X.25 Virtual Circuits - Transpac in France - Pre-Internet Data Networking

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INTRODUCTION

Two previous papers in this series, by Peter Kirstein and Tony Rybczynski, covered early histories of packet switching in the UK and in Canada [13] [14]. This one is about the early history of packet switching in France. It will present steps that led the public Transpac network, based on standards of this period, to become the largest of its generation.

Tony Rybczynski having already described in his article the contents of X.25, the dominating standard of the eighties, and major official steps that led to its approval in 1976 by CCITT (Comité Consultatif International Téléphonique et Télégraphique), we will concentrate here, concerning standardization, on the rationale behind choices made, and on some turning points that influenced the outcome.

HERMÈS PROJECT AND RCP EXPERIMENTAL NETWORK

Studies on packet switching started in the French Telecommunication Administration when Jacques Dondoux, then directing the CNET (Centre National d'Étude des Télécommunications), launched Project Hermès in 1971. The project objective was to specify a specialized network architecture for data communications, and to do it in relationship with the international work of CCITT in its NRD group (Nouveau Réseau pour Données).

The British Post Office (BPO), which was very active in the NRD group, was promoting a circuit-switching network with fast circuit establishment, but was also suggesting to study a new concept, the "packet-mode of operation", or "packet switching". In view of the experience of my team on computer software (with Alain Bache and a few colleagues, we had developed a time-sharing system for an in-house general-purpose computer), I was proposed to investigate this subject, perceived as esoteric in the telecommunication world. The goal was to determine whether it could be useful for a public service. The most influential publications in this domain were then some from Donald Davies and from Larry Roberts. Donald Davies, leading a team at NPL (the National Physical Laboratory where Newton had used to think below apple trees), had invented the packet-switching concept for shared data networks [2]. Paul Baran, at the Rand Corporation, had before that worked on related ideas for the US Department of Defense, but in a more speculative and futuristic perspective [1]. Larry Roberts and his colleagues had generously documented their approach for Arpanet, the US network for resource sharing among academic computer centers they were developing for the ARPA (Advanced Reasearch Project Agency) [3]. Readily convinced of the great potential of packet switching for data traffic, I enthusiastically took the job. After a theoretical study, I proposed to validate the practicability of a packet-switching-based public service on a small size network called RCP (Réseau à Commutation par Paquets). Alain Profit, then manager of the Hermès project, accepted to finance RCP. One year later, he also accepted that the project team be moved to CCETT (Centre Commun d'Etudes de Télévision et Télécommunications), a newly created research center where hiring more engineers would be significantly easier than in CNET.

RCP's configuration, as planned in 1972, is shown in Figure 1. Packet-mode customer devices, typically computers or protocol converters, had access to the network via point-to-point synchronous leased lines (SLL). On these access lines, they could support interleaved data communications with multiple other packet-mode devices and with multiple character-mode devices. Character-mode customer devices were at that time teletypewriters and simple keyboard-display terminals. They had access to RCP via the switched telephone network (STP), via the switched Telex network (STX), or via point-to-point asynchronous leased lines (ALL). Each one could establish a data connection with a packet-mode computer, or with a computer supporting multiple character-mode interfaces to RCP, or with another character mode terminal. The three switching nodes were standard PDP-11 minicomputers of Digital Equipment. Character-mode multiplexors were standard products of SAT (Société Anonyme de Télécommunications), which also developed for RCP PDP11-adapters to remotely control them.

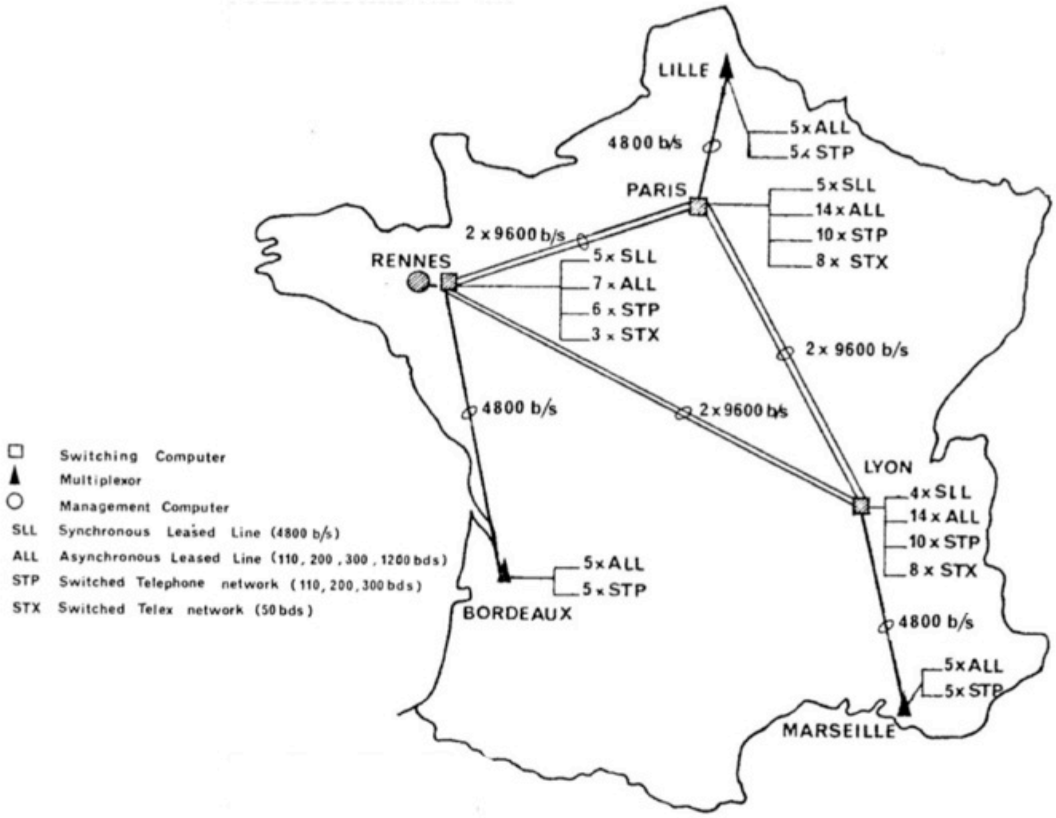

Figure 1. *The RCP experimental network in 1975*

RCP served as a test bed for the Virtual Circuit (VC) model. With VCs, the network is aware of connections established between packet-mode devices. RCP opened service in 1974. It confirmed that a public data communication service could be offered with switching nodes based on available computer technologies, and with easily understood and implemented protocols [5]. It also proved that computer manufacturers could rather easily adapt their software to support and use VC protocols like those of RCP. IBM was first to do it, at its research center of La Gaude in France, followed by Honeywell-Bull and by CII (Compagnie Internationale pour l'Informatique).

RATIONALE FOR THE VC PARADIGM

During the first phase of our work on packet switching, in 1971, we had a private presentation of the EPSS (Experimental Packet Switching Service), a project of the BPO [7]. It introduced, for packet-mode devices, the concept of "virtual calls" and "permanent virtual circuits". Although detailed proposed protocols were in our understanding far too complex, and had severe limitations, the idea of combining packet transmission and connection-based service had immediately a great appeal to us. We endeavored then to simplify and complete the concept, and to validate it on RCP. We adopted the generic term "virtual circuit" to cover both virtual calls, renamed "'switched VCs" (SVCs), and permanent virtual circuits (PVCs).

On one hand, packet transmission was attractive for data traffic because of its potential for multiplexing on transmission links traffic mixes having widely different characteristics. At that time, data transmission rates ranged from 50 bit/s to 48 Kbit/s, and silence ratios on established connections were also largely variable. Another key feature of packet transmission was that it made communication between customer access links having different data rates much easier than with circuit switching. The counterpart was that some flow control would have to be exercised on high-speed sources when they transmit toward low-speed destinations but, at least with VCs, simple solutions could be found for this.

On the other hand, connection-based services were attractive for data traffic because they permitted to specify the quality of service (QoS) of each connection, and to enforce differentiated committed data rates on heavily loaded shared circuits [4]. They also permit great savings on link utilization. At that time, both these properties were important because the cost of customer access links was high, with a strong dependence on supported data rates, and international links were extremely expensive. Since the average number of octets to be sent per packet was very small in the late seventies, in particular with character-mode terminals, it was important that packet headers be kept small. As we wanted a flexible address format, capable of supporting a virtually unlimited number of customers, it would have been a great waste to repeat full addresses in every packet. With a connection-based service, once a VC is established across a transmission link, packet destinations can be implicitly coded in short labels that identify VCs to which packets belong. Thank to this, X.25 supported 60-bits-long addresses with data-packet headers, including their error-control and flow-control fields, having 32 bits. For comparison, current Internet supports 32-bits-long addresses with TCP/IP packet headers having 320 bits. This would not have been economically competitive at that time.

A major departure of RCP protocols from those of EPSS was the introduction of a simple and reliable link layer protocol. The EPSS link layer, between a customer device and its network packet switch, could duplicate some packets, couldn't sustain continuous transmission at full speed, and necessitated a sophisticated specialized hardware. The RCP link-layer protocol made duplications impossible, permitted continuous transmission at full speed, and was implementable in software with existing hardware. Based on an improved version of an error-correction mechanism invented at the NPL, it was very simple. It was not retained for X.25, for a reason explained below, but became in 1981 part of signaling system No 7 for inter-exchange signaling in telephone networks (CCITT Recommendation Q.703).

With data integrity ensured at the link layer, specifying a protocol for a reliable end-to-end service becomes easy. For flow control to be independently exercised for each VC that traverses an access link, each end of the link informs the other end, on a per VC basis, when it is ready to accept more data. For this, a classical sliding window mechanism can be used for each VC, simplified by the fact that no packet is lost at the link layer. If the network has an irrecoverable failure, established VCs are cleared (or just re-initialized if they are PVCs). Since the effect of such a failure on applications is the same as that of a temporary physical-access or customer-equipment failure, it must be acceptable provided network failures are made rare enough.

For a switching node to announce that it is ready to accept more packets on a VC, it must have enough memory to store them when they arrive. This proved to be easy to ensure at reasonable costs with available technologies, both for RCP and for the full size Transpac later on.

The complete VC protocol of customer links, being symmetrical at both the link layer and the VC layer, can also be used to interconnect two operator networks. It can even be used internally between nodes of each independent network. The end result is a great simplicity of the overall model. By comparison, the TCP protocol of Internet, having to perform error and flow control end-to-end, over an underlying "best effort" infrastructure, is highly sophisticated. It took years to complete it, with in particular a major revision in 1988 to prevent network instability that had been observed [12].

GOING MAINSTREAM WITH TRANSPAC

In October 1973, Louis-Joseph Libois, then Directeur Général de Télécommunications, publicly launched a study to determine how a packet-switching public data service might open as early as in 1976. He entrusted CCETT with the task of its technical specification. This decision, first of its kind in the world, had been in part influenced by external pressure: several powerful public and private organizations had grouped in GERCIP (Groupe d'Etude pour un Réseau Commuté Interprofessionel de Paquets), and claimed their intention to build a common packet-switching network; independently, the Ministry of Industry had decided to fund its own packet-switching network, Cigale, a part of the larger computer-communication project Cyclades of Louis Pouzin [6].

Respoinsibility to supervise the work of CCETT, to manage contacts with computer manufacturers, and to coordinate with Cyclades, was assigned to Alain Profit. Philippe Picard was given responsibility for economic and early marketing studies.

At the end of 1974, a detailed specification was available for a public network, in the mean time officially named Transpac. A draft, written by Yves Schwartz, Guy Pichon and myself, had previously been submitted for external reactions to the BPO (then working on its EPSS), to IRIA (then working on Cyclades), and to GERPAC (Groupe pour l'Étude du Raccordement à Transpac, a new avatar of GERCIP after it had renounced to build its own network) . Upon request of the Ministry of Industry, the draft had included, besides its detailed VC specification, a datagram service specification (DG) derived from that of Cigale. This precaution having been taken, only minor remarks were received, and the draft was finally approved. The DG specification was so imprecise that potential contractors would have had to complete it in their own way, but, when international agreements on VCs had progressed, the request for a DG service was abandoned.

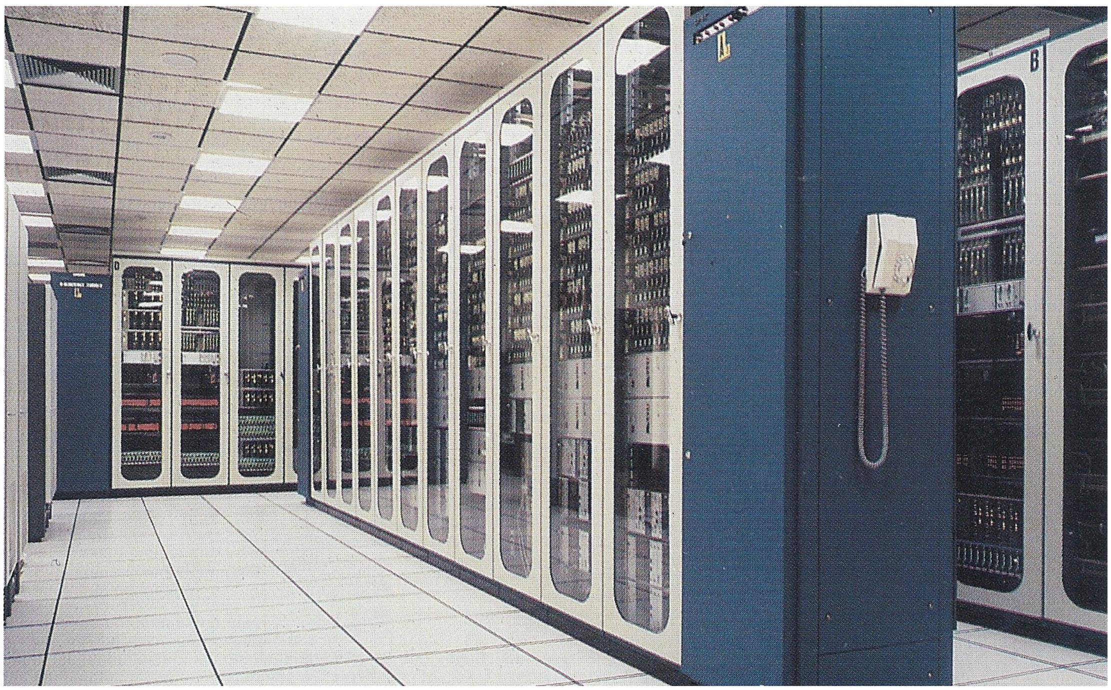

Figure 2. *CP50 X.25 switches in a Transpac center*

Before the end of 1974, Philippe Picard had convinced the newly appointed Directeur Général des Télécommunications, Gérard Théry, that the Tranpac project was ready to be launched. The necessary green light from the government was then given with three conditions: Transpac must be operated by a separate company; user representatives must have shares in this company; specifications of the network must be approved by Ministry of Industry. These conditions being accepted, the call for tenders was issued in February 1975.

The winning proposal was that of the consortium led by SESA (Société d'Etude des Systèmes d'Automation). Managed by Jacques Stern and Jacques Arnould, SESA had already acquired some packet-switching know-how as co-contractor for EIN (European Informatics Network). EIN was an experimental network financed by the European Economic Community, and technically derived from Cigale. High-capacity and redundant packet switches proposed by SESA, the CP50s shown on Figure 2, had been designed by TIT, a company that had sold message-switching computers to the French Navy. CP50s were to be manufactured by TRT, a dynamic telecommunication equipment company already selling a large range of modems. Control units, which handled VC establishments, were Mitra-15 minicomputers of CII. Leveraging its Transpac experience, SESA later commercialized X.25 products for Euronet (a pan European network funded by the EEC in order to boost the scientific database market in Europe), and later for various national networks including some in Australia, Brazil, New Zeeland and China.

The contract for the first configuration, supporting up to 1500 packet-mode customers, was signed in April 1976 [9]. In the mean time, the initial Transpac VC specification had been replaced by that of X.25, without cost or delay implication as the standard was very close to what had been originally specified. Later in 1976, when the CCITT agreement on X.3/X.28/X.29 for character-mode support was finalized, its specification replaced the original one, but this time with negotiated contractual implications.

While the contract was followed through, a dedicated Transpac project team had been set up. Philippe Picard was at its head, with full responsibility on economic, marketing, technical, and operational aspects of the project.

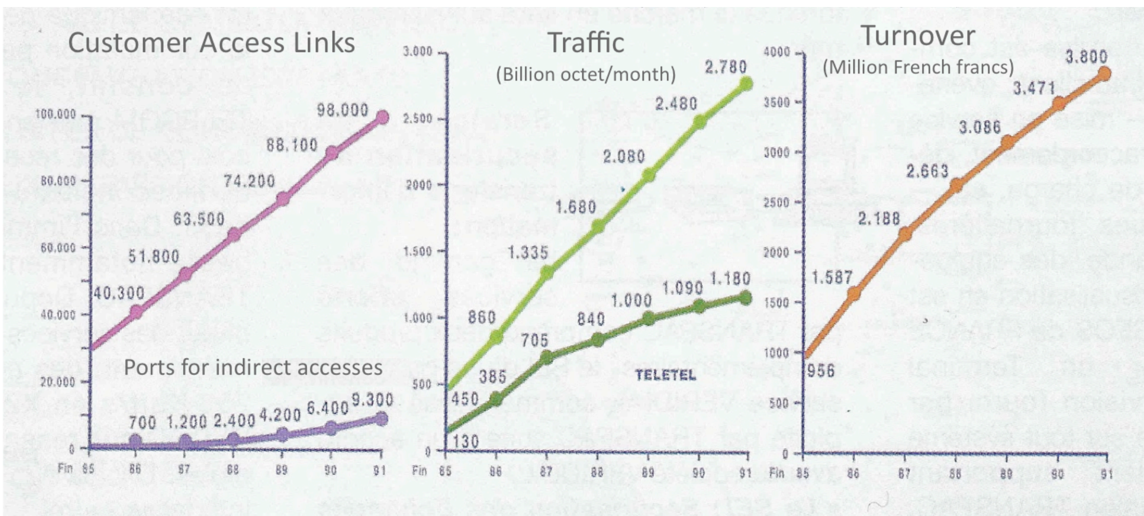

Figure 3. *Transpac growth from 1985 to 1991*

For future customers to decide to use Transpac in advance, tariffs had been discussed with GERPAC, and announced two years before service opened, with an uncertainty officially limited to 10 %. According to an innovative decision made by Gérard Théry, tariffs had to be independent from distance in all their constituents. When Transpac opened, in December 1978, the initial tariff was structured as follows (1 French franc being roughly worth US$ 0.20). At peak times, the volume-based charge was 0.06 F/Koctet, and SVC duration charges were from 0.01 F/min, for a 1.2 kbit/s committed data rate, to 0.20 F/min for a 48 kbit/s committed data rate. Important discounts were applicable to these charges at off-peak times (- 80 % during weekends and during weekdays from 0:00 to 6:00 AM; - 40 % during weekdays from 6:00 AM to 8:00 AM and from 7:00 PM to midnight). Dedicated access links had monthly charges ranging from 330 F/month for character mode accesses at 300 bauds, to 5,000 F/month for packet-mode accesses at 48 kbit/s. PVCs had monthly charges ranging from 108 F/month for a 1,2 kbit/s committed data rate, to 2,160 F/month for a 48 kbit/s committed data rate. These tariffs, which progressively decreased as the network grew, proved their adequacy: customer subscriptions consistently exceeded initial expectations; the financial break-even point was reached earlier than expected.

In the seventies, any device connected to a telecommunication network, for example a modem on a leased line, had to be certified to check that it could not disrupt network operation. But with a proper implementation of X.25 VC protocols in switching nodes no connected device could endanger normal operation. After some hesitation, it was decided that the burden of certification, which would have been detrimental to a fast take-off of the service, could be dispensed with. Instead, a detailed, rigorous, and comprehensive, description of the planned Transpac behavior was documented in the STURS (Specifications Techniques d'Utilisation du Réseau) so that manufacturers planning to have products connectable to Transpac could be ready in due time. In addition, a CCETT team led by Paul Guinaudeau implemented, in one year on a Mitra-15 minicomputer, a switching node that simulated Transpac's behavior, REX25. Manufacturers were allocated test sessions on REX25 to validate their implementations before Transpac could be available.

Service acceptance has been encouraging from the beginning [10]. In 1980, with 2,395 operational X.25 access links, banks counted for 28 % of established VCs, Service Bureaus for 19 %, Industry for 15 %, and Public Sector for 14 %. One year later, more than 5,000 X.25 accesses were operational (at a time when Internet was still in its infancy, with its first 213 hosts). Transpac's continuous growth during the 1985-1991 period is shown in Figure 3, and its configuration in 1991 is shown in Figure 4.

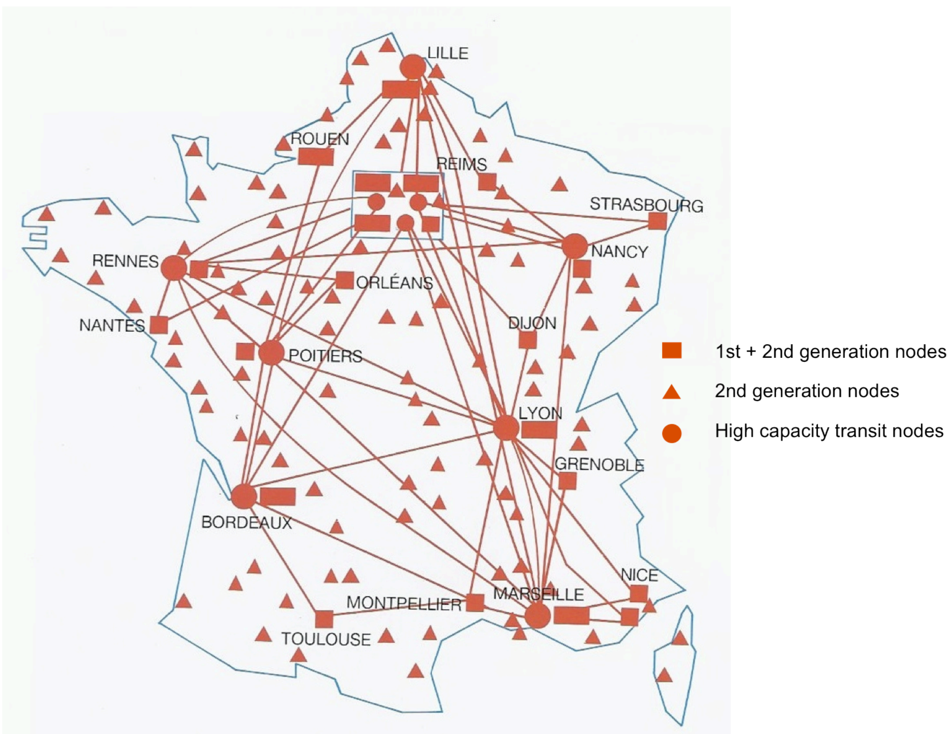

Figure 4. *Transpac map in 1991*

QoS, a key criterion for VC acceptance, was carefully checked, with periodical reports to UTIPAC, the Transpac user association that had replaced the GERPAC. During initial traffic buildup, a few bugs had to be eliminated, and the QoS stabilized to a satisfactory level during the first quarter of operation. Four years later, when real traffic had exceeded that which traffic generators used for acceptance tests had been able to generate, the network from time to time unduly cleared some VCs. A flaw in the design of the CP50 software was quickly identified, and corrected once and for all.

Three years later, in 1985, more than a million character-mode terminals, the Minitels, were in operation They were made available to telephone customers to consult the national telephone directory, and were also used for other applications (those of the Teletel service about which another article of this series is planned). The resulting increase of VC establishments per second revealed a dormant software bug that caused a serious degradation of the service. After two weeks of service interruption for Minitels, which caused much discontent, the problem had been diagnosed and solved. After that, Transpac's quality of service remained satisfactory and generally praised by its users.

THE X.25 STANDARDIZATION SAGA – VCs and DGs

In 1972 both the CCITT and the CEPT (Commission Européenne des Postes et Télécommunications) had appointed Rapporteurs on the Packet-Mode of Opereation. Norwegian Halvor Bothner-By being that of CCITT and myself that of CEPT, we both participated in meetings organized by the other. Having different views on how a packet-switched public service could best be offered, both Rapporteur groups decided to work in parallel on DGs and VCs. The term "datagram", so successful later on, was coined by Halvor Bothner-By and a colleague in a train between Paris and Rennes, taken to attend a CEPT Rapporteur meeting. The DG model was defined as one in which standard-format packets are transmitted across a network independently of each other, and for which flow control within the network relies on a friendly cooperation of end-user devices. The network discards packets when and where its internal queues tend to grow too much; end-user sources are expected to refrain from transmitting too many packets toward destinations in directions of which packets tend to be discarded. Note that this definition of DGs differs significantly from that of Internet specified in 1981: in Internet, each DG can be transmitted as a series of packets that share a common DG identification; the network may further fragment each of these packets into several smaller ones; final destinations are responsible for reassembling all fragments [11].

A major turning point of international discussions took place at a meeting organized by Dave Horton, head of the Canadian Datapac project, and Philippe Picard, with participations of Tony Rybczynski and myself. Both parties had two objectives in common: opening a service as soon as possible; obtaining an international standard. Since our two projects were the two major ones at that time, chances of reaching a standard would be good only if the two of us could agree. But there was a problem: the Datapac proposal, the SNAP (Standard Network Access Protocol), was DG based; ours was VC based. After a long discussion between Tony and myself, walking in Paris streets, and continuing in a bar late at night, the first sketch of what might be an agreement was drawn. The point-to-point link layer protocol would be that of SNAP. It was technically more complex than that specified for Transpac but was based on the emerging HDLC (High Level Data Link procedure) promoted by IBM in ISO (the International Standards Organization). As such, it was a much better candidate for an international agreement. Above this link layer, we would adopt the VC layer of Transpac. It was much simpler and more efficient on customer links than the SNAP proposal which had two layers, one for DGs and one for error and flow control, were one was sufficient. Soon after I went to Ottawa with Paul Guinaudeau to more deeply discuss pros and cons of the new combination. Dave Horton then gave his green light. After several meetings in Canada and in France, Tony Rybczynski, Claude Martel, Paul Guinaudeau and Bernard Jamet had assembled a detailed specification. Dave Horton and Philippe Picard then made a common commitment to implement it in our networks, and to amend it only after common approval.

The next good news came soon after, when I met in Washington Larry Roberts, Arpanet's father, and Barry Wessler. Their startup, Telenet, was known to prepare a commercial packet-switched network, but the chosen technical approach was unknown. Discovering that their choice was a VC model has been a notable confirmation that we were on the right track. They had an HDLC link layer rather similar to ours. Above it, their VC layer was different in a number of details, but there was no essential difference that would preclude compatibility. With a few agreed minor complements to the current specification, Telenet joined the agreement.

The next important step forward was when Philip Kelly, of the BPO, agreed with Philippe Picard that the Transpac technology should also be adopted for Euronet. After that, the British stand in CCITT, so far mildly in favor of datagrams by reference to the EIN project, abruptly switched to a dedicated and active support for the VC multilateral agreement. Philip Kelly, highly experienced in CCITT practices, quickly helped with his colleagues to structure an appropriate set of contributions. He also involved Japan, where Dr Masao Kato of NTT also had plans for a packet-switched service.

At the CCITT-Study-Group-VII meeting in February-March 1976, a formal contribution was submitted jointly by France and the UK, the two parties involved in the agreement that had voting status in CCITT. It contained a complete X.25 draft based on the multilateral specification [8]. Many objections were expressed by delegations that had not participated, and had been surprised by so fast a progress. I was then appointed as editor to try and resolve these issues during the weekend. After a full Saturday and a full Sunday of intense meetings, all points raised had been resolved among participants. On Monday morning, Tony Rybczynski and Paul Guinaudeau had spent all night rewriting clean handwritten versions of the modified specification. Thus, both English and French versions were available, as required to forward a proposal to the CCITT plenary. All delegates had the photocopied documents necessary for a formal vote, and unanimously approved them. At the CCITT plenary itself, in June 1976, X.25 was unanimously endorsed, with two subjects left for future studies. One, asked for by IBM, was that a lighter variant be designed for the simplest terminals, a wish that was later found unnecessary. The other was that the specification of a DG service should be added to X.25. This addition did take place at the end of the next CCITT plenary, in 1980, but, no implementation being planned, it was deleted in 1984.

Complementary Recommendations X.3/X.28/X.29 for packet assemblers-disassemblers (PADs), necessary to support character-mode-terminal, were finalized in 1977, with Bernard Jamet and Chris Broomfield as main editors. Recommendation X.75, the variant of X.25 adapted to links between X.25 networks, was finalized in 1978. The scene was thus completely set for a worldwide packet-switched service to be extensively deployed in the eighties.

INTERNATIONAL LINKS AND PRIVATE NETWORKS

For international connections of Transpac with other X.25 networks, the team that had developed REX25 implemented an International Transit Node (NTI).

Close cooperation then took place with US International Record Carriers (ITT, WUI and RCA), and with Tymnet which implemented their equivalent of the NTI. The first transatlantic links were then opened in 1979, on pairs of 9.6 kbit/s circuits. Typical international applications were then accesses to remote servers by character-mode terminals, and exchanges between bank message centers. Direct links followed with European countries operating their own X.25 networks (Germany, the UK, Spain, the Netherlands, Luxembourg), and with Canada and Japan (Figure 5). The link with Euronet, operated by a consortium of Telecom Administrations, completed connectivity which the remainder of Europe.

Aside form Transpac, a number of private networks using X.25 started to appear for intra-site communications, and also for short-distance private networks (for these, Transpac tariffs, being distance independent, were not optimum). Products that were successful on this market included the Compac range of TRT, the Megapac range of Sagem, and the Ecom range of OST (a startup later acquired by the Canadian Newbridge Networks). Tekelec-Airtronik developed and successfully commercialized worldwide an X.25 protocol analyzer, the TE92.

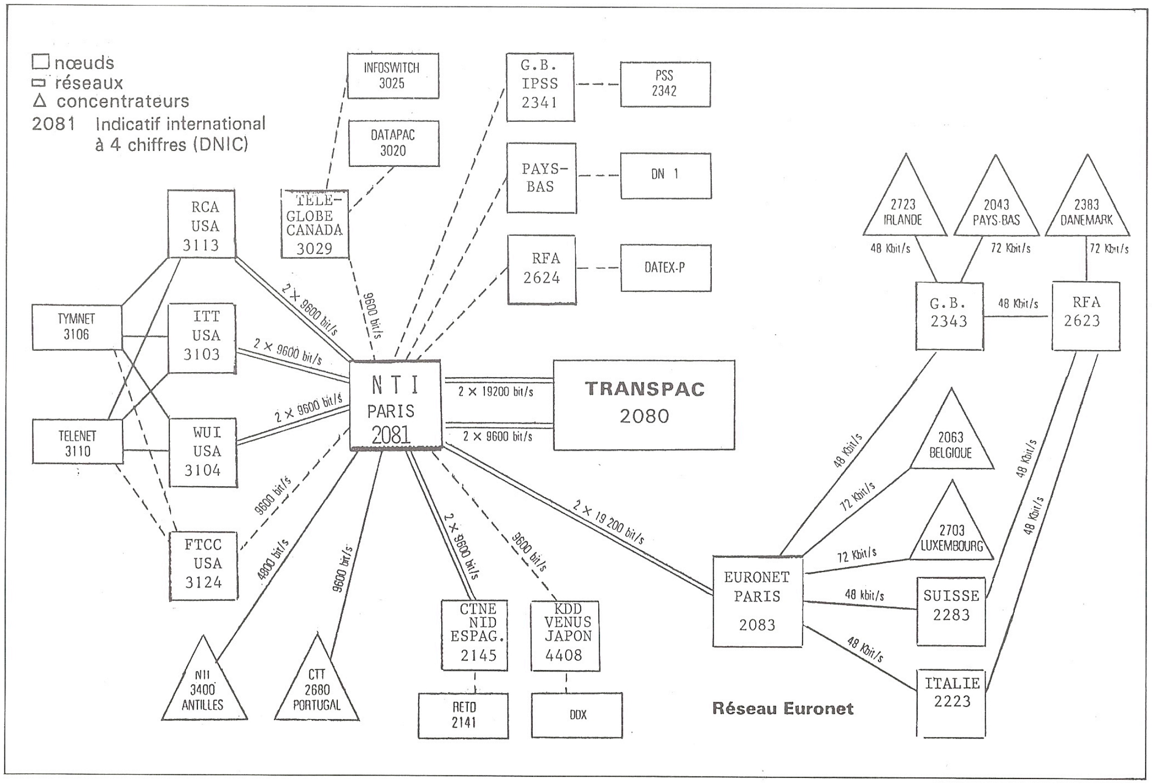

Figure 5 . *Transpac existing and planned international links in 1980*

EPILOGUE

As everyone knows, Internet has become the ubiquitous data network of the globalized planet. Its initial penetration in less developed countries used pre-existing packet-switching infrastructures, with Internet IP packets transmitted on X.25 VCs, but this is now pure history.

Predominance of X.25 VCs was first shaken when Frame-Relay PVCs were marketed as permitting data rates much higher than those of X.25. At a time when the Frame-Relay Forum distributed leaflets explaining that X.25 could never exceed 64 kbit/s, there were already switches supporting X.25 at 2 Mbit/s, but the buzz prevailed. It was true, though, that X.25 had a limitation for links having very high data rates on links having long propagation delays. For this reason, X.45, a variant of X.25 that eliminated this limitation, was endorsed by CCITT in 1996. It was designed for transparent interworking between X.25 and X.45 customers, thus permitting incremental deployment. But it arrived much too late and was never commercially supported. The irresistible success of Internet, and its TCP/IP protocol suite, was already too advanced.

For some time, ATM (the Asynchronous Transfer Mode) was presented as a panacea that could replace X.25 and Frame Relay, and even replace TCP/IP, but it did none of these. It was successful only as a flexible multiplexing technology, for high-capacity and long-distance transmission trunks and for some ADSL customer access links.

The Transpac company, which had been created in 1978 to operate the Transpac network, was fully reintegrated in France Telecom in January 2006. It had in the mean time evolved to sell to its professional clients less and less X.25, more and more Frame Relay, and more and more TCP/IP. The number of Minitel terminals using Transpac had peaked at 6 millions in 1993, and the number of X.25 customers had peaked at 105.000 in 1995. In January 2010, France Telecom announced that commercialization of X.25 would be discontinued after July 2010, and that X.25 services would be closed after November 2011.

From a purely technical point of view, applications that caused the exponential growth of Internet, e-mail and the Web, could have worked on a VC based worldwide infrastructure, but other considerations didn't make it possible. Some of the QoS features of connection-oriented services might some day re-appear in Internet, but this doesn't seem to be a priority today.

ACKNOWLEDGEMENTS

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BIOGRAPHY

Rémi Després, after eight years of implementation experience on assemblers, compilers, and time-sharing systems, started working on packet switching in 1971. During successive first phases of the Transpac project, he was in charge of its technical aspects until 1980. After one year at Cap-Gemini-Sogeti as Telematics Division Manager, he joined SESA in 1981. There, he contributed to the design of X.25 products of second-generation, and started a Local Area Network activity. In 1985, he founded RCE (Réseaux de Communication d'Entreprise), a startup that sold LAN equipment at successively 1, 10, and 100 Mbit/s, and that provided the first Frame-Relay concentrators of Transpac. After RCE had been bought by the Compagnie des Signaux, he founded StreamCore, a startup specializing in TCP/IP bandwidth management. Leaving the company after financial investors and a new management chose a different direction for the company, he created RD-IPtech to work as an independent researcher and consultant on Internet technologies. As such he invented in 2007 the 6rd mechanism of RFC5569 whereby IPv6, the new-generation of IP, can be made available across unchanged IPv4 infrastructures. Graduate engineer from Ecole Polytechnique in Paris (1961-1963), he holds MS and PhD degrees in Computer Science and Electrical Engineering from Berkeley University in California (1967-1969).