Quality of Service for Multimedia Communications

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Quality of service is commonly defined as the service users' degree of satisfaction during a given communications session. Consistently anticipating and meeting users' quality of service needs is what distinguishes successful communications service and product providers from their competition. Yet, as users explore the expanding world of multimedia communications, the standard that developers and providers must meet keeps rising: New applications are increasingly complex, and the tools to measure them often fall short of the user's ability to perceive quality of service differences.

The Multimedia Communications Forum (MMCF) has developed a Multimedia Communications Quality of Service (QOS) document—the first of its type—which offers both providers and users universal performance guidelines and service parameters for multimedia communications. These guidelines provide performance objectives against which multimedia solutions can be specified and delivered. These guidelines are based on:

- A combination of existing industry standards and practices for digital networks.
- Realistic assumptions about multimedia equipment and premises networks.
- User expectations of typical multimedia applications

Using these tailored QOS parameters, engineers, manufacturers, and customers can now communicate with one another the performance parameters they need for their products and services. This will translate into more satisfied users which will, in turn, increase multimedia communications product and service usage and market size.

Although this migration toward multimedia communications is accelerating, it is not without difficulty, and the applications are still in an evolutionary stage. As new networking technologies and applications emerge, quality of service requirements will evolve. Correspondingly, the MMCF document will also evolve.

Building Foundations on Bedrock

The general topic of communications quality of service—and its relation to the performance of communications terminals, systems, and networks—is addressed extensively in the works of other standards bodies, such as the ATM Forum and IEEE. In particular, several published standards identify and define detailed performance parameters upon which quality of service depends. In an effort to incorporate parameters and definitions that are already widely accepted, the MMCF QOS document uses existing standards, to the extent possible, as a basis for defining quality of service.

The International Telecommunications Union recommends a high-level 3 × 3 matrix as the primary structure for identifying all quality of service sources and relationships relevant to network performance. This high-level matrix (see Figure 1, recommends using the criteria of *speed*, *accuracy*, and *dependability* to judge the quality with which the basic user functions of connection set-up, user information transfer, and connection release are performed. Careful consideration of this framework of telecommunications service quality should facilitate user acceptance.

The current MMCF QOS document focuses on:

- The quality of service framework.
- A foundation for future work.
- Specific requirements for multimedia conferencing applications.

The shaded area in Figure 1 represents the primary focus of the Multimedia Desktop Collaboration (MDC) discussion in this article.

Future research by the MMCF will be focused on the unshaded areas of this matrix. Additional research addressing the requirements for multimedia information retrieval, multimedia mail, and multimedia distribution services will follow.

Multimedia Communications Systems Structure

At the heart of the MMCF QOS framework is a Network Performance Reference Model. It is based on the assumption that networks consist of multiple hardware and software components. Often different organizations will provide and maintain the hardware and software between two endpoints. Figure 2 depicts a multimedia network where three classes of components reflect the variety of providers contributing to a complete end-to-end solution.

Users are not typically concerned with how providers deliver a particular service. However, they are interested in comparing services in terms of universal, user-oriented performance parameters which apply to any end-to-end service. From their perspective, quality of service should be expressed by parameters which:

- Focus on user-perceivable effects, rather than their causes within the network.
- Are independent of the network internal design.
- Take into account all aspects of the service from the user's point of view and can be objectively measured.
- Can be assured to a user by the service provider(s), i.e., a service provider can't assure that there will be a high-quality signal coming in from one (or any number of) terminal endpoints, but can be expected to carry whatever signal is captured without further degradation.

Teleservices provide complete end-to-end functionality, including terminal equipment (TE) functions, for seamless communications between users. Quality of service parameters for multimedia teleservices are useful to set expectations for individual end-users.

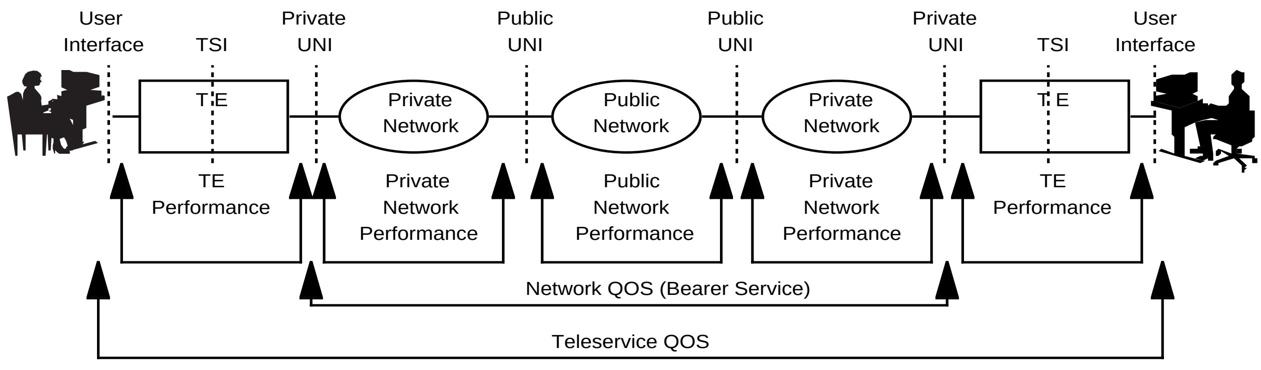
Bearer services provide the capability for transmission of signals between user-network interfaces, and do not include terminal equipment functions. Quality of service parameters for bearer services are useful to set expectations between user departments which may provide their own terminal equipment, and a corporate network organization which may provide networking services for these departments.

Figure 1
High-Level 3 × 3 Matrix for Quality of Service

User Functions	Quality Criteria		
	Speed	Accuracy	Dependability
Connection Set-Up (Access)			
User Information Transfer			
Connection Disengagement (Release)			

Source: MMCF

Figure 2
Quality of Service and Network Performance Reference Model



Source: MMCF

Notes

(1) For some services, only one user interface exists, in which case one of the TEs performs the function of the client and the other the function of a server. The server may be part of the public network.
(2) For some users or services, the private network will not be present. However, the possibility that it may exist should always be considered from a performance point of view.

Terminal equipment performance and network performance parameters are of interest to equipment and service providers to define the efficiency and effectiveness of the product or service offering. From an equipment or service provider's perspective, performance should be expressed by parameters which provide information for:

- System development.
- Network planning.
- Operation and maintenance.

The quality of service provided by the end-to-end network is dependent upon the performance of each of its components. The performance parameters of each component should permit network designers the flexibility to allocate performance degradation to each component, e.g., to minimize cost while maintaining a required end-to-end quality of service objective.

Terminal Equipment

In the MMCF QOS document, terminal equipment encompasses the multimedia communications application. Terminal equipment is directly connected to the private network through a private user-to-network interface (private UNI) or to the wide area network through a public user-to-network interface (public UNI). Examples of terminal equipment are desktop devices, video servers, and MCUs (multipoint control units).

Private Network

The private network, as defined in the MMCF QOS framework, consists of communications equipment and transmission media typically owned and operated by an end-user organization. It provides communications services supporting the multimedia applications residing in the terminal equipment.

The private network is connected to terminal equipment through private UNIs and to the wide area network through public UNIs. Examples of private network components are wiring closet hubs, PBXs, multiplexers, and building wiring. Private networks are often referred to as local area networks (LANs).

Public Network

The public network provides communications services supporting multimedia applications outside the premises of the end-user organization. It is connected to terminal equipment and private networks only through public UNIs. Public network services are often offered through a combination of service providers, including local exchange carriers (LECs), interexchange carriers (IXCs), and international carriers. Public networks are often referred to as wide area networks (WANs).

Quality of Service Classes

As defined in the MMCF document and earlier relevant documents published by other standards bodies, quality of service describes the collective effects of service performances which determine the degree of satisfaction of a user of the service.

The set of relevant parameters, and the values of these parameters that correspond to an acceptable quality of service, are heavily dependent upon the category of multimedia application and its purpose. Multimedia service alternatives within each category facilitate comparison. Quality of service parameter values described in specific QOS guidelines map directly into four different quality of service classes, reflecting different levels of user requirements.

QOS Class	User requirements
Class 0	No defined requirements
Class 1	Basic performance, ubiquitous network access, low cost, mobility
Class 2	Enhanced performance, moderate cost, small office/home office
Class 3	Professional performance, improved productivity, shared office environment

Definition of a small number of generally accepted QOS classes will simplify the design, deployment, and use of multimedia communications systems. Based on the multimedia application category (see sidebar), users and application providers can define the minimum QOS class required to support them. Correspondingly, network service and equipment providers can specify the QOS class supported by the product without detailed knowledge about the application. The QOS class, determined by the lowest classification of any of its QOS parameters, thus becomes a simple yet powerful tool to set the expectations between users and providers.

Multimedia Desktop Collaboration Requirements

Multimedia desktop collaboration is a combination of videoconferencing and collaborative computing. The vision of multimedia desktop collaboration is to provide a range of capabilities that will allow users to select the appropriate communications for each call they make or receive.

Currently, the MMCF defines three distinct MDC QOS classes aimed at users with different application requirements and network capabilities. Characteristics of each QOS class appear below, and Table 1 summarizes the requirements for each class. It should be noted that the requirements for all modes, i.e., audio, video, data, and control, must be satisfied simultaneously. For example, the transfer of a document is not allowed to slow the video frame rate or increase the audio delay beyond the specified limits. The MMCF requirements define guaranteed quality of service levels unless the service is unavailable.

Ideally, a user would select a QOS class to satisfy his or her perceived requirements, and then select a multimedia communications service for which each QOS parameter meets or exceeds the requirements of that class. This simple approach is primarily for broad horizontal applications that are of interest to users across industries and professions.

In many cases, user requirements are more specific, and the simple approach described above may not result in cost-effective solutions. Depending on the application, a user may choose to consider the QOS class for each parameter individually (e.g., placing heavy emphasis by requiring QOS Class 3 for video resolution, and less emphasis on audio delay by requiring QOS Class 1 for audio delay). This approach, although more complex, may be suitable for vertical applications focusing on a specific industry or profession, e.g., telemedicine.

Using this universal framework, additional classes of service will address new market needs. For example, there is already a need for MDC QOS classes to support higher video requirements, including broadcast quality and HDTV quality video.

MDC QOS Class 1

MDC QOS Class 1 is for the broadest possible set of users, where cost considerations and network access are of overriding importance. Class 1 offers very basic multimedia conferencing support, which includes conventional telephone quality—narrowband—audio, still image video (less than five frames per second), and document conferencing. The maximum audio delay, limited to 400 milliseconds (ms), is slightly worse than a single satellite hop. The exchange of documents and images will involve significant delay, with a 10 kilobyte document transfer

Table 1
Summary of MMCF MDC QOS Classes for End-to-End Service

	QOS Class 1	QOS Class 2	QOS Class 3
Audio	Max. delay: 400 ms Bandwidth: 0.3-3.4 KHz Level: -20 dBm0	Max. delay: 400 ms Bandwidth: 0.3-3.4 KHz Level: -20 dBm0	Max. delay: 150 ms Bandwidth: 0.05-6.8 KHz Level: -20 dBm0
Video	Still image only	Max. delay: < 600 ms Diff. delay: < 200 ms Frame rate:> 5 fps Resolution: >176 × 144 QCIF	Max. delay:< 250 ms Diff. delay: < 100 ms Frame rate:> 25 fps Resolution: >352 × 288 CIF
Data (binary files, text, documents, graphics, facsimile, images, animation)	Data rate: > 5 Kb/s (corresponding to a transfer rate of 37.5 KByte/min. of user information)	Data rate: > 50 Kb/s (corresponding to a transfer rate of 6.25 KByte/sec. of user information)	Data rate: > 500 Kb/s (corresponding to a transfer rate of 62.5 KByte/sec. of user information)
Control (pointer, control, and echoplex information)	Diff. delay: < 1 s (the relative delay with respect to audio)	Diff. delay: < 200 ms (the relative delay with respect to audio)	Diff. delay: < 100 ms (the relative delay with respect to audio)
Errors (user perceivable errors in audio, video or control)	Error rate: < 12 errors/hour	Error rate: < 4 errors/hour	Error rate: < 2 errors/hour

Source: MMCF

Note: Parameter values worse than those specified in the table correspond to QOS Class 0.

taking up to 16 seconds. Lack of synchronization between audio and pointer movements is noticeable with up to a one second difference in delay in MDC QOS 1.

MDC QOS Class 1 remains appealing because it is potentially a ubiquitous, lowest common denominator. Class 1 can be realized over conventional telephone lines or even certain cellular connections. Terminal applications can, to a large extent, be implemented in software on modern personal computers, resulting in a very low cost. QOS Class 1 is, therefore, expected to be of interest to a large group of occasional users as well as mobile users.

MDC QOS CLASS 2

MDC QOS Class 2 is ideal for the small office/ home office (SOHO) user, where a reasonable compromise between network cost and application performance is the objective. Class 2 supports multimedia desktop conferencing applications with moderate performance requirements. This includes narrowband quality audio and video at QCIF resolution (covers 8.25% of a 640 × 480 VGA screen, also known as “talking head”) with at least five frames per second and document conferencing.

The maximum audio delay, limited to 400 ms, is quite acceptable for certain applications, but is likely to impair a highly-interactive conversation. Audio/ video synchronization, although less than perfect, is limited to a maximum delay difference of 200 ms, which should be acceptable given the limited resolution and potential jerkiness of the video. Document conferencing should be perceived as near real-time, with a transfer delay of less than 1.6 seconds for a 10 KByte document, and less than 200 ms difference between audio and pointer movements. MDC QOS Class 2 can be realized, for example, on ISDN basic rate services.

MDC QOS Class 3

MDC QOS Class 3 is most appropriate for the business user connected to a local area network, where support of a wide range of MDC applications is desirable and the cost of network access is amortized between multiple users. Class 3 supports multimedia desktop applications with demanding requirements, including wideband audio, group conferencing video quality at CIF resolution (covers 33% of a 640 × 480 VGA screen) with at least 25 frames per second, document conferencing, and application sharing.

The maximum audio delay is limited to 150 ms, the same requirement as for an international terrestrial telephone call. Audio and video, with a maximum delay of 100 ms, should be perceived as synchronized by most users. Document conferencing can be performed with little or no consideration for time and distance, with a transfer delay of less than 160 ms for a 10 KByte document, and less than 100 ms difference between audio and pointer movements.

MDC QOS Class 3 can be realized on ISDN-PRI (primary rate interface) services or their equivalent. It is especially well-suited to LAN-attached professional and managerial office workers, where increased productivity and improved customer service are major driving forces. Access to high-performance WAN services such as ISDN-PRI is becoming widely available and can be shared between multiple users. Therefore, QOS Class 3 is a strong contender for designation as the "standard" for the shared office environment.

Focus on Audio Performance

The MMCF QOS document offers definitions and rationale for the requirements associated with each area (Table 1). As an example, and because voice performance is commonly the least understood area among computer networking professionals, we have chosen to focus on the audio requirements. A detailed discussion of video, data, and other requirements is available in the MMCF QOS document.

Unless the performance for voice in multimedia desktop conferencing is at least on par with conventional telephony, users will not be satisfied. Realizing the importance of audio in the overall user's experience, the MMCF has three specific audio QOS parameters—audio delay, audio level, and audio frequency range. Of these, audio delay is by far the most challenging to satisfy in the Multimedia Desktop Collaboration (MDC) environment.

For connections with adequate echo control, audio delay of less than 150 ms is considered acceptable to most user applications. The MMCF has specified this value for QOS Class 3. For QOS Classes 1 and 2, a limit of 400 ms is specified. End-to-end audio delay in excess of 400 ms is generally considered unacceptable for interactive applications involving voice.

In the presence of noticeable echo, even small amounts of delay make echo effects worse. Echo effects are caused by coupling between the transmit and receive direction of transmission, e.g., through acoustic coupling between microphone and loudspeaker or through the telephone network when conventional telephone terminals participate in the conference. Echo control, e.g., through the use of echo cancelling techniques, is required if the one-way end-to-end audio propagation time exceeds 25 ms.

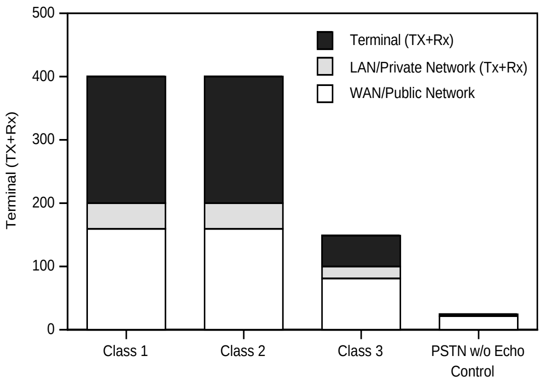
The end-to-end audio delay specified in Table 1 must be more or less constant over time, as the human ear is extremely sensitive to any frequency shift or discontinuity in the delivered audio. For packet and cell-based networks, which by nature offer varying delay depending on traffic conditions, buffers designed to smooth out any network-imposed delay variations must be included. However, these buffers will add delay to the end-to-end path.

Breaking Down the QOS Requirements

Point-to-point quality of service is dependent on the performance of each component within the multimedia network. Unless each component performs to expectations, the end-to-end QOS is likely to be unsatisfactory. To guide users and providers of terminal equipment, LANs, and WANs, the MMCF specification provides an allocation of each end-to-end requirement on the individual system components. For audio delay, the allocation for each MDC QOS class, as well as the allocation for connections without echo control, is shown in Figure 3 and Table 2.

A substantial portion of the end-to-end audio delay is contributed by the terminal. The primary reason for this is not the delay of the audio codec, but rather the delay introduced by the video codec. The requirement for lip-synchronization between the audio and the video requires that buffers be introduced in the audio path. The MMCF specification suggests that the end-to-end audio delay be kept slightly shorter than the video delay, thereby minimizing the audio delay within the constraints of acceptable synchronization.

Figure 3
Allocation of End-to-End Audio Delay Requirements



Source: MMCF

Table 2
Allocation of End-to-End Audio Delay Requirements

	Class 1*	Class 2*	Class 3*	PSTN w/o Echo Control*
Terminal (Tx+Rx)	200	200	50	1
LAN/Private Network (Tx+Rx)	40	40	20	2
WAN/Public Network	160	160	80	22
End-to-end	400	400	150	25

Source: MMCF

* Milliseconds

Of the remaining delay budget, 80% has been allocated to the WAN and 10% to each of the LANs. Most of the delay in the WAN is due to propagation delay. For a maximum length terrestrial international reference connection (Anchorage to Cape Town, for instance) of 27,500 kilometers, the propagation for a circuit-based network is estimated to be 140.5 ms. The additional budget allocated to the WAN for Class 1 and Class 2 service is to accommodate the unavoidable delay increases anticipated in future cell-based networks.

With the delay budget available to the WAN for Class 3 service, it is not possible to support calls over a

MMCF End User Application Subcommittee's Classification

The ITU-T has provided guidelines for classification of broadband teleservices and applications in Recommendation I.211.[1] This classification is also useful for classification of multimedia applications. The MMCF End-User Applications Subcommittee is developing a detailed description of important multimedia applications for reference (available from the MMCF upon request). The following table, largely derived from the CCITT Recommendation I.211 (Integrated Services Digital Network, General Structure, and Service Capabilities) provides a useful classification of multimedia applications into different categories, and offers a number of example applications in each category:

Multimedia Communications Applications

Application	Example
Interactive *Multimedia Collaboration*	Videotelephony/ Videoconference Distance Learning Remote Presentation Audiographics Videosurveillance
Multimedia Information Retrieval	Video Retrieval Image Retrieval Document Retrieval Data Retrieval Videotext
Multimedia Mail	Videomail Voicemail Document Mail
Distribution	Existing Quality TV Distribution High-Definition TV Distribution Pay TV Document & Image Distribution Audio Information Distribution Digital Information Distribution Video Information Distribution Full Channel Broadcast Videography

maximum length reference connection—the delay introduced for such calls will limit the quality of service to Class 2. However, at least for terrestrial circuit-based networks, the delay budget for Class 3 should support many international calls, such as between the continental United States and Western Europe or between the United States and Japan, and all terrestrial national calls. It should be noted that satellite connections, which introduce an additional delay of 270 ms, will not satisfy the delay requirements for any of the QOS classes.

The delay budget available to each LAN, 5% to 7.5% of the total, may appear overly stringent at first sight. On the other hand, given the overall delay requirements defined by the nature of human interaction, the propagation delay constraints given by the size of the earth, and the inherent complexity and associated delay of video codecs, the LAN may actually have been allocated more than its fair share of the total budget. Most LANs in operation today, such as Ethernet or token ring, violate the specified QOS guarantees even for Class 1 by a wide margin. However, relatively incremental enhancements to the LAN, such as the recently adopted IEEE 802.9a isoEthernet standard, offer delay performance that is well within the MMCF requirements for Class 3. Cell-based ATM LANs, although not ready to deliver adequate QOS guarantees today, are also expected to satisfy the requirements as the technology matures.

Calling Anybody and Anywhere

During an extended transition period, it will be of interest to place calls from MDC terminals to conventional telephones, and vice versa. The column "PSTN w/o Echo Control" in Table 2 provides requirements applicable to this mode of operation. Echo control has haunted telephone networks from the early beginnings, and the result is a delicate balance which is best left undisturbed. Part of the recipe is to limit delay at the end-points. With the MDC LAN replacing the PBX for conventional telephone calls, it will also be required to satisfy the stringent delay requirements of the PBX. In fact, many telephone companies may not allow the MDC LAN to place conventional phone calls otherwise. Terminals and LANs supporting both MDC calls and conventional phone calls must satisfy the delay requirements for conventional telephony or provide the necessary echo control for these types of connections. IsoEthernet, which was specifically designed for this purpose, is the only standard LAN technology available today that satisfies the PSTN (Public Switched Telephone Network) requirements.

Conclusion

Delivering service to meet end-user needs and expectations is essential for the continued development of a multimedia communications market. An end user's quality of service needs must be understood by all parties, from product designers to network administrators. The MMCF QOS framework provides the tools with which to develop discrete and useful yardsticks for different application categories.

Although they may be among the first to use them, quality of service guidelines are not limited to use by design engineers. The QOS class system will be of considerable value to systems integrators, service providers, and end users who evaluate and identify desirable characteristics for networked multimedia solutions. The MMCF will continue to develop and publish updates to the quality of service document as applications, products, and services evolve.

Authors' Note: The MMCF distributes the MMCF Multimedia Communications Quality of Service Document electronically to interested parties at no cost from the MMCF WWW site, http://www.mmcf.org. To obtain a hard copy ($8.00/copy) of the original document or for more information about the MMCF, please contact the MMCF Administrative Headquarters, Suite 201-931 Brunette Avenue, Coquitlam, BC, CANADA V3K 6T5, Tel: (604) 527-1004, Fax: (604) 527-1046, e-mail: 72630,107@compuserve.com.

[1] CCITT, Recommendation I.112, "Integrated Services Digital Network (ISDN), General Structure and Service Capabilities, B-ISDN Service Aspects" (1991).