ISDN—The Path to Broadband Networks

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Invited Paper

We are in the midst of revolutionary improvements in data communications. The need for connectivity has never been as great as it is today due to the rapid growth of desktop processing machines which must communicate among themselves as well as with centralized computing and database facilities. Alas, in the midst of this progress, we find ourselves burdened by the curse of incompatibility among vendor-specific products, protocols, procedures, and interfaces.

At the same time, the national and international bodies have been hard at work attempting to provide some stability by introducing standards for connectivity. The problem, of course, is one of timing; a premature standard stifles the development of mature technology, while a tardy standard is in danger of being rejected by a community that is locked into irreversible commitments to cumbersome ad hoc solutions. ISDN is an emerging standard which represents an international effort to solve some of our connectivity problems. If it rolls out in a timely fashion and addresses real needs to the end user community, it has a chance for success in the networking world.

The carriers are committed to ISDN and have a clear motivation and potential for succeeding in its development. Narrowband ISDN is a ho-hum service for which some important applications have been identified, but which has not sparked a stampede of acceptance. On the other hand, broadband ISDN (BISDN) is a service that has identified capabilities that are truly exciting and could very well dominate data networking in this decade. The success of BISDN will depend strongly on the rollout of products, the ubiquity of its presence, and the tarriffing of its services.

I. Introduction

Telecommunications is currently a huge industry approaching an annual revenue of $200 000 000 000; it has one of the fastest growth rates of all industries today. Moreover, it is based on some of the most exciting technologies available, changing rapidly, and influencing almost every aspect of business, commerce, education, health, government, and entertainment. Its products are visible to everyone, and yet, the full impact of this juggernaut is not yet appreciated by most observers.

What has caused this enormous growth has been the explosion of digital technology (which itself was fueled by semiconductor electronics, namely, integrated circuits of very large scale, as well as the development of the unbelievable capabilities of fiber-optic communication). This digital technology appeared first as data-processing machines and soon had its impact on data communications. This impact emerged as data communication networks, principally in the form of packet switching in the 1970's [1]. Since then, the data-processing industry and the data communication industry have converged in a fashion that will never again let them separate. You can no longer discuss one without the other.

The product rollout has been staggering and we have been provided a broad range of advanced services, but not without a price. We have now reached a stage of uncontrolled chaos in the marketplace of data processing and data communications. Multivendor systems are almost universal, and the inability of the elements in this heterogeneous environment to interwork is legion. There have been international efforts to bring some order to this chaos through the introduction of standards. Such efforts are almost always slow, laborious, political, petty, boring, ponderous, thankless, and of the utmost criticality. The International Standards Organization has developed the seven-layer Open Systems Interconnection (OSI) reference model for communications. The IEEE 802.X series of standards for communications is growing. We have seen the Consultative Committee for International Telephony and Telegraphy (CCITT) recommendations for their X series of standards proliferate. Moreover, and of most interest to this paper, CCITT has been developing the Integrated Services Digital Network (ISDN) standard since the mid-1970's. The definition and details of this standard are covered elsewhere in these Proceedings.

It is the purpose of this paper to evaluate the effect of ISDN on the field of data networks, to anticipate future directions for this technology, and to discuss how the user should view these developments.

Whereas this paper discusses such issues, the fact is that the underlying issue is really one of *infrastructure*, rather than of ISDN networking by itself. Network technology provides us the capability to install a powerful communications and information technology infrastructure that will enable untold growth and access in the years to come. ISDN is one cornerstone of that technology.

II. Current Status

There are more than 200 000 ISDN access lines installed today, and that number will likely grow to three-quarters of a billion by 1995 [2]. Its use in public networks is clear, and it is beginning to penetrate the private network market as well. It has taken 29 years from the first digital T1 system to today's ISDN developments. 1988 was a critical year, for it was in that year that Signalling System Seven (SS7) installations increased enormously, providing the out-of-band common channel signaling capability on which ISDN is based [3]. We have seen a very rapid rollout from the availability of the basic rate interface (BRI) at 144 kb/s

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(2 B + D) and the primary rate interface (PRI) at 23 × 64 kb/s to today's beginning of BISDN at 155 Mb/s and growing to over 13 Gb/s speeds. Indeed, we have already seen the early demonstrations of the 802.6 Metropolitan Area Network (MAN) standard based on the distributed queue dual bus (DQDB) access method; this demonstation was part of the switched multimegabit data service (SMDS) offered at 45 Mb/s. Things are moving quickly.

A. The Barriers

Indeed, it is remarkable that ISDN is here at all, given the large number of compelling barriers that it has had to overcome. Primarily, the problem has been that ISDN is a technology developed and desired by the carriers, and not one that was initiated by user demand. As a result, a deadlock persisted that took the following form. First, the carriers were unwilling to deploy a central office ISDN switch until they could estimate the market that would justify the huge expenditures involved. The market could not be estimated until the users judged their likely use of the technology; but the users could not make this judgement until they could be given cost and timing of the ISDN products. To provide this product cost and timing information, the system suppliers needed the chip set cost. But the chip manufacturers were unwilling to tool up until they could see the market that could not develop until the central office switches were in place. This deadlock could only be broken by the carriers who did indeed take the first step and got the process moving.

As we unwind from this deadlock, users are concerned that if they buy now and ISDN is a failure, then they will be left stranded with an obsolete technology whereas if ISDN is successful, then costs will drop due to the usual economies of scale. In both cases, the user is motivated to wait; the user is clearly unclear as to when he should jump on the ISDN bandwagon. Further, the real attraction of ISDN will come when the service is ubiquitous and becomes available in all of the locations in which he is interested; but networking technology expands at a slow rate due largely to the enormous cost of providing broad coverage. We have seen this curse of distributed services many times in the past; for example, it occurred with the introduction of telephones, of Federal Express overnight mail, of public packet switched networks, of FAX, of electronic mail, and more.

The problem is further exacerbated by the fact that not all implementations of ISDN products are interoperable; for example, it is the usual case that ISDN adapters from different manufacturers cannot communicate with each other. The average price of an ISDN adapter for a PC today is $1500, whereas adapters for LAN interconnection of PC's sell for less than $800 (and include a microprocessor as well). The full ISDN standard has not yet been finalized by the CCITT. The fact that there is no equivalent of the Corporation for Open Systems (COS) for ISDN leads to the problem of vendor products that are incompatible. The existence of more than one version of a standard is an oxymoron. And the specter of possible changes in the standard or in the unofficial portions of the standard many well cause today's purchased equipment to become obsolete.

B. The Enablers

In spite of the barriers seen by the carriers, the suppliers, and the users to the introduction and deployment of ISDN, these same groups see significant advantages to ISDN that have been hastening its introduction.

The carriers have passed through a number of years of equal access since divestiture, which has produced a highly competitive marketplace. They have been energized to offer more than just transport and to extend their offerings to central-office based services of various types, most of which are dependent upon the introduction of ISDN. Moreover, the flattening demand of PBX equipment has produced a marketplace in which one vendor's gain is the other vendor's loss (i.e., a zero-sum game). Consequently, a carrier must add value to its offerings to differentiate it and to expand the size of its market; ISDN is the vehicle for this added value. The chip manufacturers have long since recognized that the mass-produced memory chip marketplace has been lost to the Japanese. These manufacturers need other markets, and the ISDN chip market is an attractive one for them.

Major corporate users have seen the cost of their separate voice and data networks rise. These users have begun to recognize that an advanced, integrated corporate network offers them a critical competitive edge as well as lower network costs. The additional function being offered by advanced networks is becoming very attractive to them and their top management is being convinced of these facts. ISDN offers a migration path to achieve these goals. The first customers of the ISDN services have been very large organizations with growing networking needs; the large consumer contact firms (e.g., American Express) are quickly moving in this direction.

The success of ISDN depends critically upon the success of the applications that take advantage of its capabilities. Indeed, it is the identification and development of a rich set of applications that will hasten the growth of ISDN more than any other factor. We have seen this phenomenon at work in a number of other network related systems in the past. Packet switching succeeded in the commercial environment largely because of the electronic mail application that it supported. SNA took hold because of the support it provided for transaction processing. PC LAN's have proliferated because of the need to share peripherals and data.

We have yet to identify the hot new application(s) that will drive ISDN steeply up the demand curve. Some of the applications that have been identified so far include automatic number identification (ANI) as well as the ability to turn off ANI, reduced call setup time from 20 s to less than 3 s, the availability of a single access point for digital services (thus eliminating multiple dedicated access lines), the ability to provide video-based telephony, voice-data applications, desktop ISDN links, etc. So far, none of these have sparked a rush to the ISDN market.

Nevertheless, the carriers are overwhelmingly behind ISDN and they will do all in their power to promote it. It is in their interest to do so. In the long run, it will be in the user's interest as well, for the carriers are the ones who will provide the networking infrastructure that is called for. Today's networks are disorganized, expensive, not integrated, slow, complex, difficult to manage, and unable to interoperate with each other; an international standard interface such as ISDN is badly needed. To their credit, the Europeans have been much more aggressive than the North Americans in implementing ISDN. And if you still doubt that the case for ISDN is justified, consider the fact that the less-developed and under-developed regions of the world are anxious to connect to the world standard network. There is no way that each of them can or should establish their own standard. There absolutely must be an available world standard to which they can attach.

ISDN is a technology that allows those who have not kept pace with the growth in networking technology to catch up immediately.

III. Narrowband ISDN is not Enough

The BRI and PRI ISDN offerings are often collectively referred to as *narrowband* ISDN (NISDN) to distinguish them from BISDN. The data rates associated with NISDN are inadequate for many applications of interest. On the one hand, the BRI providing 64 kb/s channels is not a large improvement over today's modems, which provide data service at 9.6 kb/s and 19.3 kb/s and which are widely available. It is also the case that 64 kb/s is a nonstarter for the data transmission speeds to which today's users have become accustomed (e.g., local area networks running at 10 Mb/s and more). The PRI running at 1.54 Mb/s is a clear improvement over BRI, but is no different in available speed than is the popular T1 offerings in use by the community today (so why abandon T1 and introduce new equipment interfaces for PRI?). Add to that the nasty incompatibilities faced by multinational corporations when they find that PRI in Europe is 2.05 Mb/s rather than 1.54 Mb/s in North America; of course, this problem already exists in today's T1 offerings. The PRI rate is still a significant step away from the bandwidth needs of the data processing community; it takes almost 5 min to move a 50-megabyte file at T1 transmission speeds.

From the viewpoint of data networks, the real excitement of ISDN comes about when one discusses the capabilities of BISDN. 155 Mb/s is a real improvement over today's speeds. The 50-megabyte file can now be moved in 2.5 s! The precursor to BISDN is the growing use of the T3 service (45 Mb/s). Indeed, the huge popularity of T1 and the growing popularity of T3 are setting the stage for the introduction of BISDN at 155 Mb/s and 620 Mb/s.

The need for broadband speeds comes from a number of applications. The existence of today's high bandwidth customer premises networks (i.e., local area networks (LAN's) require long distance broadband to interconnect them; LAN interconnetion using switched broadband data service is a clear and current application. The emerging field of teleradiology in which one transmits medical imagery among hospitals, physicians, and patients requires large bandwidths due to the enormous data files; the typical pair of chest X-rays we all get in a routine medical examination requires as much storage as four volumes of the Encyclopedia Britannica. A similar need comes from the field of telepathology, i.e., the transmission of optical images of biological samples. On-line access to supercomputer output showing real-time rotation of complex molecules in three dimensions in full color can be a real bandwidth hog. File server access to rapid scanning of visual and textual data is another application. The growth of CAD applications will be one source of rapid development and deployment of customized ISDN chips.

Indeed, the first applications of BISDN will be in the commercial and scientific sectors. However, following that, a real drive for broadband will be in the residential sector in order to provide entertainment. For example, CATV cable service passes by 86% of American homes, 55% of homes subscribe to CATV cable services, 30% of homes purchase more than one premium movie channel, 10% buy pay-per-view services, and the average home consumes 7 hours of television per day [4]. HDTV will increase the demand for sevices and will place enormous bandwidth requirements on our communication plant. If the FCC allows CATV services to be offered by the telephone companies, it would be a tremendous pull from the demand side for the installation of broadband capability to the subscriber base. Of course, optical fiber will be the medium providing these large bandwidths, and the economies that support fiber installation are already here. Currently, there are well over a million miles of installed fiber in the U.S. It is now less expensive to install fiber than it is to install copper for large office buildings. Fiber to the curb (FTTC) is becoming competitive for new installations, and fiber to the home (FTTH) is under serious consideration already. The appropriate strategy is to begin the FTTC and FTTH installations now, while NISDN is deploying.

Thus the real payoff in the data networks world for ISDN is the promise of BISDN and all the services and capabilities it will bring.

IV. Current Nets are Inadequate

It is clear that the data networks we inherited from the 1980's are inadequate to handle the applications and capabilities required by the 1990's. Today's packet switched data networks have a number of problems with them: They are high cost, they are low speed, they introduce large switching delays, they have relatively high error rates, the switches require too much intelligence, the switches are electronic, there is too much storage in the network, the protocols are too heavyweight, and too much processing is done in the network.

For example, X.25 packet switching networks are serving a real need as they currently exist. However, they are based essentially on 64-kb/s speeds and use heavyweight protocols (they process up to layer 3 at every hop). As an alternate to X.25 packet switching, frame relay is currently being considered for the interim version of fast packet switching, whereby the LAPD link level protocol will be used to perform switching functions at layer 2 without the layer 3 processing overhead [5], [6].

Tomorrow's broadband networks require new architectures to handle the changing requirements. The move from megabits per second to gigabits per second requires dramatic changes in thinking and in structure. In Table 1 we list some of these contrasts.

Table 1 Packet Network Characteristics: Present Versus Future

	Today	Broadband
Packets/s	Thousands	Millions
Bandwidth	64 kb/s	150 M/–620 Mb/s
Bandwidth allocation	Fixed	Dynamic
Services	Voice, data	Integrated voice, data and image
Switch delay	50–100 ms	10 ms
Propagation delay	Insignificant	Dominant
Error control	Link-to-link	End-to-end
Protocols	Heavyweight	Lightweight
Bottleneck	Link bandwidth	Switch bandwidth

The path from today's data networks to those of tomorrow is being paved right now. T3 offerings at 44.7 Mb/s are beginning to penetrate the private networking marketplace. The synchronous optical network (SONET) standard for optical transmission was agreed upon by the CCITT in 1988 [7] and has promoted BISDN product development. The operations, administration, and maintenance (OA&M) portions of the SONET standard should be completed by the end of 1990 and will only require software updates to implement. SONET has laid out a hierarchy of transmission speeds from 51.8 Mb/s up to 13.27 Gb/s and higher. These enormous speeds are fine for point to point communications (assuming the end points can gobble up gigabits per second), but certainly place some outrageous demands on the internal switches in the network.

These very large communication bandwidths have caused a wealth of research and experimentation to take place in the research laboratories in the advanced area of fast packet switching [8]. Fast packet switching will likely use parallel processing architectures in the switch to handle the millions of packets per second mentioned above. There is a number of competing architectures being proposed for the interconnection networks within these switches and many of them use the Banyan switch in one form or another [9]. The advantage of these architectures is that many packets can be switched simultaneously through the switching fabric using the concurrent processing capability of the parallel processors.

A new multiplexing scheme known as asynchronous transfer mode (ATM) [10] has been adopted for BISDN which uses fixed length packets (called cells) of length 53 bytes (48 bytes of data and 5 bytes of header), has highly simplified protocols (no windowing and no processor-intensive work), incorporates no error detection on the data (only on the header), and implements only layer 1 and basic layer 2 functions in the 7-layer OSI standard. ATM provides connection-oriented virtual circuits, handles continuous and bursty data, eliminates the need for multiple TDM channel rates, provides separate signal and information channels, and is independent of the transmission medium. ATM differs from packet switching in the following ways: ATM has fixed length cells (instead of variable length packets); ATM uses highly simplified protocols (instead of processor-intensive protocols); ATM does not do error correction on the data on a link-by-link basis; and ATM does not do any layer 3 operations.

In addition, the IEEE 802.6 committtee has recently approved a protocol for use in MAN's based on the Distributed Queue Dual Bus (DQDB) [11]. This 802.6 MAN standard is compatible with ATM/BISDN and provides a natural addition to the emerging world of Broadband. The common format shared among this MAN standard, ATM, and BISDN greatly simplifies the internetworking problems of the forthcoming broadband era. Meanwhile, the fiber distributed data interface (FDDI) has met with some success as a 100-Mb/s offering [12].

The carriers are beginning to offer their switched multimegabit data service (SMDS) [13] which will probably be the first manifestation of the 802.6 MAN. SMDS has already been demonstrated at 45 Mb/s and will soon be offered on a tariffed basis. SMDS differs from ISDN in that it is a connectionless data service that includes broadcast and multicast features. ISDN, on the other hand, is an integrated voice and data service offering both circuit-switched and packet switched features.

A near-term problem we foresee for the carriers who are to offer these services is the issue of establishing a tariff that will satisfy the end user in matching his patterns of use in the emerging applications.

In the next five years, we can anticipate that X.25 packet switching will migrate to frame relay, to FDDI and then to the 802.6 DQDB via SMDS, finally bringing us to the ATM/BISDN offerings.

As these brave new broadband capabilities develop, it must be understood that our current networks are ill-suited to provide services using these increased bandwidths. We must re-engineer the architecture of our networks to accommodate these bandwidths, a topic we address in the next section.

V. High Bandwidth Networking

Broadband ISDN is the proposed foundation for wide area networks (WAN's) that are capable of supporting applications needing high speed, low latency, rich functionality, and support of mixed media (i.e., voice, data, image, video, graphics, fax, etc.). The market demand for these advanced applications is clearly growing. Furthermore, the core technologies to provide these services are emerging: high-speed switches are being designed, high-speed fiber access networks are being deployed, the SONET hierarchy has been defined, ATM multiplexing techniques are agreed upon, etc. Indeed, technology is solving most of the performance problems we can foresee (link speeds, processor speeds, and memory sizes are increasing on their own).

As we move into gigabit networks, however, we must take a "clean sheet" approach to many of the systems issues [14], [15]. The critical areas to be considered include switching technology, processor interfaces, protocols, connection-oriented communications, routing, layered architectures, and coexistence with carrier environments. We must be prepared to allow different switch technologies to work in the future broadband networks; these include the BISDN fast packet switching techniques, photonic switches, and wave-length division multiplexing (WLDM). The architecture we select must not depend upon which of these happens to be implemented.

As for switching, tomorrow's networks must be prepared to handle packet, circuit, and hybrid switches. Large packets or groups of packets will have to be switched simultaneously; at gigabit bandwidths, one cannot afford the overhead of switching small blocks independently. Sophisticated dynamic bandwidth reservation algorithms must be developed. Multicast algorithms and capabilities must be developed (fiber is point-to-point, whereas satellite and ground-based radio are broadcast and multicast).

Beyond all of these, the question of the network management system is extremely important. Today's nets are reactive, not proactive. We must introduce proactive diagnosis and service restoral before users sense a problem. We need proactive resource management. Since huge volumes of raw data will be flowing into the management control center, we must use thresholds, filters and alerts, and even expert systems, for early problem detection and resolution. These management functions must operate in a distributed fashion for fault containment, privilege definition, and localization of security failures. Multiple classes of service must be supported. Adaptive protocols and error recovery mechanisms must be developed. Indeed, the management of the emerging internetwork is turning out to be the ultimate challenge in distributed systems.

As we consider these problems, it is clear that the carriers have been facing large network problems for most of this century. They understand management, billing, accountability, security, availability, introduction of new technology on a large scale, etc. However, over the last twenty years, the innovations in data networking have come from the data-processing industry, and not from the carriers. (This in spite of the fact that the data-processing solutions have used the underlying carrier plant to establish their data networks). As we move into the broadband era, it is essential that these two (merged) industries cooperate in providing service to the user community. BISDN holds much promise for advanced networking, and the technological and managerial hurdles that must be overcome are best solved jointly by these two industries.

VI. Conclusions

The concept of ISDN was generated from the carriers. Its early growth was much slower than had been promised due to a number of reasons, key among them being the lack of real user demand for the service. However, in the past two years, the narrowband ISDN (NISDN) penetration has accelerated faster than the skeptics had been predicting.

ISDN is the means by which the less advanced users can quickly catch up to today's technology. However, the real payoff will come with BISDN. The data network services and capacity offered by BISDN are truly exciting and advanced. But we must proceed with NISDN before we can achieve BISDN.

The carriers have an enormous investment in ISDN and they are highly motivated to bring about its success. The carriers are the key to the future networking infrastructure for the U.S. and the rest of the world. The data-processing industry cannot "go it alone" in this endeavor; they must cooperate and encourage the carriers. Both groups must agree on common standards for both private and public networking as this infrastructure grows. ISDN is one important step in this direction. Beyond that, however, it must be recognized that a revolutionary approach must be taken in providing the gigabit/second services about which we are talking. The fundamental architecture of our plant must be overhauled significantly; that overhaul is already well underway.

It is perhaps worthwhile to review some of the economic factors that have, and will, affect the architecture of our communication networks. The cost of moving data across a network consists of two important components; the cost of the channels and the cost of the switches. In the early days of communications, the channel was the expensive component (copper wires strung up on telephone poles) and the switch was a poorly paid human operator. As a result, one could afford to waste switch capacity to save on the expensive communications component. Then, a revolution occurred in communications: microwave radio was introduced and this dramatically dropped the cost of the communications component. At the same time, the switch cost dropped (automatic switches in the form of relays and vacuum tubes appeared), but not as dramatically as the channel. Consequently, a reversal occurred where the switch was now more expensive than the communication channel. Now it was sensible to waste communications capacity in order to save on the switch. Thus circuit switching was introduced. In the 1970's, another reversal occurred when integrated electronics (VLSI) appeared, which dramatically dropped the switch cost relative to the communications cost. Once again, we could afford to waste switching capacity in order to save yet more on the communications costs. Thus packet switching was introduced.

That was the past. Let us now peek into the future. Is there anything out there in the near term that will dramatically drop the cost of the switch? Gallium arsenide components will help, but they do not represent a revolutionary change. On the other hand, warm superconductivity, if it comes, would indeed be a dramatic improvement in switch technology. It would allow the wires to be thinner (and still not generate much heat) thereby allowing smaller dimensions (i.e., reduced latency due to the speed of light) and tighter packing. However, warm superconductivity is not a near-term likelihood. Further, photonic switching would be a revolutionary improvement in switch technology. Here, too, we are talking about a laboratory experiment and not a near-term development. So the answer is "no"; we cannot foresee a dramatic improvement in switch technology near term. But how about a revolution in communications? Is there a technology out there that will dramatically reduce the cost of communications? The answer is a resounding "YES!" Indeed it is already taking place, and it is called fiber optics. As stated above, we have well over a million miles of fiber optics in place in the U.S. alone. We are in the midst of the next reversal, which leads us to a situation where communications are plentiful and the bottleneck has once again become the switch. Our networking architectures are undergoing a massive revamping as we move into this environment. Our 1980's architectures are inadequate for the economics and applications of the 1990's.

In response to this current reversal, we see BISDN services coming along, we see fast packet switching architectures, we see ATM, we see the 802.6 MAN, we see LAN developments, we see FDDI, etc. And, once we get all that wonderful technology in place, is it possible that either warm superconductivity and/or photonic switching will come along so as to cause yet a further reversal and thus another reshuffling of the cards? It seems there will be a need for continual improvement of architectures and systems as new technological developments spawn new possibilities and new applications.

As we begin to move through the 1990's we forsee that broadband ISDN will play an important role in bringing about some of the exciting networking developments. A great deal of research has gone into broadband networking in the last few years. The next few years will see development of products and growth in demand. There is no question but that this technology will provide the basis for a ubiquitous communications infrastructure of enormous capacity.

Let us conclude this paper by listing some of the components that we are likely to see in this time frame:

- Worldwide Data Networks
- Advanced Network Machines
- Optical Fiber Networks
- Gigabit/second Networks
- Megapacket/s Superswitches
- Optical Switches
- Pervasive Local Area Networks
- LAN-MAN-WAN Hierarchy
- Processing Satellites
- Intelligent Network Directories
- Continuous Speech Recognition
- Image Communication Mode
- Digital Signal Compression
- Massively Parallel Systems
- Massively Connected Systems
- Neural Networks
- Pervasive Expert Systems.

It is clear from this list that the convergence of data processing and data communications is virtually complete. Distributed information networks are poised to provide the many services required for the emerging information society. ISDN will serve to hasten access to these information networks, eventually providing a major thrust when BISDN products and services begin to roll out.

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