServ model [1 and 3], traffic entering a network is classified and possibly conditioned at network boundaries, before being dispatched to different behavior aggregates or *classes*. Each class-of-service (CoS) is identified by a single DS codepoint, a re-defined layout of the IPv4 TOS byte. Within the core of the network, packets are forwarded according to the Per-Hop-Behavior (PHB) associated with the CoS. DiffServ is more scalable, easier to implement and can be gradually deployed. Indeed, the amount of state information is proportional to the (limited) number of classes rather than the number of flows. DiffServ-incapable routers simply ignore the DS field of the packets and assign them a best effort service.

1.3 Paper organization

In the ensuing section, we propose a classification of applications QoS requirements to help identifying different traffic classes. Section 3 classifies the basic generic components needed to make the network QoS-aware, in order to introduce judiciously key mechanisms for dynamically ensuring and maintaining end-to-end QoS. This dynamic management of the QoS is the subject of the last section, where appropriate organizational and managerial actions are introduced in a host-to-host DiffServ-based architecture in a flexible way that can scales with legacy infrastructures.

2. Requirements classification

Different network applications have different operational requirements that demand different network services. To help matching requirements and offers, there is a need to minimize characterization elements that are intelligible to both users and network operators. We made use of traffic parameters (E and θ) which make it possible for an operator to know users needs in terms of connectivity and resources utilization. We identified four QoS criteria: Availability, Reliability, Capacity and Delay. On one hand, users can refer to these criteria to appreciate the quality of the *transfer service* being delivered to its traffic. On the other hand, they can be used by the operator to evaluate a priori the requirements that users will clam. By considering the applications sensitivity to each criterion, we managed to identify seven applications sets (AS) that can be significantly matched to seven different service classes (fig. 1).

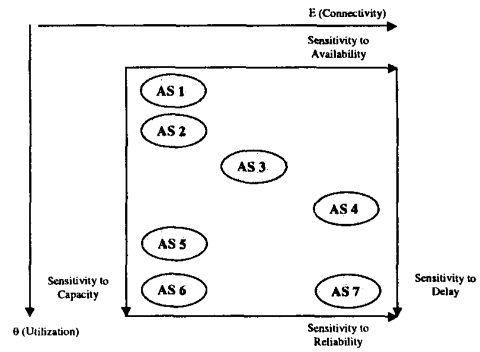

Figure 1. Requirements classification

3. Offers classification

In order to introduce and situate QoS-preserving mechanisms that are needed to achieve a flexible and adaptable management, we first make a classification of QoS-enabling generic components according to both time scales axis and execution planes (user, control and management planes) axis. The considered components (fig. 2) are those which are likely to influence the behavior during data forwarding.

3.1 QoS-enabling components

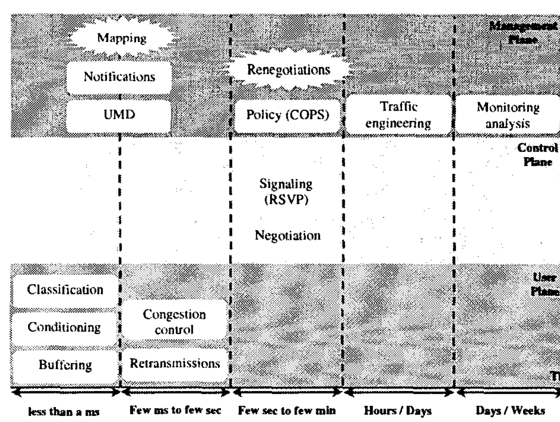

Figure 2: Time vs. Planes classification

In the user plane, traffic control mechanisms act on packets and enable very short reaction delays. Short-term components lay into 3 categories: traffic *classification* (Classifiers, Markers), traffic *conditioning* (Meters, Shapers, Droppers, Re-Markers) and traffic *buffering* (Queuing, Schedulers). Algorithms performed by these components closely influence the behavior of TCP/IP *congestion control and retransmission* mechanisms that intervene at the round-trip-time scale [4, 11].

Control plane components take place in the few-seconds-to-few-minutes time scale to enable an end station or a network node to communicate with, or to signal, its neighbors to request special handling of certain traffic. A *negotiation* mechanism deals with making agreements, while *signaling* is usually used to request resources reservations. Signaling may be either in-band (IP Precedence, 802.1p) or out-of-band (RSVP).

In the management plane, architectural components aim to optimize system organization and planning. In the less-than-few-seconds time scales, we find UMD (Usage Metering Data) which allows to use the set of QoS-related structured information, filtering and scooping functions that have been beforehand instrumented, and notifications mechanisms which give information on the delivered performances and any violation of the agreed QoS. These data are then used by *Monitoring analysis* components, which evaluate evolutions of traffic characteristics at a days/ weeks scale. At the hours/ days time scale, *traffic-engineering* mechanisms are needed to arrange traffic flow distribution throughout the network so that congestion caused by uneven network utilization can be avoided. The success of QoS-enabling algorithms deployment depends on the consistency of the *Policy* rules defined and distributed, usually at the few-seconds-to-few-minutes time scale, to the multiple devices that run these algorithms.

3.2 QoS-preserving components

In order to be more efficient, and to conform strictly to the required QoS, we are in need of components that enable to decline (*map*) the requirements and to rectify (*renegotiate*) in case of degradations. Adaptation allows to make up for the QoS deficiency as well as to reduce an eventual surplus in the quality offered to a service.

As we have seen in 3.1, user plane mechanisms run very quickly because they act at a packet level, while control plane components act less quickly as they relate to end to end resource reservations. At the management plane, although notifications can provide relatively quick information, this information is not exploited before the monitoring analysis. We have introduced at this level the *Mapping* mechanism in which service requests realization take some ms, and the *Renegotiations* mechanism whose execution delays can be of some minutes.

3.2.1 Negotiations & Renegotiations. The QoS negotiations function is responsible for analyzing an activity into components and finding a composite of the individual QoS levels that can be supported by those components. When an activity is initiated, each component states the level of QoS it is able to provide. Then depending on the results, negotiation function assigns particular QoS levels to each component or reports that the activity cannot be supported.

A renegotiations process may be invoked if QoS degradation occurs without any means for local resources adjustment. Such a process involves a global reconfiguration of all the activity components through re-invocation of the end-to-end negotiation functions. Re-negotiation process may also be invoked by the user, for example when downgrading a lower priority activity among a set of activities or upgrading from monochrome to color video [13].

3.2.2 Mapping. *Mapping* intervenes to decline the initially issued SLA. When components involved in an activity argue on new bilateral or multilateral SLAs resulting from a renegotiations process, mapping functions undertake to translate these SLAs onto lower level characteristics.

3.3 Conclusion

We have seen that enabling end to end QoS may call for a huge variety of mechanisms that intervene at various time and execution levels. Each of these architectural components performs algorithms whose selection is dictated by the QoS strategy. This strategy is service, context and cost dependent. It distributes a task execution among execution planes, and should be considered as early as system design to determine how these planes cooperate to globally perform the expected service.

4. End-to-end IP QoS: Dynamic Management for an effective service personalization

Now that we have discussed the QoS-enabling mechanisms, we can consider how to effectively achieve this end to end QoS and how to maintain it. In our opinion, granting such an end-to-end QoS and preserving it at the right level through the whole network can not be done without the ability to react rapidly on the service being supplied to each user flow. What is needed is a QoS dynamic management that will be able to react on the end-to-end through intermediate QoS evaluations and controls. This is why we propose organizing the end-to-end line into autonomous management domains. In our IP context, we advocate for each domain the DiffServ model, which, as we see it, lays a valuable foundation for IP QoS. It actually proposes service classes that enable aggregated flows to get QoS support.

To encompass all its dimensions, the proposed solution is structured through five models [16, 17]:

- An organizational model, to identify participating elements,
- An informational model, to define QoS with emphasis on unifying its perception among all the protagonists,
- An architectural model, to describe the general structure of the entities performing management activities,
- A functional model, to describe the action to take in order to meet management goals,
- A communication model, to govern interactions among components.

4.1 Organizational model

To enable quick reactions when a network portion experiences some difficulties, we recommend a management organization through autonomous administrative domains (fig. 3), capable of giving information about and acting on QoS per-domain realizations.

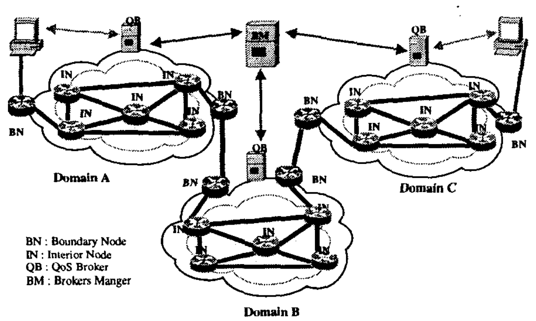

Figure 3: Organizational Model

4.1.1. Actors and roles. Each domain adopts the DiffServ service model, and consists of nodes operating under a common set of service provisioning policies and PHB definitions. A boundary node (BN) connects to a BN of another domain or to an end user's host, whilst interior nodes (INs) only connect to other INs or BNs within the same domain. To deal with legacy infrastructure and minimize intervening areas, some INs could consist of classical IP Routers. Management actions will focus on interconnection units, formed by BNs.

In each domain, a QoS Broker (QB) is in charge of internal resources sharing and traffic control. It is also responsible for setting up and maintaining bilateral service agreements with the QBs of neighbor domains to assure QoS handling of its border-crossing data traffic.

Administrative domains participating to offer differentiated services between two end hosts pertain to a DiffServ Region. In each region, a Brokers Manager (BM) coordinates and updates QoS information of the involved QBs.

4.1.2 Dynamic management process. Participating elements identified in the organizational model achieve the global management process in order to meet the end to end goal [19]. As opposed to classical management process, the considered one is dynamic (fig. 4).

End-to-end management is obtained by concatenating inter-domain and intra-domain management. The end user negotiates an SLA with its attached domain QB. The resulting agreement includes on one hand the user expected end-to-end QoS expressed in a meaningful way to the customer, and on the other hand the traffic profile to which customer promises to adhere to, expressed in a meaningful way to the provider. The domain makes its own decisions on strategies and protocols to use for internal QoS support. According to policy rules, individual QBs instruct their respective border routers how much traffic each border router should export and import for each class of service.

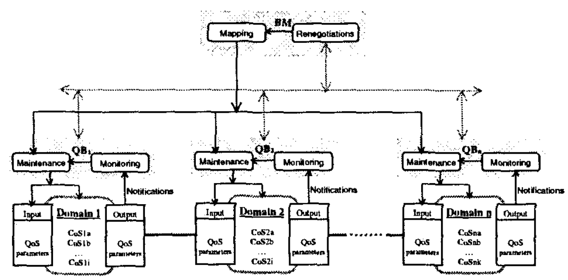

Figure 4: Dynamic management process

Monitoring observes the current load of each service class at each boundary router, and makes it possible to supervise consistency level by comparing the offered QoS parameters with the contracted QoS ones (e.g. delays and losses). In case of inconsistency, *Maintenance* performs curative actions on input sides and or inside domains. Monitoring comparisons are based on output sides measurements, reported via feedback *Notifications* channels. When the maintenance functions cannot achieve the contracted QoS parameters (due to major changes or failures in the system), a *Renegotiations* phase is invoked to achieve a new agreement. *Mapping* then allows updating accordingly the maintenance strategy in each domain.

4.2 Informational model: QoS

An informational model should be able to inform about contracts. A contract is a relation between a service user and a service provider (Desirable QoS, Contracted QoS, Offered QoS, and Expected QoS [10, 12, and 20] and by refinement between the client and server interfaces of two components that have to be identified in the contract. To control conformity to a contract, we should be able to evaluate the QoS in terms of generic criteria (Availability, Reliability, Delay, and Capacity) that apply to all the visibility levels [13, 15]. In a DiffServ context, the requested QoS has to be mapped to the related classes of services.

The quantitative aspects can then be measured through significant parameters of each visibility level. The resulting end to end QoS is then the aggregation of the intermediate QoSs of the considered flow. ENST has already applied such a model in connection oriented networks. For our connectionless context, other criteria than source and destination addresses should be used to characterize a given flow's packets (service classes). Flow characterization becomes domain dependent, and every domain may fix its own criteria to link a set of packets to a specific flow.

4.3 Architectural Model

In this paragraph, we outline the architectural components that have to be provided to perform an end to end delivery service with personalized QoS.

In core routers, a behavior aggregate classifier is needed to recognize the CoS demanded by packets. Conditioning functions are not essential at this stage. A multiple logical Queue strategy is advisable to dedicate a separate queue to each CoS aggregated flow. Depending on the CoSs set defined in the domain, buffer acceptance and scheduling algorithms have to be chosen accordingly.

In boundary routers, classifications have to be SLA based. Classifiers can be multi-field to restitute flow identification from multiple header fields. Markers are also needed to set the DS field to the CoS resulting from classification. Within egress routers, markers act as a mapper that sets the DS filed to a CoS defined in the next domain. Meters will compare traffic profiles to inter-domain contracts. Non-conforming packets will be dropped by *Policers* at ingress routers, or delayed by shapers at egress nodes.

On the management plane, a core router has to be able to send notifications to its QB and to get ready for being monitored by it. When some degradation is experienced by a flow crossing its domain, a QB notifies to its BM the lateness level with quantifying information. This allows the BM to make an anticipation strategy regarding the domains that remain in the flow path. This anticipation strategy may include routing table updates. Monitoring is needed to evaluate the long-term impact of the strategic anticipations made by the BM.

4.4 Functional model

Here, we focus on the management actions that must be dynamically performed at inter-domain nodes to adapt local QoSs in order to respect the end to end QoS. This adaptation is needed, given the changing nature of the context, to make up for the QoS deficiency or to reduce an eventual surplus in the quality offered to the service.

To guarantee the end-to-end QoS requested by users, the management process has to be cooperative among the individual QoS entities. Such a cooperative process can conform to the functional lifecycle model shown in figure 5. The QoS is requested (1) and then translated into comprehensible parameters (2), i.e. desirable QoS parameters. The user attached QB then initiates an intra-domain negotiation process among participating hops. If the negotiations fail, the process terminates with rejecting the request (3'). Otherwise, an inter-domain negotiation process is engaged among participating domains (3). Depending on whether the negotiations fail or succeed, the process either terminates with rejecting the request (4') or enters the according state with the contracted SLA (4). Once the according state is entered, mapping rules for the considered flow are conveyed to each participating domain (5). These rules make it possible for the domain to distinguish the considered flow and to assign it the CoS that it is subject to.

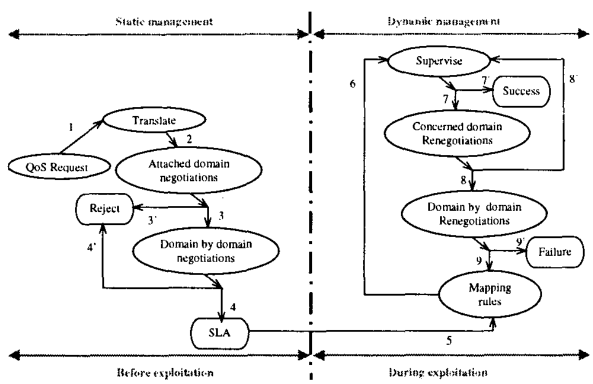

Figure 5: Functional model

During the flow lifetime (i.e. during exploitation phase), the current offered QoS parameters are supervised (6) and compared to the contracted ones. If the compared result remains satisfying, the process terminates with a successful result (7'). Otherwise, a renegotiations process must be first triggered into the problematic domain to attempt to make up for the QoS deficiency through local resources adjustment (7). If there is no means to recover with intra-domain resources adjustment, the remaining domains are subject to an inter-domain renegotiation process (8). Provided these negotiations don't fail (9'), new rules update the mapping strategy at each participating domain (9).

4.5 Relational Model

A communication model is needed to apprehend the exchanges system components participate in, both in their qualitative and quantitative aspects. In the case of our proposition, the question is how to make relations among the various components that cooperate to grant and maintain an end-to-end QoS. Currently, we are investigating two possible approaches: in-band communication, and out-of-band communication.

In-band communication may be performed with OAM (Operation And Maintenance) flows. As out-of-band alternatives, we may investigate heterogeneous TMN compliant architectures such as SNMP and CMIP. These are needed to notify the manager of the tactical decisions made on a domain-hop by domain-hop basis. The region manager can then anticipate and renegotiate contracts with other domains.

5. Conclusion

In this paper, we have addressed the dynamic management for an end-to-end QoS support in IP networks. After having categorized applications requirements, we proposed a time Vs planes classification of QoS-enabling components. We made use of both this classification and the DiffServ approach to formulate a proposition in which we delegate service personalization to interconnection units (boundary nodes) which perform renegotiation and mapping functions. The included QoS model enable to have components efficiently instrumented in order to have the most pertinent notification for any QoS contract violation. As for the organizational model, it advocates a distributed management between QoS brokers and boundary nodes.

For future work, the efficiency brought by dynamic planning level encourages us to investigate potential enhancements that might be functionally obtained through judicious usage of innovative new technologies such as active networks based solutions.

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