ISDN3: The Next Generation Networks*

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ABSTRACT

Two generations of Integrated Services Digital Network (ISDN), namely ISDN1 and ISDN2, have been developed in the last century. In our view, the convergence of ATM, Internet and active networks will form the basis for the next generation networks called ISDN3. In this paper, we first review ISDN1 and ISDN2 as well as the Internet and active networks. We then discuss some fundamental questions related to the design of ISDN3. Finally, we compare ISDN3 with ISDN1 and ISDN2, and outline what ISDN3 might look like.

1. Introduction

In the last century, we have experienced two generations of Integrated Services Digital Network, which are referred to in this paper as ISDN1 and ISDN2 respectively. ISDN1 is basically an extension of the telephone network to provide multiple (n x 64Kbps) bit rate services and to support asynchronous data traffic [1,2]. Due to its synchronous nature, ISDN1 has many limitations, especially in supporting broadband services. Based on Asynchronous Transfer Mode (ATM) to transport fixed size packets (cells) [3,4], ISDN2 emulates circuit switching over an asynchronous network. The use of cells not only facilitates the design of high-speed switches but also gives greater flexibility to provide broadband services. However, because ATM is based on a connection-oriented architecture, it is less effective to support the ever-increasing connectionless data traffic, multicast communications and active network services. In general, ISDN1 and ISDN2 can be viewed as an evolution of the connection-oriented telephone network. Both of them provide circuit-switching services over a connection-oriented network. As we enter the new century, it is an appropriate time to initiate research on the next generation of integrated services digital (data) network (referred to as ISDN3). The aim of our ISDN3 project is to investigate what the network will look like and what new network services can be introduced. In this paper, we give an overview of the ISDN3 project in general and discuss its design philosophy in particular.

The organization of the rest of the paper is as follows. Section 2 gives an overview of ISDN1, ISDN2, Internet and active networks. Section 3 presents the objective of our ISDN3 project and its design philosophy. Finally, section 4 concludes the paper.

2. Overview of emerged and emerging networks

Before discussing ISDN3, it is of interest to review some of the emerged and emerging networks.

ISDN1: Narrowband ISDN and Frame Relay

Voice is our primary means of communication, hence our early communication networks (i.e. telephone networks) were mostly designed for supporting voice communications. The major breakthrough on the scene was the digitalization of the telephone system. This included the invention of the pulse code modulation technique for multiplexing analogue voice calls, the development of electronic telephone exchanges for switching voice calls and the introduction of Signaling System No. 7 (SS7) networks for providing call control and advanced call functions. The digitalization of the telephone networks led to the development of Integrated Services Digital Network (ISDN) [1] in the 1980s. Its main purpose is to integrate voice, data, and video over the same digital network. The ISDN standard defines various reference points (R, S, T and U) for terminals and network devices to connect to the networks. For example, Terminal Equipment (TE) such as digital telephones are connected to the S reference point. Non-ISDN terminals can be connected to the network via an adapter at the R reference point.

Fig. 1 shows the ISDN protocol layers. The physical layer is specified in the I.430 and I.431 standards, which define two types of interfaces, namely the Basic Rate Interface (BRI) and the Primary Rate Interface (PRI). The BRI supports two bearer (B) channels and one data (D) channel (2B+D), whereas the PRI supports twenty-three bearer channels and one data channel (23B+D). The Control (C)-plane is for sending and managing control signals over the D-channel, whereas the User (U)-plane is for transferring user information over the B channels. The layer-two (data link) protocol for the D-channel is called the Link Access Procedures for D-channel (LAPD), which is similar to the well-known High-Level Data Link Control (HDLC) protocol. It provides common data link functions for the D-channel. Layer-three Q.931 protocol is for establishing, managing and terminating user calls. For the link layer and network layer at the U-plane, a user may use many different protocols.

Narrowband ISDN led to the development of Frame relay [2,5] in the early 1990s. This is a fast packet switching technique for transmitting variable-sized frames. As shown in Fig. 1 [1,2], frame relay protocols are closely related to the ISDN protocol. In particular, (although not necessary), frame relay can make use of the physical layer services of ISDN. Frame relay supports both permanent virtual connections (PVCs) and switched virtual connections (SVCs). PVCs are controlled by the Q.933 signaling messages. In the case of SVCs, Q.933 defines a call setup protocol similar to Q.931 for supporting switched virtual calls. At layer two, an extended LAPD for frame-

Control Plane	User Plane
Q.931[Q.933]	
Q.921 (LAPD) [Q.922]	Different protocols [Q.922–core]
I.430 (BRI) + I.431 (PRI)	

Fig. 1 ISDN protocols
(The frame relay protocol is specified inside the brackets [ ])

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relaying services (LADF or Q.922 protocol) defines the frame relay bearer service (LADF-Core) and the data link service for Q.933 messages (LADF-Control) [2,5]. Different virtual connections can be multiplexed over the same link according to the data link connection identifier (DLCI) in the LADF frames.

ISDN2: ATM Networks

ISDN1 is basically an extension of the telephone network to support integrated narrow band services (i.e. up to T1/E1 speed). Due to its synchronous nature, ISDN1 has many limitations, especially in supporting broadband services and asynchronous data traffic. The Asynchronous Transfer Mode (ATM) was introduced in the 1990s to form the basis for broadband ISDN (ISDN2). Essentially, ISDN2 emulates circuit switching over an asynchronous network by using fixed-sized packets called cells. The use of cells greatly facilitates buffer management, the design of high-speed switches and latency control. Fig. 2 shows the ATM protocol layers. Basically, four classes of high-level services are defined according to the timing relationship between the sender and receiver. Specific adaptation layer (AAL) services are provided for generating protocol data units for each class of service. For example, AAL5 is commonly used for transporting connectionless data traffic. The ATM layer segments the protocol data units into cells by adding an appropriate cell header. Each cell header contains a Virtual Channel Identifier (VCI) and a Virtual Path Identifier (VPI) for cell forwarding purposes. VCI/VPI tables are set up in the intermediate ATM switches during call establishment. The physical layer specifies how ATM cells can be transmitted over different physical media such as copper and SONET. From the network point of view, an ATM network is formed by linking ATM switches. When a switch receives an ATM cell, the cell is typically switched from an incoming VCI to an outgoing VCI based on the pre-established VCI table. It is also possible to switch cells based on VPI (VPI switches).

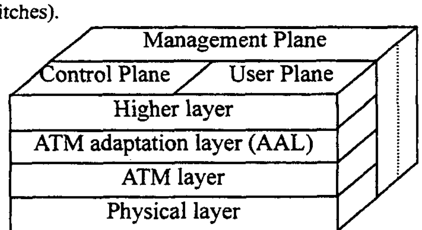

Fig. 2 ATM protocols [3]

Internet

Unlike ISDN1 and ISDN2, the Internet [6] is connectionless rather than connection-oriented. Basically, networks are interconnected by routers, which forward packets according to the Internet protocol (IP) address on each packet and its routing table. The routing table is changed dynamically by the routing protocol based on the traffic conditions. The Internet is based on the TCP/IP model, which is a simplified version of the OSI model. It has four layers. The link layer such as the Ethernet protocol provides access facilities to the users. It addresses the physical and data link layer issues of the OSI model. The network layer handles the internetworking issues, including addressing and routing. As the Internet Protocol (IP) provides an unreliable and connectionless datagram service (which is often referred to as a best-effort service), a transport layer is included to provide a reliable service over the unreliable network. Effectively, an end-to-end transport service is provided over the connectionless network. Making use of the underlying layers, the application layer provides value-added services to the users (e.g. file transfer protocol). In recent years, many new protocols/proposals have been made to enhance the performance and functions of the Internet. A new Internet Protocol Version 6 (IPv6) [7] has been proposed to address some limitations of the previous Internet protocol. In particular, IPv6 provides a much larger address space, better security, and support of flows for real-time traffic. For supporting multimedia communications over the Internet, a number of protocols have been developed. On the network layer, these include the multicast routing protocol for handling point-to-multi-point communications efficiently, the Resource Reservation Protocol (RSVP) [8] for providing guaranteed services, and Differentiated Services (DiffServ) [9] for providing priority services. On the transport layer, the Real Time Protocol (RTP) and the Real Time Control Protocol (RTCP) [10] have been developed for providing transport functions and session monitoring/control for real-time traffic. On the application layer, the Real Time Streaming Protocol (RTSP) [11] has been proposed for managing media streams. To prepare the Internet for future high-speed applications, various high-speed router architectures have also been investigated [12]. Furthermore, switching techniques are employed for forwarding IP packets. Two representative examples are IP switching, which is traffic driven [13,14] and tag switching, which is control driven [13, 15].

Active Network

Traditionally, standardization and deployment of new network services usually take a very long time. Moreover, customized network services cannot be provided easily. The active network [16] represents a major breakthrough and in fact a paradigm shift to address these issues. Under the new paradigm, networks are active and programmable. This not only introduces new network services but also provides more effective solutions to existing networking problems. Active networks are based on either the programmable switch approach or the programmable packet approach [16,17,20]. In the former approach, programs are loaded at the network nodes on demand. The programmable packet approach takes a more innovative approach by allowing each packet to carry a program with it for execution at the network nodes. Currently, a number of active network projects are being carried out such as, MIT's ANTS project for developing a programming interface for active networks, BBN's smart packets project for supporting network management, and the University of Pennsylvania's SwitchWare project for developing a scripting language called PLAN [17].

Fig. 3 shows a possible active node architecture as described in [16]. Under this architecture, different types of Active Applications are run or executed by different Execution Environments (EEs), which function like a "shell" program. The Node Operation System (OS) is responsible for managing the operation, particularly the resources of the active node.

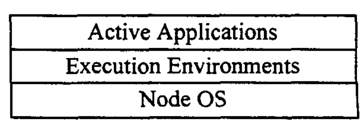

Fig. 3 Components of an active network node

3. ISDN3 project

In our view, the convergence of ATM, Internet and active networks will form the basis of ISDN3. The aim of our ISDN3 project is to investigate what the network will look like and what new network services can be introduced under the following situations:

- Network nodes (i.e., switches and routers, etc.) are very powerful in terms of their processing capability.
- Network links have almost unlimited bandwidth, are almost error-free, and are very reliable.
- Connectionless data traffic (such as Web traffic) becomes the dominant traffic in the network.
- All types of traffic in the network are essentially "data", consisting of "1s" and "0s", so ISDN3 is effectively an Integrated Services Data Network.
- Users demand more control over the network (e.g., how their packets should be forwarded).

In this paper, we discuss some fundamental questions related to the design of ISDN3.

- Connection-oriented or connectionless base network?

The most fundamental question is whether we should build ISDN3 based on a connection-oriented network or a connectionless network. In a connection-oriented network, communication paths are pre-established by going through a set-up phase. A key advantage is that call admission can be controlled, packet order can be maintained and required resources can be reserved in advance. However, it is less flexible and may not be effective in supporting asynchronous data traffic, particularly multicast communications. Due to its connectionless nature, the connectionless network is generally more flexible. It is also easier to re-configure the communication paths by taking advantage of the spare network capacity. However, it is more difficult to support quality of service (QoS) over a connectionless network. In recent years, RSVP, QoS routing and DiffServ are being developed to address this important issue.

In ISDN1 and ISDN2, a connection-oriented base network is chosen, partly because they are the natural evolution of the connection-oriented telephone network. Now, the situation is changing. With the advent of the Internet based on the TCP/IP protocol suite, we are reaching a turning point where connectionless data traffic may become the dominant traffic in future communication networks. Furthermore, it is expected that future networks will be active and programmable. A connectionless network will be more suitable for supporting these active network technologies. Hence, it is expected that ISDN3 will be based on a connectionless architecture and evolved from the current Internet.

- Fixed size packets or variable size packets?

It is well known that transmitting packets as cells (short, fixed-length packets) in high-speed networks has many advantages over datagrams. The main advantage is that it facilitates the implementation of high-speed switches in a cost-effective manner. By using short cells rather than datagrams, better latency control can also be provided. Although cells are well-suited for supporting connection-oriented traffic, they are not effective for connectionless data traffic (e.g., IP packets). For example, if one or more cell(s) of a packet is discarded (e.g., due to congestion), the remaining cells of the same packet should also be discarded so as to minimize resource wastage. To implement this function in ATM networks requires additional processing due to packet fragmentation. It is also difficult, if not impossible, to support the emerging active network technologies if packets are fragmented into cells.

Motivated by the VC-merging method [13] used in tag switching and a similar method employed in A/I Net [18], we are currently investigating a new type of packet called the quantum packet in order to preserve packet integrity at the network level if necessary while enabling cell-like multiplexing. Further, the quantum packet is specially designed to support emerging active network services. In general, a quantum packet consists of one of more quantum cells. Hence an ATM cell can be viewed as the simplest type of quantum packet (i.e. a quantum packet with only one quantum cell). Fig. 4 shows that the quantum packet can be used to support synchronous and asynchronous traffic. In the former case, the simplest type of quantum packet (with one quantum cell) can be used to emulate circuit switching. For asynchronous traffic, it is preferable to preserve packet integrity to facilitate routing and to perform active network functions. In this case, a quantum packet typically consists of multiple quantum cells. In particular, one type of quantum packet is active. We propose to call this Packlet, which is likely to be programmed using Java. Note that the proposed name is in line with the existing Java terminology i.e. Servlet for server-side application, Applet for small applications run on the client-side and Packlet for network side application using active packets.

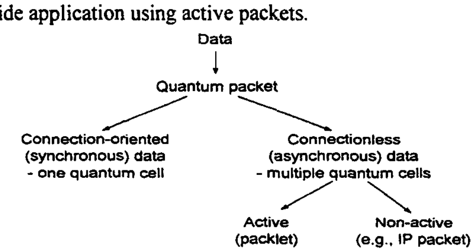

Fig. 4 The family tree of the quantum packet

- Switching or routing?

Switching and routing are the two main methods for forwarding traffic in a communication network. In switching, communication paths are pre-established to forward the packets. There is no need to include a detailed destination address in each packet but a short identifier is attached instead. Basically, when a packet arrives at a switch, the switch table is called to map the incoming identifier to the outgoing identifier and the packet is forwarded to the corresponding outgoing port. The identifier is changed because it may not be globally unique. Routing is based on a different technique. The key advantage of routing is that routing tables, and hence communication paths, can be changed dynamically based on the traffic. However, as the destination address is to be included, more overhead is needed.

In ISDN1 and ISDN2, switching was used, not only because they are based on a connection-oriented architecture, but also because it was more difficult and costly to build high speed routers. Recent advances in router research have removed some major barriers. These include using a distributed and parallel architecture, more advanced route lookup techniques and a high-speed switch fabric for interconnecting various router components [12]. Another on-going trend is to integrate switching and routing in the same packet forwarding device. As mentioned before, IP switching and tag switching are two representative examples. As a result of the label switching proposals, a multi-protocol label switching standard [19] is being developed. From these developments, it is anticipated that switches and routers will be integrated into a more generalized traffic forwarding device in ISDN3. We call this the Forwarding EnginE (FEE). The proposed name reflects what it does (forwarding packets) but not how it does it (switching or routing). Besides their forwarding functions, FEEs can provide active network functions.

- Non-active or active network?

Traditionally, networks only have a simple mission: forward packets to their destinations as quickly as possible. As networks become more powerful in terms of processing power, we may need to refine or even redefine their role. In [20], two sample applications of active network technologies, namely stock quote and online auction are discussed. The former application allows real-time information, such as stock quotes, to be cached at network nodes. Using active network technologies, the nearest network node with the cached stock quotes can respond to a client's request directly. Similarly, for the online auction application, a network node with the cached bid price can be used to filter unqualified bid prices. These two applications illustrate an important concept. Although it may take more time to process a packet in an active network, the overall network performance may be improved, e.g. due to the filtering of unnecessary network traffic. Besides caching, active networks can also be employed to support adaptive multicast services, facilitate effective network management and enable network-based quality of service as discussed in [16]. It is expected that active and non-active network services will coexist in ISDN3, thus opening a new era of network services for end-users.

In summary, we think that the convergence of the ATM, the Internet and active networks will shape the framework of ISDN3. The main features of ISDN3 are summarized in Fig. 5 in comparison to those of ISDN1 and ISDN2.

	ISDN1	ISDN2	ISDN3
Time	1980's	1990's	2000's?
Base network	Connection-oriented	Connection-oriented	Connectionless
Transmission units	Frames	Cells	Quantum packets
Traffic forwarding device	Switch	Switch	Forwarding EnginE (FEE)
Network nature	Non-active with little intelligence	Non-active with more intelligence	Active with high intelligence

Fig. 5: A comparison of ISDN1, ISDN2 and ISDN3

Fig. 6 illustrates a high-level network overview of ISDN3. FEEs with integrated switching and routing capability are interconnected by high-speed links. Due to their modular design, they can be connected to ATM networks, Internet and active networks easily. Both active and passive network services can be provided under the same integrated network (i.e. not only data traffic but also network functions are integrated). Quantum packets with one or more quantum cells are used for carrying synchronous traffic and asynchronous traffic (both active and non-active data) over ISDN3.

4. Conclusion

In conclusion, we have presented an overview of ISDN1, ISDN2, Internet and active networks as well as some views to shape the framework of ISDN3. In our view, all traffic in ISDN3 is treated as data. The base network for ISDN3 is connectionless. To support different types of services, a novel quantum packet is being investigated to preserve packet integrity and to support active network functions while enabling cell-like multiplexing. Switching and routing are combined in the same traffic forwarding devices called FEEs, which can operate under both non-active and active network environments. Ongoing work is being done to formulate the architecture of ISDN3 with a focus on investigating quantum packets.

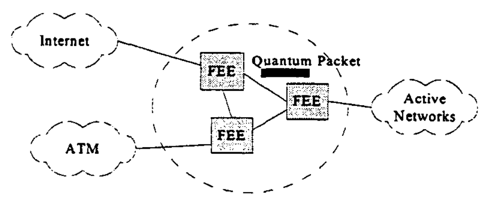

Fig. 6: Network architecture of ISDN3

References:

[1] G. C. Kessler and P. V. Southwick, *ISDN: concepts, facilities and services*, 4th edition, McGraw Hill, 1998.

[2] U. Black, *Emerging Communications Technologies*, 2nd edition, Prentice Hall, Mar. 1997.

[3] D. E. McDysan and D. L. Spohn, *ATM theory and application*, signature edition, McGraw Hill, 1998.

[4] M. Kawarasaki and B. Jabbari, "B-ISDN architecture and protocol," *IEEE Journal on Selected Areas in Commun.*, vol. 9, no. 9, pp. 1405-1415, Dec. 1991.

[5] M. Rahnema, "Frame relaying and the fast packet switching concepts and issues," *IEEE Network*, vol. 5, no. 4, pp. 18-23, Jul. 1991.

[6] W. R. Stevens, TCP/IP Illustrated Volume 1, Addison Wesley Longman, 1994.

[7] S. Deering and R. Hinden, "Internet protocol, version 6 (IPv6) specification," RFC 2460, IETF, Dec. 1998.

[8] L. Zhang *et al.*, "RSVP: a new resource ReSerVation Protocol," *IEEE Network*, vol. 7, no. 5, pp. 8-18, Sept. 1993.

[9] S. Blake *et al.*, "An architecture for differentiated services," RFC 2475, IETF, Dec. 1998.

[10] H. Schulzrinne, S. Casner, R. Frederick, and V. Jacobson, "RTP: a transport protocol for real-time applications," RFC 1889, IETF, Jan. 1996.

[11] H. Schulzrinne, A. Rao, and R. Lanphier, "Real Time Stream Protocol (RTSP)," RFC 2326, IETF, Apr. 1998.

[12] H. C .B. Chan, H. M. Alnuweiri and V. C .M. Leung, "A framework for optimizing the cost and performance of next-generation IP routers," *IEEE Journal of Selected Areas in Commun.*, vol. 17, no. 6, pp. 1013-1029, Jun. 1999.

[13] B. Davie, P. Doolan and Y. Rekhter, *Switching in IP networks*, Morgan Kaufmann, 1998.

[14] H. M. Ahmed *et al.*, "IP switching for scalable IP services," *Proc. of IEEE*, vol. 85, no. 12, pp. 1984-1997, Dec. 1997.

[15] Y. Rekhter *et al.*, "Tag switching architecture overview," *Proc. of IEEE*, vol. 85, no. 12, pp. 1973-1983, Dec. 1997.

[16] K. L. Calvert *et al.*, "Directions in active networks," *IEEE Commun. Mag.*, vol. 36, no. 10, pp. 72-78, Oct. 1998.

[17] D. L. Tennenhouse *et al.*, "A survey of active network research," *IEEE Commun. Mag.*, vol. 5, no. 1, pp. 80-86, Jan. 1997.

[18] C. T. Lea *et al.*, "A/I Net: A Network that integrates ATM and IP," *IEEE Network*, vol. 13, no. 1, pp. 48-55, Jan.-Feb. 1999.

[19] A. Viswanathan *et al.*, "Evolution of multiprotocol label switching," *IEEE Commun. Mag.*, vol. 36, no. 5, pp. 165-173, May 1998.

[20] D. Wetherall *et al.*, "Introducing new Internet services: why and how," *IEEE Network*, vol. 12, no. 3, pp. 12-19, May-Jun. 1998.