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Interactive Distance Learning over ISDN in Electronic Engineering Education*

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An ISDN-based distance learning system is presented, and its main components are discussed in some detail, together with the guidelines which have led to its realization and determined its current further development. Some results derived from the use of the system in electronic engineering university lectures are discussed. In particular, the results of an evaluation of the minimum acceptable level of some quality of service parameters are reported, showing that a single, basic ISDN interface can be sufficient, in this environment, to support the service.

INTRODUCTION

THE market today is calling for new telecommunication facilities and the keywords 'interactivity' and 'multimedia' are characterizing almost all new network applications and projects. Of these, real-time distance learning is going to become one of the top applications in the near future. It allows students to attend, in real time, a lecture that is taking place on a remote location, giving them the ability to be seen by the remote teacher and to interrupt the lecture to ask questions. This service is not only useful within the school environment, where the real presence of the teacher is sometimes unavoidable, but it has also a wide range of applications in industries and companies that have branches spread around a large territory and that have to offer courses to their employees [1, 2].

From the telecommunications point of view, an interactive distance learning service requires bidirectional transmission of audio and video between the teacher and the students, along with data, still images (with pointers), computer animations and many other teaching material needed to carry out the lecture.

In Italy, the National Research Council (CNR) has sponsored a telecommunications project that, for five years, has involved manufacturing industries, operating companies, public research laboratories and university departments, with the aim of getting the necessary experience to develop new networks and new telecommunication services [3]. Within this project, the study and development of a distance learning service has been carried out by the Department of Communications, Computer and Systems Science (DIST) of the University of Genoa, the Fondazione Ugo Bordoni (FUB) and Italtel, an Italian telecommunications company. A pilot distance learning environment has been set up between the two Italian towns of Genoa and Savona and is currently being expanded to other towns of the west Riviera. The Genoa–Savona system relies on two different telecommunication facilities, namely a dedicated proprietary radio link and a 128 kbit/s ISDN connection.

The short-term target has been how to get the best quality in terms of teaching functionalities with the minimun bandwidth, keeping the highest level of interactivity; a longer-term target was to get the necessary experience for characterizing the main components of low-cost, efficient, distance learning systems.

This paper describes the experimental setup and the results obtained after a period of 3 years, during which real university lectures have been held on a regular schedule. The next section highlights various aspects of the distance learning service. We then describe our experimental system and give the results of a period of quality of service monitoring. The final section gives our conclusions.

THE DISTANCE LEARNING SERVICE

In the first part of the project we analysed the main characteristics of a distance learning service, in order to be able to design the basic architecture of the system. Table 1 sums up the main characteristics, described in some detail in [4, 5], together with the research milestones that have led to the system currently developed and represent the framework for future actvity.

Throughout the experimental period all the functionalities pertaining to the 'short-term' part have been realized.

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Table 1. Distance learning service characterization

	Initial settings	Short term	Medium term
Network configurations	• Remote classroom semi-permanent connection	• Remote classroom switched connection	• Dynamic clustering of lecturers' and students' posts
Distance learning typologies	• Remote lecture (classroom)	• Multiple remote classrooms	• Remote training • Remote lecture (workstations) • Batch lectures (lecture server)
Multimedia educational tools	• Moving image • Still image	• Telewriting • Remote pointer	• Educational data multi-access management

Network configurations

For the distribution of teleteaching services, two basic operating modes have been considered. Both of them make use of a specially equipped classroom for the teacher. They differ in both the equipment devoted to the students, and the switching characteristics of the network. The defined modes are:

- *Interconnection between the teaching post and a small number of remote attending sites*: this configuration requires that students be gathered in specially equipped classrooms. If such classrooms can be utilized intensively then it is feasible, even given the high cost of setting them up, to connect them in a semi-permanent point-to-point way.
- *Dynamic clustering of attending and teaching sites*: this configuration minimizes the cost of setting up specially equipped remote classrooms, by connecting, in a switched point-to-point or point-to-multipoint fashion, teaching posts and workstations with multimedia capabilities. It is conceivable, in fact, that remotely transmitted full-motion video, as well as teaching support material, can be displayed to the students within windows on their individual workstations, with the possibility of 'capturing' frames (e.g. by means of frame-grabber hardware) and operating on them with the aid of multimedia editors. Point-to-point connections, in a WAN environment, can be set up, for example, by utilizing one or more ISDN Basic Rate Interface (BRI), where available. Point-to-multipoint is easily implementable on LAN/MAN networks; when a WAN has to be utilized, the management of the videocommunication might require the presence of a multiconference control unit (MCU). Internet is another possibility but, for the time being, the bandwidth it offers is still too low in our opinion to support full-motion video for regular lectures in such a way as to keep the students' attention and avoid tiring effects; however, seminars are currently being successfully transmitted over the Internet M-bone, and we believe this is the way to be followed in the medium term.

Distance learning typologies

Basically, we were considering three types of distance learning sessions, reflecting different modes of the learning process; the first session type (remote lecture) has actually been experimented upon for three academic years.

- *Classroom teleconferencing*: this type of service offers a remote lecture scenario (with interactivity). Students receive audio and video material from the lecturer, as well as all information regarding teaching support (e.g. data, graphics, still and moving images); the lecturer should have a reconstruction of the class through audio and video return channels.
- *Remote tutoring*: this application involves the remote supervision of the students' work. In this framework, the tutor has the possibility of supervising a set of students that are working on a specific task by means of a system of interconnected multimedia workstations.
- *Self-learning within a distributed environment*: in this type of session, teaching posts are not involved, because the system enables the student to use learning material, by supervising the learning session. Multimedia material, stored in a distributed database, is shared among students with the use of self-learning tools.

Communication systems

As regards the communication systems, they must be capable of supporting the transmission of educational videocommunication and multimedia educational tools, as defined in Table 1. In particular, video and audio distribution of the teacher's image as well as video and audio feedback from the remote class may be basically realized by videoconferencing equipment, by making use of state-of-the-art video and audio codecs. Still-image management systems deal with the acquisition, storage (along with compression/decompression), transmission and presentation of fixed images, together with a simplified graphical framework, by means of which pointers and handwritten notes can be superimposed. Fixed images can be grabbed from sources such as camera or computer animations, acquired by means of scanners (e.g. slides, transparencies) or prepared with graphic editors.

Table 2. Requirements for the video-communication

Educational Video-communication					
Direction	**Mode**	**Video Quality**	**Coding Standard**	**Bit Rate** (Mbit/s)	**Services Offered**
lecturer⇒ ⇒students	isochronous / multipoint	video-conference	H.261 (or the like)	0.064 – 0.5	• lecture • movie
		TV	MPEG	1 – 6	• lecture • educational movie
		HDTV		20 – 40	• educational movie
students⇒ ⇒lecturer	isochronous / point-to-point	video-conference	H.261 (or the like)	0.064 – 0.5	• feedback image

Table 3. Requirements for teaching support

Multimedia Educational Tools			
Direction	**Mode**	**Bit Rate** (Kbit/s)	**Services Offered**
lecturer⇒ ⇒students	non-isochronous / multipoint	64	• image broadcasting - animation; - still images: - photographic; - vector graphics; - fax; • audio segments.
lecturer⇒ ⇒students	isochronous / point-to-point	10	• image management control signals, remote pointer control signals; • overlaid writing.
bi-directional	non-isochronous / point-to-point	64–2,000	• data for processing or control.

Two main alternatives can be chosen for the transport of information: utilizing two (or more) independent telecommunication network channels, one for isochronous traffic and the other for the asynchronous traffic (e.g. ISDN and Internet); or sharing the same channel, with dynamic bandwidth allocation, among all the streams involved in the session. A general picture of the various components of a teleteaching session along with the corresponding bandwidth ranges is given in Tables 2 and 3.

THE EXPERIMENTAL SYSTEM

The general functional structure of the experimental system that has been installed in Genoa and Savona is shown schematically in Fig. 1. There are three video cameras in the classroom: two of them, with controllable orientation, zoom and focus, are devoted respectively to the lecturer and local students. The third one points towards a special whiteboard that can be used for projecting slides or writing during the lecture, and has controllable zoom and focus. Two large screens are devoted to moving and still images, respectively. The teacher has a small microphone and there are other (cordless) microphones that students can use to ask questions. An audio mixer sends audio signals to loudspeakers.

The teleteaching system is composed of two subsystems:

- the video-communication system;
- the still-picture management system.

The video-communication system allows a "virtual class" to be set up, by means of which teachers and students (located in different places) can interact with both audio and video in a framework that resembles videoconferencing.

The still-picture management system allows the lecture to be supported by still images, over which a pointer can be superimposed, and can be remotely operated.

Distance learning sessions have tried using two main connection modes: point-to-point and point-to-multipoint. For the second mode, a multicast control unit has been utilized. The point-to-point connection has been initially realized with a pair of flexible multiplexers connected by a leased line; the classrooms were subsequently connected via ISDN.

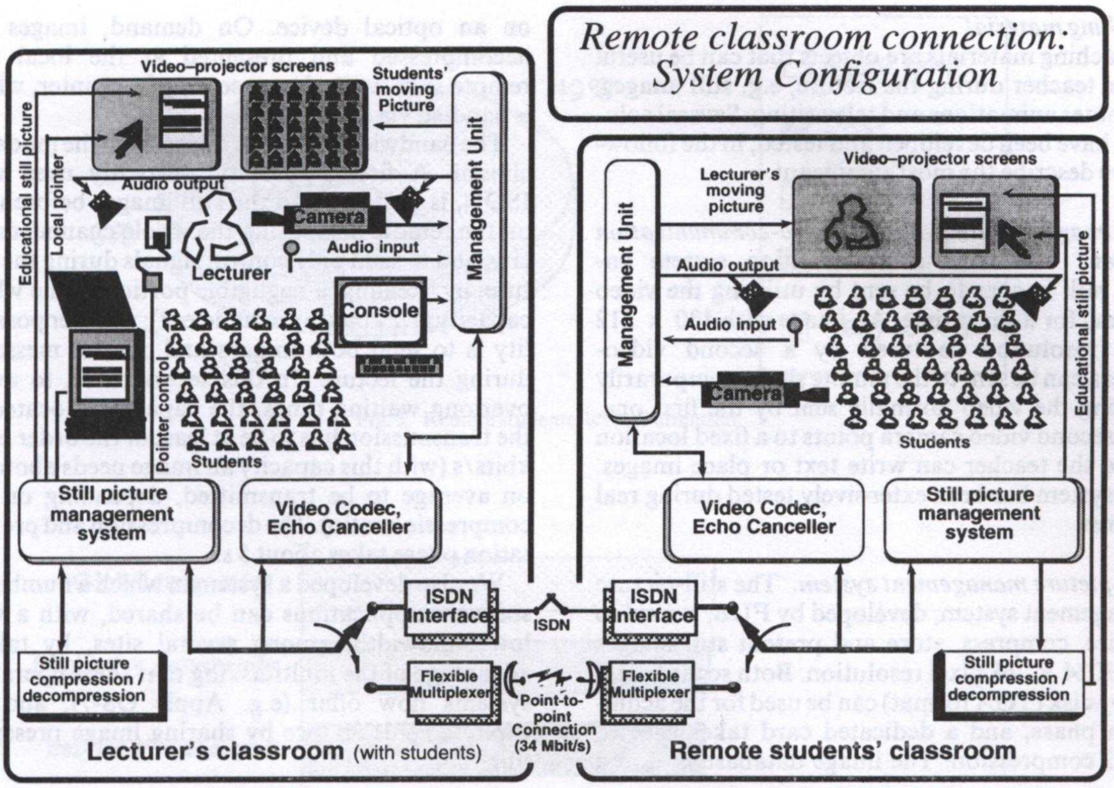

Fig. 1. The experimental system.

In the following we give a more detailed description of the main components of the system.

The video-communication system

The video-communication system, developed by Italtel, provides a real-time 'virtual class' by means of a bidirectional transmission of audio, voice and data signals.

Transmission takes place through a digital network with bit rates ranging from 128 to 384 kbits/s. The connection can be either dedicated or switched. Two building blocks can be identified: the network interface and the management unit. The network interface consists of an audio/video codec, for bidirectional transmission of either moving (240 × 280 pixels resolution) or still images (480 × 512 pixels resolution), and an echo canceller, which enables full-duplex (7 kHz) audio between the two sites. The coding algorithm can be proprietary (Picturetel) or ITU-T H.261. The management unit takes care of the control of the various audio/video facilities, such as switching between local audio and video sources, sharing of the local 'screen', sharing of the network interface, management of switched and dedicated connections, local and remote video camera control, local and remote codec configuration, opening and releasing of the connections.

A point-to-point teleteaching session takes place between a 'master' site and a 'slave' one. The 'master' site, usually the one where the teacher is located, starts and ends the session, selects the video source to be utilized as teaching support, controls both local and remote video cameras, controls a pointer which is superimposed on both local and remote images, and utilizes a telewriting board to superimpose written text. The 'slave' site is completely controlled by the 'master'.

The multi-conference unit

Since ISDN does not provide multicast, it has been necessary to use a special system able to do this: the multi-conference unit (MCU). In essence, this unit handles as many ISDN connections as the number of sites that have to be connected in a multicast fashion. Multicast lectures have been tested in cooperation with Milan Polytechnic. The system was therefore tested by connecting three sites, located in Genova, Savona and Milan. During a multipoint connection, all the audio signals are decoded, summed up and coded again before they are transmitted to the terminals; only one video signal can be broadcast to all the connected locations. The MCU can handle up to eight independent conferences at the same time. The management system, comprising a PC, utilizes a serial port, so that the MCU can be remotely controlled (via a modem). To sum, the MCU enables a teacher to broadcast video signals coming from one site to all the other connected sites, to receive one video signal from one of the remote sites, set up an audioconference among all the connected sites, and to send still images to the remote sites.

Teaching material

Teaching materials are objects that can be useful to the teacher during the lecture, e.g. still images, computer animations and telewriting. Several solutions have been developed and tested; in the following we describe the most significant.

Still-image handling by the video-communication system. The video-communication system enables still images to be sent by utilizing the video channel for a short time. An image with 480 × 512 pixel resolution captured by a second video-camera can be sent to the remote site by temporarily freezing the video normally sent by the first one. This second video camera points to a fixed location where the teacher can write text or place images. This system has been extensively tested during real lectures.

Still-picture management system. The still-picture management system, developed by FUB, is used to acquire, compress, store and present still images with 1024 × 768 pixel resolution. Both scanner and floppy disk (TGA format) can be used for the acquisition phase, and a dedicated card takes care of JPEG compression. The image database is stored on an optical device. On demand, images are decompressed and presented at the local and remote sites, with the presence of a pointer, which is handled via a mouse.

The bandwidth required depends on the modality chosen. A first possibility, currently used with ISDN, is to download the still images beforehand on the remote disk, using the whole channel capacity, and to send only control signals during the lecture, by 'stealing' a negligible portion of the whole capacity (1.2 kbits/s are sufficient); another possibility is to send both images and control messages during the lecture. In this second case, to avoid overlong waiting times, the capacity allocated to the transmission has to be at least of the order of 64 kbits/s (with this capacity an image needs about 5 s on average to be transmitted, depending on the compression ratio). The decompression and presentation phase takes about 5 s.

We also developed a system in which a number of software applications can be shared, with a very low bandwidth, among several sites, by taking advantage of the multitasking that some operating systems now offer (e.g. Apple OS-7), and we exploited this feature by sharing image presentation tools.

Table 4. Remote students' opinion about several aspects of quality of service

QOS Aspect	Average	Standard deviation
Global quality of service	3.42	0.45
Moving image quality	3.33	0.43
Still image quality (1024x768)	3.45	0.38
Movement resolution	2.85	0.45
Contrast	3.08	0.39
Audio signal quality	3.42	0.76
Echo canceller quality	3.88	0.62
Still image quality (480x512)	3.34	0.59

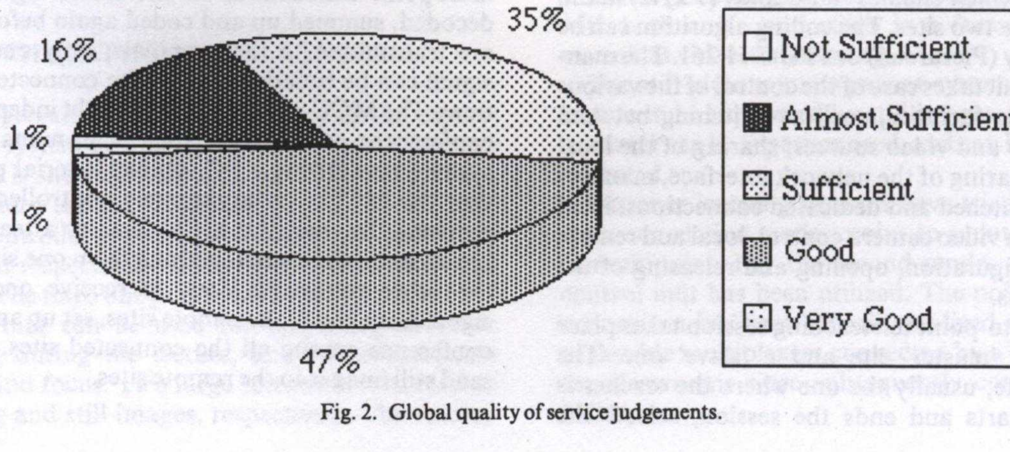

Fig. 2. Global quality of service judgements.

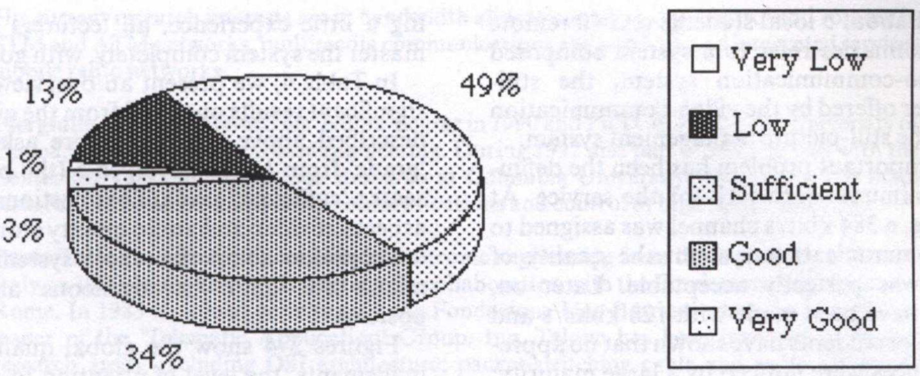

Fig. 3. Remote students' level of attention.

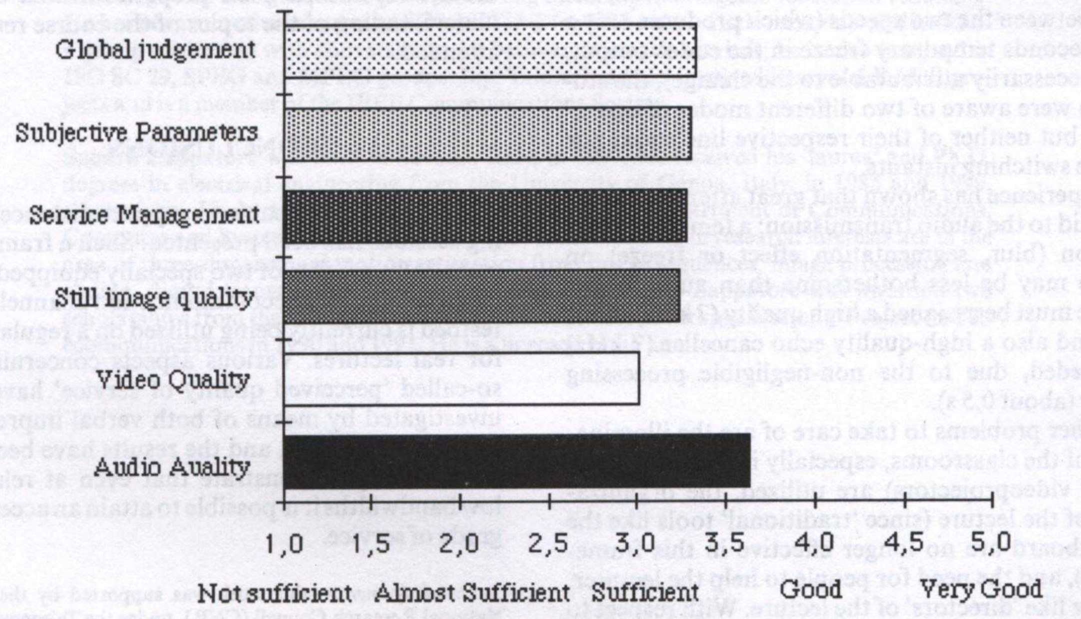

Fig. 4. Global averages.

QUALITY OF SERVICE EVALUATION

The general environment described above has been in use for the past three academic years and is currently being used at the Faculty of Engineering of the University of Genoa, within the electronic engineering curriculum, where distance learning sessions are held on a regular timetable at the town of Savona (about 60 km away).

The system has been tested during real distance learning sessions by means of the opinions of both the lecturers and the students who are asked to fill in questionnaires. These questionnaires address the main factors that contribute to the overall level of quality: *audio* (audio signal quality, echo cancellation); *video* (global image quality, static definition, movement resolution, contrast, quality of handwritten text, comparison at different line speeds, etc.); *still image* (high [1024 × 768] and medium [480 × 512] resolution image quality, acceptability of transfer time); *service management* (usefulness of remote camera controls, acceptability of limitations in movement, etc.); *subjective parameters* (student–lecturer interactivity, lecturer adaptability, students' attention level); *overall quality of service* (learning efficiency, influence on teaching attitude, comparison with 'conventional' lecture, usefulness of educational support). Quality of service monitoring has been conducted within three courses offered by the Faculty of Engineering at the University of Genoa, within the electronic engineering curriculum, namely Telecommunication Networks, Technologies and Materials for Electronics and Statistics. The first course had the majority of students (about 40) at the master site and a small number (about 8) at the remote one, whereas for the second course all students (about 35) were at the remote site. The third course involved had about 5 local students and 40 remote ones. Questionnaries refer to a system composed of the video-communication system, the still-image handler offered by the video-communication system and the still-picture management system.

The first important problem has been the definition of a minimum bandwidth for the service. At the beginning, a 384 kbit/s channel was assigned to the video-communication system: the quality of the service was perfectly acceptable. Later on, experiments have been made with 128 kbits/s and the responses of students have shown that no appreciable differences were noticed by a large majority: if the video picture consists of only a foreground of limited motion with an unchanging background, which is the typical 'remote lecture' teaching scenario, a 2 × 64 kbit/s channel gives acceptable quality. The evaluation was conducted by switching on-line between the two speeds (which produces only a few seconds temporary freeze in the codec output, not necessarily attributable to the change); the students were aware of two different modes of operation, but neither of their respective line speed nor of the switching instants.

Experience has shown that great attention has to be paid to the audio transmission: a temporary distortion (blur, segmentation effect or freeze) on video may be less bothersome than audio noise. Voice must be assigned a high quality (7 kHz) channel and also a high-quality echo canceller (7 kHz) is needed, due to the non-negligible processing delay (about 0.5 s).

Other problems to take care of are the illumination of the classrooms, especially if passive screens (with videoprojectors) are utilized, the organization of the lecture (since 'traditional' tools like the blackboard are no longer effective in this framework), and the need for people to help the lecturer, acting like 'directors' of the lecture. With respect to this last point, it is worth noting that, after acquiring a little experience, all lecturers were able to master the system completely, with good results.

In Table 4, we present an overview of the most significant results obtained from the questionnaires described above. Students were asked to give a 'grade' from 1 (the worst) to 5 (the best); 3 represents a 'sufficient' grade. The questions span several aspects of video and audio quality along with a general opinion about the whole system. The judgements are quite homogeneous and generally positive.

Figures 2–4 show the global quality of service judgements, the level of attention to a remote lecture and the global averages of the main components of the distance learning service, respectively. All show an almost always more than sufficient grade. Moreover, and most important, remote students have shown good preparation and a good understanding of the topics of the course remotely attended.

CONCLUSIONS

A framework capable to support distance learning sessions has been presented. Such a framework essentially consists of two specially equipped classrooms linked by telecommunication channels. This testbed is currently being utilized on a regular basis for real lectures. Various aspects concerning the so-called 'perceived quality of service' have been investigated by means of both verbal impressions and questionnaires, and the results have been presented. They demonstrate that even at relatively low bandwidths it is possible to attain an acceptable grade of service.

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