Quality of Service in High-Speed Networks for the Support of New Communication Services

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ABSTRACT

High-speed networks have the potential to support a large variety of applications in a distributed environment, like, for instance, applications involving full-motion video, bulk data transfers, or interactive multicast video conferencing. Nevertheless, in order to make use of that potential, communication protocols and services must be given the functionality necessary to the support of the quality of service (QoS) required by applications. Quality of service functionality must bridge the gap between high-speed network technology and application requirements. This paper presents a framework that addresses the quality of service functions and mechanisms from an integrating point of view, covering the QoS aspects relevant to the user services, communication resources and protocols.

1. INTRODUCTION

The support of communication services like multimedia, compressed video, video-conferencing, or cooperative-work, presents new challenges to communication systems technology. These challenges relate not only to the underlying network technology, but also to the information transfer protocols, mechanisms and functions for the provision of *quality of service* . Quality of service can be looked at as the indispensable element that can turn high bandwidth network technologies into useful, manageable and efficient communication systems.

Quality of service provision has become a major issue of high-speed networking due to a set of important factors. One of them, is the shifting of the bottleneck from bandwidth to processing capacity [Lundy 94]. The technology known as packet switching, used in a significant part of nowadays wide area networks, was developed with the main goal of optimizing the use of bandwidth in the communications systems. For that purpose, it consumes more processing resources than necessary. Today, it is important to change this strategy. It is also important to understand that the biggest limitation of the communication links is no more their bandwidth but, instead, their latency - the propagation time of the signals from one end of the link to the other. The high bandwidth-delay product of new communications links, which results in enormous quantities of information traveling, at any instant, along the communication channel, is another important issue related to high speed networks.

Another important factor, in terms of quality of service, is the unsuitability of existing communication protocols for operation in high-speed environments, since they were designed for bandwidth-constrained, error prone communication systems. There are two ways to implement the protocols needed in the new communications systems, in order to provide the quality of service required by applications:

- to develop new protocols, designed specifically to operate in high-speed communication environments, or
- to improve the existent protocols, so that they can correspond to the needs of the new generation applications.

In either case, there is a set of mechanisms and functions, with certain characteristics, that protocols must support/provide, if they are to fulfill the new network application requirements. The present paper addresses those functions and mechanisms, and proposes a framework for quality of service control and provision. In section 2, some technologies for high-speed networking are briefly presented. Section 3 identifies the main types of high-speed network applications, their main requirements and characteristics. Section 4 presents a quality of service framework, that identifies the main issues of quality of service provision at the service/application level, at the communication system resources level and at the protocol level. Section 5 presents the conclusions and identifies future work items in line with the proposed framework.

2. TECHNOLOGIES FOR HIGH-SPEED NETWORKING

The emergence of high bandwidth communication media and technologies, which allow very high transmission rates and reliable information transfer, is leading to significant changes in the communication systems. In this section we briefly mention some of the low-level technologies that are expected to play a significant role in high-speed networking.

One technology that is well placed to take advantages of the new capacities of high bandwidth communication media is the Asynchronous Transfer Mode (ATM) technology. ATM is a standard approved by ITU-T to support the Broadband Integrated Services Digital Network - BISDN - and results from a joint effort of the data communications and telephony communities, which is a good reason to believe in its future. It is an example of a switched cell, connection oriented and multicasting technology. The connection oriented paradigm is necessary because it is the only way of providing quality of service guarantees for the new generation of applications. The multicasting mechanism is also important because many of those applications have the purpose of interconnecting several users simultaneously. Last, the cell switched technology is convenient because it simplifies the processing of the traveling information as it passes through communication equipment.

Frame Relay can also be seen as a low level technology for the support of high-speed networking. It is a packet switching technology that supports connection oriented, multicasting services. It was designed with the main goal of taking advantage from the high reliability of new communication media. The evidence of that is the reduction to a minimum of all processing overhead related to error detection and correction, which allows higher throughput and lower delay in the information transfer. Frame Relay maintains, with high probability and minimum variance, the agreed quality of service [Subramanian 95] and is capable of providing throughputs from 56 Kbps to 45 Mbps. It is expected that the advent of ATM, which has better characteristics to the support the new communications services, will result in the preclusion of the, nowadays generalized, Frame Relay technology.

The Distributed Queue Dual Bus - DQDB or IEEE 802.6 - is a LAN/WAN joint standard of IEEE and ANSI. It is a shared medium network, that works over two slotted busses. Each slot can hold a 53 byte cell and can be permanently reserved - pre arbitrated - which allows the transport of traffic with stringent needs of quality of service, namely real time data. DQDB was carefully designed to maintain full compatibility with ATM, in order to facilitate the interconnection of DQDB networks through ATM long-distance networks. Nevertheless, there are now some important differences that have resulted from a recent slightly divergence from the ATM standard [Partridge 94].

Another technology that is worthwhile to mention is known as High Performance Parallel Interface - HIPPI - and it is an ANSI standard [Tolmie 95][Bell 95][Praag 94]. It was created to satisfy the stringent supercomputer I/O demands. HIPPI is indeed a point-to-point technology. Nevertheless, through the use of switches, it turns out in a reference technology to construct high speed local area networks. It is a circuit switched, connection oriented, simplex technology, that, in its basic configuration, transports the data in parallel through paths of 32 or 64 bits (with maximum length of 50 m), at speeds of 800 Mbps and 1,6 Gbps respectively. The HIPPI can transport IP or peripheral commands (for tapes or disks) and supports remote memory access. It can also be extended to provide serial transmission through electrical or optical interfaces over 300m or 10 km links. Some people think that, as HIPPI was thought to work at higher speeds than ATM, both technologies will coexist. The work that is being done to define interfaces to extend HIPPI over ATM networks might help on that.

3. HIGH-SPEED NETWORK APPLICATIONS

The new networks will transport different types of information with different characteristics and, consequently, different needs, that have to be satisfied by the underlying transport technology. For example, multimedia, compressed video VBR, and file transfer applications, which produce difference kinds of traffic – namely isochronous and bursty traffic – will certainly utilize the same transport technology in the future, from which they expect different attention in order to achieve good performance levels.

In the case of multimedia applications, the communication system needs to guarantee that the isochronous traffic arrives at its destination in time. In other words, the communication system must agree, with the application in question, upon the maximum delay that can be introduced in the delivery of the information. Also, it must agree upon the maximum variance that the referred delay can suffer. Applications that generate bursty traffic, by other hand, normally need to have guarantees about the bandwidth they can use.

In short, the main difference between old and new communications applications, which determines the characteristics of new communications systems, is the need the first ones have to obtain some guarantees relating the quality of service they can count on from the used communication system. These guarantees can be different from application to application, and typically are: maximum transport delay, minimum bandwidth, minimum reliability, minimum availability, maximum time to establish a communication session, and maximum jitter (i.e., variation of the transport delay).

We can roughly divide high-speed applications up into two groups: distributed computation applications and interactive distributed applications [Partridge 93]. The first group comprises the applications which have high processing needs. In an attempt to achieve better performance, the problems that these applications need to address are broken up into several smaller ones, which are processed, in parallel, at different processors. This leads to stringent requirements in terms of communication system performance. The second group comprises the applications which run in several computers and must continuously supply human users with huge amounts of information with rigorous time constraints, namely in a time-scale consistent with those users. Catlett, in [Catlett 92], refers several examples of supercomputer applications which can be classified into one or the other group.

It is interesting to notice that the first Gigabit Networking IEEE Workshop defined a set of characteristics - criteria - the applications should have to be considered high-speed applications [Touch 95]. These characteristics were not only the result of the identification of technological requirements but also result from the identification of real user applications, and are the following:

1 - realistic consumer or business application (current or future),
2 - minimum bandwidth per user of many Mbps,
3 - minimum potential base of thousand of simultaneous users,
4 - number of users*application bandwidth in excess of 1 Tbps, and
5 - consumer video applications must be more sophisticated than broadcast or simple video-on-demand multicast.

The last criterion tries to filter out the applications that satisfy the other criteria but still perform well when they make use of the existing protocols. Touch’s opinion is that it is necessary to refine more those criteria in order to exclude cases where the existing protocols suffice. Independently of the used criteria, it is nowadays obvious the existence of several kinds of interesting applications with real needs for high-speed networking technologies. The increasing performance of computers we can now find in our homes or workplaces, which are, at least potentially, multimedia stations, makes possible the generalized use of some of those applications. In fact, it allows the widespread use of applications like video-conferencing, cooperative-work, or client interactive real-time access to WWW servers, with understandable advantages. For that we clearly need high speed networks.

4. QUALITY OF SERVICE FRAMEWORK

In the previous sections we looked at some of the technologies and types of applications for high-speed networks, and identified some of their requirements and constraints. This section presents a framework for the functions and mechanisms for the support of the quality of service required by high speed network applications. A detailed presentation of this framework can be found in [Monteiro 95a].

The complexity associated with the definition of the functions and mechanisms for the provision of a given quality of service requires an analysis based on a multi-dimensional model, in which each dimension - or plane - represents a specific view of the problem. The planes are a result of the identification of the intervening functional elements, followed by their grouping by affinity, having in mind the minimization of the interaction between planes. The identification of the various planes, complemented by the characterization of their respective functions and mechanisms, constitutes an *architectural framework* for quality of service provision in communication systems.

4.1 Planes of the QoS framework

Quality of service activities can be classified into three main groups: the group concerning the communication services, the group concerning the communication resources, and the group concerning the communication protocols and operation. Each of these groups corresponds to an architectural congestion control plane described below:

- the *service plane* — that groups the activities related to service characterization. This plane contains all the aspects of congestion control that relate to communication services or applications;
- the *resource plane* — that groups the activities related to resource planning, resource reservation, and resource monitoring. This plane contains all the aspects of congestion control that concern the communication resources. The functions of this plane are integrated with or associated to systems management functions because, according to the OSI reference model [ISO 89] resource management is one particular aspect of communication systems management;
- the *protocol plane* — this plane contains all the congestion control aspects that are related to the operation of the communication protocols. Namely, it contains the congestion control activities related to traffic transportation and traffic monitoring. The functions of this plane are integrated with or associated to the communication protocols.

Table 1 summarizes the quality of service functions and mechanisms in each of the planes. In the following sections, the identified planes will be analyzed in more detail. The analysis will include the characterization of the functions and mechanisms necessary for the implementation of the congestion architecture.

4.2. The service plane

This plane comprises three groups of functions: the functions for service establishment and characterization, the service monitoring functions, and the service control functions.

Functions for service establishment and characterization

This group of functions covers the aspects of the global characterization of the system from the perspective of quality of service, and the characterization of the communication services with respect to their traffic needs. It also covers the translation of the service needs into a set of descriptors used in service establishment and traffic transportation (e.g., normal variation limits and degradation thresholds).

Table 1 Summary of the QoS architectural framework

Plane	Functions	Mechanisms
Services	Service characterization and establishment	Characterization of the P_{QoS} set
		Characterization of the service QoS matrixes, M_{QoS}
		Service establishment
	Service monitoring	Algorithm for the evaluation of $I_d(t_k)$ and $I_c(t_k)$
		Algorithm for the evaluation of $C_{si}(t_k)$
		Algorithm for the evaluation of $C_g(t_k)$
	Service control	Traffic shaping
Resources	Resource planning and creation	Resource planning and installation
		Resource configuration
	Resource control	Resource calculation
		Resource reservation
		Resource control
	Resource monitoring	Resource monitoring and accounting

Protocols	Service acceptance control	Service acceptance/refusal
		Service QoS matrix verification
		Routing control
	Traffic monitoring	Traffic monitoring
		Algorithm for the evaluation of $Ic^{p}_{s_i,q_j}(t_k)$
	Traffic parameter control	Transmission scheduling
		Traffic policing

The functions for service establishment and characterization use a set of mechanisms which includes:

- *system QoS characterization mechanisms* — these mechanisms act at system configuration (or reconfiguration) time, and enable the specification of the set of the system QoS parameters, P_{QoS}. The definition of P_{QoS} corresponds to the characterization of the supported system QoS parameters, which includes the description of the physical significance of each parameter, the identification of the respective measurement units, and the classification as *cumulative* or *non-cumulative* [Monteiro 95b]. The P_{QoS} set has a global significance, and its members are defined according to the technical and architectural characteristics of the communication system;

- *service characterization mechanisms* — service characterization is based on the supported P_{QoS} set. The service characterization mechanisms enable the specification of each service QoS matrix (M_{QoS}), that identifies the normal variation limits and the degradation thresholds of each parameter relevant to the service. The service characterization mechanisms can be executed in a static way, in the scope of the systems management configuration functions, or dynamically, in order to periodically correct the values stored in the service QoS matrix based on the information collected by the service monitoring mechanisms and traffic monitoring mechanisms (that act in the protocol plane);

- *service establishment mechanisms* — prior to the establishment of a communication service, it is necessary to solicit the required resources to the protocol plane — by passing it the service QoS matrix — and to verify the existence of end-to-end capability for the support of the service. These actions are performed using the service establishment mechanisms.

Although the main monitoring functions are located in the protocol plane, the service plane also requires some functions of this type. The main difference between the monitoring functions of the two planes is their scope which, in the service plane, have an end-to-end significance, while in the protocol plane they have a communication module significance.

Service monitoring functions

The objective of the service monitoring functions is to gather data on the global behavior of the communication system, for preventive, statistical or, eventually, fine tuning purposes. These functions rely on a set of mechanisms that implement the following algorithms:

- *algorithm for the evaluation of the deviation index of QoS parameters* — computes the deviation index of each parameter of the active services, $Id_{s_i,q_j}(t_k)$, according to a deviation function. The values of the various deviation indexes are necessary for the calculation of the congestion indexes of the QoS parameters, $Ic_{s_i,q_j}(t_k)$ - defined as the different between the deviation indexes at the output and at the input of a communication module - as well as for the eventual introduction of modifications in the service descriptions;

- *algorithm for the evaluation of the service congestion indexes* — using the congestion indexes of all the QoS parameters of a given service, it is possible to calculate the congestion index of the service, $C_{s_i}(t_k)$, as a weighted average of the individual congestion indexes [Monteiro 95b]. This congestion index is an end-to-end indicator of the communication service congestion, and can be used in the activation of global control mechanisms or in the fine tuning of communication services;

- *algorithm for the evaluation of the global system congestion* — the average of the service congestion indexes is called the global system congestion, $Cg(t_k)$. Its value is a simple indicator of the congestion state of the communication system, and can be used for the determination of global congestion time averages.

Service control functions

Although service control is normally carried out in the protocol plane, by the traffic control mechanisms, some service control functions can optionally be included in the service plane. Namely, this plane can include the following functions:

- *traffic shaping functions* — these functions can act in a preventive way, modifying the characteristics of the traffic generated by the applications, in order to maintain conformance with the values specified in the service QoS matrix. The main objectives of these functions is to correct traffic deviations before the application of punitive policing methods, that act in the protocol plane. The inclusion of traffic shaping mechanisms in the service plane does not preclude the use of similar mechanisms along the communication system in the protocol plane, in order to guarantee the protection of communication services from traffic overloads due to "ill-behaved services".

4.3 The resource plane

The *resource plane* covers all the congestion control aspects that relate to communication system resources. Namely, planning functions, management functions and resource monitoring functions are located in this plane. The congestion control functions of this plane are, normally, integrated in or associated to communication systems management functions.

Resource creation and planning functions

Resource creation and resource planning are two of the most effective mid-term/long-term means for congestion avoidance. The planning and installation functions can act globally on the communication system, or specifically on one or more of its modules. These functions use a vast set of mechanisms and techniques of which we refer:

- *mechanisms for resource planning and installation* — these mechanisms act in the long-term, based on the data collected by the resource monitoring functions and on the characteristics of the services that are (or are going to be) supported. These mechanisms aim at the identification of the critical points of the communication system and at the determination of the necessary communication resources. They can use a variety of techniques like, for instance, simulation techniques and traffic analysis techniques;

- *resource configuration mechanisms* — these mechanisms support the configuration of the installed resources, in view of the support of the communication services. They enable the adaptation of the communication system to the alteration of the characteristics of the supported services, taking into account the available resources. They can act dynamically, as a function of the available resources and of the active services, or in a static way, at the time of system configuration modifications.

Resource control functions

Resource control functions are of fundamental importance to the congestion control of communication systems based on the *resource reservation* paradigm. In conjunction with the service acceptance control functions of the protocol plane, these functions guarantee the existence of the resources necessary for the support of the communication services, according to the specified quality of service. These functions use a variety of mechanisms, of which we mention:

- *resource calculation mechanisms* — these mechanisms act on the basis of the information collected by the service acceptance control functions — in the protocol plane — and are responsible for the determination of the resources necessary for the service. For this determination, these mechanisms use the values stored in the service QoS matrix. The calculation of the necessary resources can be made using a variety of techniques and algorithms, depending on the type of resources and on the services to be supported. *Statistical multiplexing techniques* are of particular importance, as they rely on the combination of statistical traffic variations to obtain significant resource economies (normally, bandwidth economy and buffer space economy);

- *resource reservation mechanisms* — resource reservation is carried out during the service establishment, based on the calculation of the resources necessary for the service. Resource reservation mechanisms aim at the allocation of free resources to the services, in each communication system module, and during the lifetime of the services. In case the available resources are not enough for the support of the required quality of service, the service can be aborted or, alternatively, a QoS negotiation/reduction process can be activated, in conjunction with the QoS verification mechanisms of the protocol plane, in order to support the service with the available resources. For services that require a highly impulsive traffic, the resource reservation mechanisms can also act during the lifetime of the service and before the occurrence of traffic pulses, in order to guarantee the necessary resources during the duration of the traffic pulses;

- *resource control mechanisms* — these mechanisms act during the lifetime of the service and are responsible for the dynamic distribution of the resources among the services within the limits established by the resource reservation mechanisms. The mechanisms for buffer space control and bandwidth control are of particular importance.

Resource monitoring functions

Resource monitoring functions collect the necessary data for resource planning and resource creation functions. Resource planning and creation must take into account resource occupation statistics. Resource control functions — namely the resource calculation mechanisms — must take into account the resource utilization history, which is constructed using the data collected by resource monitoring functions. These functions use the following mechanisms:

- *resource monitoring and accounting mechanisms* — this is a set of mechanisms that act in a distributed form in each of the communication system modules, in order to collect resource utilization data. The data is collected at three distinct levels: resource accounting by communication service; short term statistics for fine tuning of service parameters; long term statistics, for the support of communication system planning activities.

4.4 The protocol plane

The *protocol plane* of the QoS architectural framework contains three main groups of functions: service acceptance control functions, service monitoring functions, and service parameter control functions. These functions are necessary in end systems as well as in intermediate systems.

Service acceptance control functions

These functions act during service establishment and are responsible for the acceptance or refusal of service establishment. They request the reservation of the necessary resources to the resource plane. The acceptance or refusal of a given service depends, among other things, on the existence of the required resources, as established by the *service characterization functions* in the service plane. The service acceptance control functions use a set of mechanisms located in the various communication system modules, of which we mention:

- *service acceptance/refusal mechanisms* — these are responsible for the acceptance or refusal of communication services. A service is established if there are sufficient end-to-end resources for its support. In case the values contained in the service QoS matrix cannot be supported on an end-to-end basis , a QoS negotiation process can be started or, alternatively, the service will be aborted by lack of operating conditions. The availability and acquisition of the necessary resources are established with the use of the resource control functions, of the resource plane. The verification of the existence of end-to-end conditions is carried out with the use of the QoS matrix verification mechanisms, described below;

- *QoS matrix verification mechanisms* — the verification of the service QoS matrix, M_{QoS}, is carried out during the service establishment process. For each communication module, the lower and upper normal variation limits (m and M) and the lower and upper degradation thresholds (l_m and l_M) are evaluated for each parameter, taking into account the available resources and the service characteristics. Based on this evaluation and on the nature of the QoS parameters (*cumulative* or *non-cumulative*) the end-to-end normal variation limits and degradation thresholds are verified;

- *routing control mechanisms* — these are the congestion control mechanisms that are, normally, integrated in the routing protocols. They act in close cooperation with the service acceptance mechanisms and with the QoS matrix verification mechanisms, described above, and are responsible for the path selection, taking into account the system congestion state and the availability of resources. They can act in a static way, at service establishment time, or dynamically, whenever the path characteristics or traffic characteristics are altered.

Traffic monitoring functions

These functions monitor the traffic flow of all communication services, and are responsible for the determination of the indexes that are used by the traffic parameter control functions. The traffic monitoring functions use a set of mechanisms and algorithms, of which we refer:

- *traffic monitoring mechanisms* — they determine the *deviation index* of each of the QoS parameters at the input and at the output of a module ($Id^{p_{in}}_{s_i,q_j}(t_k)$ and $Id^{p_{out}}_{s_i,q_j}(t_k)$, respectively), at instant t_k, for each active service, and for each communication system module. These values are calculated on the basis of the normal variation limits (m and M) and the degradation thresholds (l_m and l_M) of each module;

- *algorithm for the evaluation of the QoS parameter congestion indexes* — the congestion introduced by a given module p, at instant t_k, in each QoS parameter, q_j, of a given service s_i, can be measured by the respective *congestion index* $Ic^{p}_{s_i,q_j}(t_k)$. The congestion index is the difference between the output deviation index and the input deviation index for that module.

Traffic parameter control functions

These functions use the results obtained by the monitoring of the traffic flow of the active communication services, and they are responsible for the active control of the traffic, within the limits specified in the QoS matrix of each service. They use a variety of mechanisms, which include:

- *transmission scheduling mechanisms* — these mechanisms — also known as *service disciplines* — have a fundamental part in keeping the services within the specified values of quality of service. They act on the transmission and switching subsystems, and are responsible for the scheduling of the transmission of the protocol data units. Their functioning has a direct influence on the main QoS parameters, as is the case of the QoS parameters related to the throughput (maximum, average and peak), and the parameters related to the transit delay (maximum, average, and delay variation);

- *traffic policing mechanisms* — these mechanisms act in order to correct traffic flow deviations in relation to the values specified in the service QoS matrix. These mechanisms have corrective objectives - as opposed to the scheduling mechanisms that try to maintain the operation within the specified QoS limits - and contribute to the protection of "well behaved" traffic against "ill behaved" traffic. They act either by discarding the traffic elements that violate the service contract, or by marking them with low priority.

5. CONCLUSION

In this paper we began to address some low level technologies that can be used in new communications systems. Although suited for high-speed networking, they are, by themselves, insufficient for the support of the new generation of applications, due to the fact that these applications require the use of communication mechanisms and functions that can provide the required quality of service.

Prior to the implementation of a set of mechanisms and functions for the provision of quality of service to applications, there is the need to define and agree upon a quality of service framework that identifies the necessary functions/mechanisms, from the points of view of the applications, of the system resources and of the communication protocols. The present paper proposes such a framework, covering the activities related to service characterization, service monitoring, service control, resource planning, resource reservation, resource monitoring, traffic transportation and traffic monitoring.

Further work is already being carried out by the authors, and is being directed to the identification, specification and implementation of specific functions and mechanisms for quality of service guarantee. In this respect, high-speed transport protocols and applications will be matched against quality of service requirements, and new quality of service functionality will be proposed and assessed.

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