INTRODUCTION TO COMMERCIALIZATION OF PACKET SWITCHING

The following article provides a fast-moving, exciting account of the early days of commercial packet switching in the 1970s, focusing on X.25 and, in particular, on Datapac, the X.25-based Canadian packet switching network. It follows an earlier article in this Column on packet switching in the United Kingdom. We hope to publish additional papers on the history of packet switching from other countries as well.

We are so used to the Internet and its amazing suite of ever growing applications that we may tend to forget that in the 1970s and well into the 1980s, common carriers and computer manufacturers worked together in a concerted effort to introduce data packet switching capability worldwide. This effort required the

rapid development of an international standard, X.25. This standard, once introduced, led to quick deployment of multiple data networks in many countries, helping lay the groundwork for the Internet. The Canadian Datapac network, in particular, was the first network to fully implement the X.25 suite.

Tony Rybczynski, the author of the article, was a key figure in these developments. He describes both the technical and political discussions involved in expediting the introduction of the standard and data networks using it. All readers of this magazine will, I feel, gain considerably in reading this article.

—Mischa Schwartz

COMMERCIALIZATION OF PACKET SWITCHING (1975–1985): A CANADIAN PERSPECTIVE
TONY RYBCZYNSKI

CONTEXT

In the 1970s packet networking research was vibrant around the world. Larry Roberts [1], who many call one of the fathers of the Internet, discussed many of these in his article. I would highlight ARPAnet in the United States, Cigale and the Reseau de Commutations des Paquets (RCP) testbed in France, and work at the U.K. National Physical Laboratory. Most of this work was built on commercial minicomputers of the day (e.g., DEC PDP11s).

A small number of commercial store-and-forward message-based services had been developed, for example, one run for the airlines by the Société Internationale de Télécommunications Aéronautiques (SITA), and one in Spain operated by Telefonica for interbank networking. There was also Tymnet in the United States, which multiplexed character streams from multiple users in addressed transmission blocks.

Enterprise networking was in its infancy, based on star networks run over leased lines. These were typically mainframe-based with remote job entry (RJE) and IBM 3270-style access, using vendor-specific protocols defined by IBM and the other computer manufacturers (e.g., Digital). General-purpose user access was provided by "dumb" async terminals (e.g., VT100) via low-speed modems over the public switched telephone network (PSTN).

At the time, T1/E1 leased lines were very expensive. There were no PCs (the Apple II debuted in 1977, the IBM PC in 1982, and the Apple MacIntosh in 1984!). Commercial LAN deployment would only start in the 1980s. IP was a research tool.

In 1972 Bell Canada, on behalf of the TransCanada Telephone System (TCTS), set up a dedicated engineering, operations, and marketing organization (called the Computer Communications Group, CCG, and referred here to as Bell/CCG) to develop advanced data services. In November 1974 Bell/CCG announced plans to introduce packet switching services by July 1976. In the United States, Telenet had launched proprietary packet network services in 1975 and saw the value of an international standard. The French post, telegram, and telephone agency (PTT) were going down the path of rolling out what became Transpac (announced in 1973), and Euronet on behalf of the European Economic Commission (EEC). The British Post Office was running their Experimental Packet Switching Service, and NTT in Japan was likewise researching packet networking opportunities.

There was one major problem with attempts to commercialize packet switching. Without a global standard, IBM (and the "seven dwarfs," as the other seven smaller computer manufacturers were called) would not have a strong business case to connect to these networks, which in turn heavily impacted the business case for these carriers to launch services.

THE DRIVE FOR GLOBAL STANDARDS AND SERVICE ALIGNMENT

Bell Canada owned Northern Electric (later called Northern Telecom, Nortel Networks, and Nortel) at the time, and together they owned Bell-Northern Research (BNR). BNR had a packet switching research group and was a strong partner in Bell/CCG's

packet project. We saw the advantages of packet switching over circuit switching summarized in Table 1.

Bell/CCG issued a draft packet interface specification proposal called the Standard Network Access Protocol (SNAP). SNAP included three layers on top of the physical layer:
1 The data link control layer
2 The datagram layer
3 The virtual call procedure layer, which included a window-based flow control/error recovery/sequencing/duplicate detection mechanism.

The datagram/virtual call procedure layers had many of the elements of TCP/IP, outlined in a 1974 paper by Cerf and Kahn [2].

The draft proposal was sent to carriers and hundreds of researchers in the preeminent laboratories around the world, and of course to IBM. Our objectives were (1) to kick start the discussion of the business need for a global standard (ultimately called the X.25 family of standards) and alignment of public service development timelines; and (2) to propose the key attributes of the required standard. To that end, Dave Horton, the VP of CCG, and I, as technical prime, took a world tour to start the face-to-face dialog.

The feedback was opinionated and varied. The central discussion was whether datagrams or virtual circuits (VCs) should form the basis of the standard.

ONE ARCHITECTURE WAS NEEDED: DATAGRAMS OR VIRTUAL CIRCUITS?

We argued that datagrams were the basis of a more robust and flexible networking technology, as all packets are

Attribute	Packet switching	Circuit Switching
Better use of bandwidth	Statistical multiplexing with bandwidth dynamically shared across users/applications	Time division multiplexing dedicated to the user/application
Speed conversion	Ability to allow low speed devices to talk to high speed devices	Speed must be the same at both ends
Dynamic routing	More options	Per circuit routing only
Acceptable delays	While variable, not seen as a major problem if kept small	Low fixed delays
Error performance	Built-in error recovery at the data link control level	Dependent on the transmission infrastructure

Table 1. *Packet switching vs. circuit switching.*

Attribute	Datagram	Virtual Circuit
Routing	Per packet	VC-based (unless datagram implemented as underlying layer)
Flow control	End-to-end function	Network function
Sequence preserving	No	Yes
Chance of packet duplication	Yes	No
Accounting	Per packet	Per VC and optionally per packet
Cost	No need for state information in the network	Higher at edge nodes; lower at transit nodes

Table 2. *Summary of datagram vs. virtual circuit attributes.*

routed independently, and there is no need to maintain state information in the network. Re-ordering and duplicate elimination could be handled by endpoints or at the edge of the network. In the future more intelligent endpoints would allow for faster networks. We proposed that datagrams could more effectively support current and future applications, for example, transaction and broadcast applications.

While researchers were supportive of our proposed approach as it aligned with their IP networking research, the response from other carriers was unanimously in favor of VCs. They argued that VC services better fitted their service models, existing applications and user expectations. Their perception was that VC-based networks would be easier to engineer. They were particularly uncomfortable with an architecture that required per-packet accounting in an environment in which packets could be lost or duplicated. Table 2 summarizes the key attributes of Datagrams and VC's.

Technically, they argued that network-based flow control would eliminate a major source of packet loss. For example, without flow control, a mainframe connected by a T1/E1 circuit could send 1500 100-byte packets/s to a 9.6 kb/s device, and the network would quite predictably drop the vast majority of these. Not only would this result in low service levels, but it raised the question of having to collect and reconcile accounting data at both ends (we eventually implemented this).

IBM's reaction to our datagram proposal was twofold. On one hand, they wanted datagrams, to keep as much of the intelligence in the endpoints as possible. On the other, they wanted a frame-based sequence-preserving non-duplicating VC service, which could replace their synchronous data link control (SDLC) layer within their planned System Network Architecture (SNA) (introduced in 1976). It took the industry another 15 years to develop a "simplified X.25" or frame relay that better fit IBM's model.

The conclusion we reached in 1974 was to work toward an accelerated VC-based standard within Study Group VII of the CCITT, the International Consultative Committee on Telephone and Telegraph (formally in response to question 1 point C of that Study Group), and to implement a common packet interface in the public packet networks that had been announced. This was a major challenge since the CCITT at the time had a cumbersome process structured around a four-year cycle. Even though a datagram option was, over time, built into X.25, it was never implemented. That said, it would be another 20 years before public IP networks would become widely available, leveraging TCP for flow control, order preservation, and duplicate elimination.

IMPORTANT PRINCIPLES ADOPTED FOR X.25

There were three important principles adopted in the development of the X.25 family of standards.

First, the layering principles of the open system interconnection (OSI) model being developed by International Organization for Standardization (ISO) at the time were followed. OSI broke the then common approach of vertically integrated data communications systems. This was a first for CCITT. For example, the X.25 physical layer definition anticipated rapid growth in higher-speed connectivity, while the X.25 data link control layer leveraged the recently defined High Level Data Link Control (HDLC) protocol [3], which had many advantages over various proprietary forms of binary synchronous communications (a.k.a."bisync"). The heart of X.25 was the packet or network layer, where all signaling took place. This principle was implicit in Bell/CCG's original SNAP proposal.

Second, it was agreed to not only define the interface between the network and user devices, but a **common end-to-end service definition**, making it easier for IBM *et al.* to leverage packet services globally [4]. For example, a lot of work went into standardizing the end-to-end behavior of packet network flow control. More specifically, the X.25 standard defined a windowing mechanism (similar to that used by TCP) whereby flow control could be exerted by the user or the network. The heart of a common end-to-end definition was allowing the user to specify the maximum number of packets in transit across the network, one option being the local X.25 window having end-to-end significance. We were one of the first to implement this scheme, greatly facilitated by our internal datagram and TCP-like architecture.

Thirdly, it was agreed to introduce the notion of a **packet assembler disassembler** or PAD to allow service providers to extend the value of their networks to non-X.25 devices. The adopted architecture included a PAD-to-mainframe protocol that rode above the network layer (following OSI principles). While the CCITT defined one set of standards (labeled X.3, X.28, and X.29) to allow support for asynchronous devices connected over leased lines or over circuit-switched connections, we saw opportunities for a number of PAD services, including one for IBM 3270 devices for which we developed a common spec with Telenet and Tymnet.

ACCELERATED STANDARDS DEVELOPMENT

Up until the early '70s, telecommunications standards had traditionally been set and implemented in largely government run public networks, but only once the technology had reached a certain level of maturity. Thus, for over 100 years the International Telecommunication Union (since 1947, a specialized agency under the United Nations) and the Comité Consultatif International Téléphonique et Télégraphique, CCITT (later the ITU — Telecommunication Standardization Sector), had been the focal point of telecommunications standards. The primary objective of the CCITT was the development of international agreements (called Recommendations) to be implemented by member countries.

In contrast, computer technology had historically operated in a highly competitive environment. Computer communications and packet switching brought these two industries closer than ever before, while at the same time non-governmental organizations (e.g., Bell/CCG, Telenet) along with national PTTs (e.g., French PTT, the British Post Office) emerged as prime movers behind public packet networks [5]. Furthermore, ISO, along with national/regional organizations such as the American National Standards Institute (ANSI) and European Computer Manufacturers Association (ECMA), were major stakeholders, representing the computer industry.

As mentioned above, we targeted the CCITT as being the most appropriate standards body. There are two major categories of participants in the CCITT:
1 Telecommunications administrations such as PTTs and the Canadian Department of Communications (DoC)
2 Recognized private operating agencies such as CCG/Bell and Telenet (recognized in April 1974)

In addition, industry organizations such as ISO, and international telecommunications organizations such as IATA could participate in an advisory capacity.

The CCITT worked in a four-year study period or cycle, at the beginning of which certain Questions were identified that would be subject to study, and at the end of which only telecommunications administrations voted on the resulting Recommendations (which had to be unanimous). Since 1968 there had been an accelerated provisional approval procedure, but it was rarely used.

In 1974 the challenges to develop a packet standard by 1976 (the end of the then current CCITT cycle) were many. First, Study Group (SG) VII was already halfway through its study period in addressing point C of a general Question on new data services: "Should the packet-mode of operation be provided on public data networks and if so how should it be implemented?" Second, Bell/CCG and Telenet were private carriers and had to work through their national organizations. In fact, both the Canadian Department of Communications (DoC) and the U.S. State Department did not take a pro-packet position due to competitive views of carriers in these countries. Third, packet networking was not the technology of choice of many PTT'=s; for example, Deutsche Bundespost in Germany and NTT in Japan already had firm plans to rollout digital circuit switching services. This complicated the consensus building process required by CCITT SG VII as 22 of 23 points being studied related to circuit switching.

On the positive side, there were a number of opportunities. First, SG VII was led by Vern MacDonald from the Canadian DoC, who was empathetic to the opportunity presented by packet switching. Second, Halvor Bothner-by (who had been involved in an experimental packet network in Norway) was appointed in July 1973 as a Special Rapporteur on packet switching. Third, there was a growing commercially driven set of operators that were determined to roll out interoperable packet services over the next couple of years, and eliminate all obstacles to having IBM *et al.* connect to these services.

At the November 1974 meeting of SG VII, the general sense was that work could begin toward what was to become Recommendation X.25. But time was of the essence. I have already mentioned the international lobbying effort undertaken by Dave Horton and myself to further accelerate the technology, business, and standards convergence of packet networking. If Datapac and partner packet networks were to be launched in 1976–1977, a fairly complete standard would be required as early as 1975!

Work accelerated through a rapid pace of meetings, some official CCITT ones and other informal ones with key stakeholders. In March 1975 we held an informal drafting meeting in Ottawa under the auspices of the CCITT Special Rapporteur on packet switching. These and other proposals were submitted (often through France via Remi Després and his team, the United Kingdom via John Wedlake and his team, or NTT of Japan) to the May 1975 meeting of SG VII in Geneva, which had in

Figure 1. *Key movers in the X.25 standard (left to right: Bernard Jamet (France), Masao Cato (Japan), Paul Guineaudeau (France), Claude Martel (Canada), Vern MacDonald (Canada), Remi Després (France), Halvor Bothner-by (Norway), Phil Kelly (United Kingdom), Mr. Ishino (Japan), Tony Rybczynski (Canada), Larry Roberts (United States).*

attendance Dave Horton of Bell/CCG, Philippe Picard who headed the Transpac initiative, and Phil Kelly who headed packet efforts in the United Kingdom. The result was a relatively complete draft definition of a packet mode standard based on VC operation, which, after further editing, was finalized in September 1975. At the time, cut and paste was a scissors and glue process! Much of the final impetus came from the active participation of Larry Roberts, the hands-on CEO of Telenet and previous chief scientist at ARPA.

X.25 was approved by the final meeting of SG VII in March 1976 (Fig. 1 is a photo from this time period), although three Rapporteurs were assigned to address a number of key areas (e.g., internetworking leading to X.75, and user options leading to X.1) even prior to the start of the next Plenary period. Given that the majority of PTTs were still more interested in circuit switching, a key "horse-trading" area was allowing both X.25 and X.21 (the digital circuit switching standard) to receive unanimous approval. Another key factor was that Euronet, an EEC research network primed by France, was also to be based on X.25.

Recommendation X.25 (1976) was a techno-marketing-business success and allowed network operators to roll out X.25 networks, although extensive work, particularly during the next two years, led to a more complete specification in the form of X.25 (1980).

In his 1981 MIT thesis, Laurence Zwiimpfer [6] concluded that the accelerated X.25 standardization process could be deemed a success. In an interview with Louis Pouzin, a noted French researcher at the time, Louis called the X.25 standardization process a "well-engineered political coup." Laurence identified eight lessons from this process. A number of these spoke to the importance of bringing together both business and technical drivers, in what we could have called a "Packet Networking Forum" — a group of key stakeholders working together outside the formal standards process to accelerate the process. The concept of Forums became the norm in the 1980s and 1990s to address, for example, frame relay and asynchronous transfer mode (ATM) opportunities.

In a Bell/CCG survey of 60 computer and terminal manufacturers in 1977 [7], it was determined that 25 were committed to implement X.25, and in fact 16 had already made announcements to this effect. As IBM was not yet among these, Bell/CCG worked with Cambridge Communications Inc (CTX) to develop software for the IBM 3704/3705 front-end processors, making remote devices appear to applications as locally connected. Ken Hayward of BNR made important contributions in this area. In the early 1980s IBM developed native support for X.25 as part of its SNA portfolio [8]. This spurred the acceptance of X.25 by enterprises.

What Bell/CCG kicked off in 1974

not only helped create a multibillion dollar packet industry, but also had a significant impact on how standards can be developed in a more business-driven manner.

DATAPAC: THE FIRST STANDARD X.25 SERVICE PLATFORM

Datapac was the first public network to fully support the X.25 family of standards. Trials of Datapac were undertaken across four cities in 1976, with numerous papers presented and demonstrations given at the International Conference on Computer Communications (ICCC) in Toronto the same year [9]. Commercial services were launched in 1977.

The Datapac architecture, which persisted through various generations of Northern Telecom packet switches (first SL-10 introduced in 1976, then DPN [1985], then DPN-100 [1988], the Passport 7400 [1992], and Passport 15000 [1995]), included a packet/datagram subnet, a VC layer, and an application/PAD layer. This VC/datagram architecture was also applied to frame relay services, providing a very robust networking infrastructure. The trunk and access physical layer were based on Dataroute [10], the world's first digital private line network. All of the Northern Telecom packet switch technology was developed in Ottawa, Canada, which was also where Bell/CCG was located, making close collaboration a reality.

When launched, each Datapac node could handle 420 access ports up to 9.6 kb/s, 6 trunks up to 56 kb/s, and 200 packets/s. The network could only support 14 nodes. Over the next 10 years, the technology evolved to support a network with 40,000 subscribers across Canada through 180 switches, all managed as a single system.

Some of the more important optional features provided included:
• Closed user groups, effectively delivering virtual private networks
• Hunt groups, allowing mainframes to be connected via multiple links
• Various performance options, including flow control parameters, throughput classes, and transit delay, and extended sequence numbering for higher throughput and satellite applications

The Northern Telecom SL-10 (Fig. 2) and successor products used in Datapac supported a broad range of PAD services, most rolling out during the decade following its launch:
• The interactive terminal interface

Figure 2. *Northern Telecom SL-10 packet switch, the foundation of the Datapac network.*

for async terminals following the X.3/X.28 and X.29 standard
• The asynchronous polled interface for point-of-sale devices
• The bisynchronous interface for IBM 2780/3780 devices
• The display station protocol for IBM 3270-compatble data entry systems
• The HASP multileaving interface for RJE devices
• The SDLC interface for SNA devices

The Northern Telecom SL-10 was the first purpose-built packet switch to go into commercial service. It had a multiprocessor architecture built around a common memory through which interprocessor data and control packets passed. Queuing and dequeuing of packets were performed by duplicated hardware controllers, with contention among processor modules resolved by a hardware arbitrator.

In 1979 the first X.75 gateway services were established between Datapac and Telenet in the United States. This was extended to other U.S. networks and internationally via Teleglobe Canada. We needed a data network identification code (DNIC), equivalent to a telephone country code, but there were no procedures on how to get one. So I chose 3020 (302 was assigned to Canada), and we sent a notification to the Canadian DoC.

Some carriers in the United States hired psychologists to determine the most memorable DNICs for their networks! As an aside, "surfing" became a reality for Canadian users, particularly once Datapac was connected worldwide. For example, Canadian medical researchers could make a local modem call and have access to the National Library of Medicine in Washington, DC. The latter had bibliographic records of over 2200 medical journals with access to 600 subscribing libraries, and was delivered through System Development Corporation's (SDC) Search Service [11]. Search services combined with packet networks were a precursor of today's Internet and World Wide Web.

The management of Datapac, a truly distributed multiprocessor architecture, was an ongoing focus of Bell/CCG. Bell/CCG worked closely with Northern Telecom and developers in BNR to evolve the administration and control in line with its needs as the subscriber base grew. The centralized network administration system provided network-wide service management capabilities, software distribution, data collection, report generation, and statistical analysis. The network control system provided network monitoring and control, and alarm management, all transported over a separate virtual private net-

work. In addition, a family of network engineering tools assisted in capacity planning for a new and dynamic environment.

The latest published plan from Bell Canada is to decommission the network in December 2009 after over 30 years of customer service. At its peak, Datapac supported 50,000 devices. The dominant application in its final years was for point-of-sale (dev)ices, which are being migrated as an IP VPN POS service on Bell's IP/multiprotocol label switching (MPLS) networks [12].

IMPLICATIONS OF X.2.5 COMMERCIALIZATION

Some of the implications of the commercialization of X.25 packet switching services are:
• Packet switching technology was established as a viable technology, setting the stage for the ultimate commercialization of IP networking. Evolution continued in the X.25 domain with higher speeds and feeds and switching capacity and scalability, leading to the introduction of frame relay and ATM.
• Carriers around the world embraced packet switching and started offering services following the success of packet services offered by Bell/CCG, France Telecom, Telefonica, Telenet, and NTT (Table 3). Datapac grew to be one of the biggest public packet networks in the world.
• Enterprises likewise embraced packet networking, including early adoptors such as Societé Generale de Banque in Belgium (1979) and the U.S. Federal Reserve System (1980).
• Multiple vendors entered the packet switching arena including Northern Telecom, Telenet (later GTE), Alcate,l and many others, which generated billions of dollars (U.S.) of revenues for these vendors. Northern Telecom's early entry ultimately established it as the number 1 vendor in this space over several years (e.g., 21 percent market share in 1990 according to Dataquest), and included building some of the largest packet networks during the 1980s. For example, the SITA network supported 120,000 terminals and printers; served 460 airlines across 31,000 offices in 187 countries; and processed 36 billion data transactions and messages each year.

• Packet standards continued to evolve in CCITT including X.75 for packet network interconnection, and various performance and related standards.

• The standards-making process evolved toward a more agile and market-responsive process.

ACKNOWLEDGMENTS

Country	Date of service	Network
Belgium	1979 experimental; 1980 planned service	
Canada	1976 experimental; 1977 public service 1978 public service	TCTS's Datapac CNCPT's Infoswitch
Denmark	1980 planned service	Datapak
Germany	1979 planned limited service	Datex P
France	1978 public service	Transpac
Italy	After 1980	Itapac
Japan	1977 experimental; 1979 planned service	DDX DDX-P
Netherlands	1980 planned service	Datanet-1
Norway	1980 planned service	Datapak
Spain	1973 public service (pre-standard)	RETD
Sweden	After 1980 planned service	Telepak
Switzerland	1979 planned service	Telepac
United Kingdom	1977 experimental (pre-standard) 1979 planned service	EPSS PSS
United States	1975 public service 1969 private network; 1976 public service 1978 public service	Telenet Tymnet Compac

Table 3. *1978 view of public packet switched data services [13].*

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BIOGRAPHY

TONY RYBCZYNSKI [SM] is retired from Nortel, where he was director, Strategic Enterprise Technologies reporting to the CTO. He has over 37 years' experience in various forms of packet switching. In the 1970s he helped Bell/CCG pioneer the commercialization of X.25 packet switching (and in fact co-authored the spec). In the 1980s at Nortel R&D Laboratories (BNR) and later in Nortel, he drove the introduction of frame relay product capabilities, and was instrumental in the definition of Nortel's ATM and IP portfolio. Over the last 10 years, he participated in a large number of strategic initiatives leveraging IP networking and Unified Communications applications. He has written over 200 trade articles and wrote a column in *IP Telephony* magazine for over a decade. He is a graduate of McGill (B.Eng EE) and the University of Alberta (M.Sc-EE), and is a co-author of a protocol reference book (*Computer Network Architecture and Protocols*, Plenum Press) and a contributor to the *ATM for Dummies* book.