A perspective on the shift/BETEL project

Olivier H. Martin

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Abstract

Because of its long standing involvement in networking activities due to the distributed nature and needs of the High Energy Physics (HEP) Community worldwide, it was very natural for CERN to participate in BETEL, the first trans-European ATM trial. It was also a unique opportunity to validate some of the distributed computing concepts recently introduced at CERN in the framework of the SHIFT project over a real high speed wide area ATM network. In this paper we describe the experience gained while deploying and using SHIFT between CERN (Geneva) and IN2P3 (Lyon) over the BETEL platform and we also suggest economically sound ways to make use of public ATM networks.

I. INTRODUCTION

The European Laboratory for Particle Physics (CERN), located on the Franco-Swiss border near Geneva, provides accelerator facilities for particle physics experiments, mainly in the domain of High Energy Physics (HEP). CERN, an International Treaty Organization with nineteen member states, has also well established scientific links with the HEP community worldwide. Quite naturally the distributed nature of the research community using the CERN accelerator facilities has led to heavy and early use of networking. Without exaggeration one can state that it is the existence of "first class" external networking facilities that allowed CERN users to maintain the necessary level of cohesion and to be successful.

Before the BETEL project, CERN was already one of the main "networking hubs" of the European academic and research community with approximately 17 Mb/s of external bandwidth distributed over 21 lines, 12 countries and 3 continents. With BETEL, a 34 Mb/s access line (i.e. 16 times faster than the fastest links (i.e. 2 Mb/s) has been introduced, which is a "genuine revolution" in terms of applications. In this paper we will first provide some background information about the BETEL project, then describe the BETEL physical and logical network as well as the router configuration and the protocol architecture. The shift/BETEL application will then be described, with a special emphasis placed on the technical difficulties met and the lessons learned. Finally, we offer some views on how the SHIFT architecture could be adapted in order to make efficient and economic use of the European ATM pilot infrastructure from July 1994.

II. BETEL project (background information)

The BETEL project (Broadband Exchange over Trans-European Links) is one of the 4 demonstration projects selected by the CEC / DG XIII following the DIVON (Demonstration of Interworking Via

1 CERN, 1211 Geneva 23, Switzerland
2 Broadband Exchange over Trans-European Links
3 Scalable Heterogeneous Integrated computing Facility

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III. BETEL platform

III.A. Router Configuration & Protocol Architecture.

Figure 1: BETEL network (physical)


The objective of DIVON, a one year program, was to stimulate the development of broadband communications in Europe by supporting demonstrations involving users located in different European States.

The total cost of the DIVON program was 7714 kEcu, with a CEC contribution of 4411 kEcu. The corresponding costs for BETEL were 2781 kEcu and 1264 kEcu.

BETEL was a fairly unique and extremely successful collaboration between 2 Telecom Operators (France Telecom and Telecom PTT Switzerland), manufacturers from the communications industry (Alcatel CIT and Cisco) and users from the research and education sectors namely, the European Laboratory for Particle Physics (CERN), the National Institute of Nuclear Physics and Particle Physics (IN2P3), the Swiss Federal Institute of Technology (EPFL) and the Eurecom Institute. The prime contractor of BETEL was Expertel, a subsidiary of France Telecom. The very nature of BETEL, a 1 year demonstrator project, made it impossible to extend the project beyond the end of January 1994, which was very unfortunate in many respects, as the users had just started to make use of the new network.

The BETEL platform interconnected FDDI rings of the four BETEL users, located in Geneva, Lausanne, Lyon, Sophia-Antipolis (Nice), in a fully meshed manner, via Cisco routers and ATM Terminal Adapters (TA) located at the user sites, 34 Mb/s optical fiber circuits, and an ATM Cross-connect located in France Telecom premises in Lyon.

The BETEL platform was operational from September 1993 until January 1994 and is believed to have been the first operational platform based on an international ATM network.
The services offered by the BETEL platform to the users are layered as follows:

- the LAN Interconnection service, denoted LANI,
- the Data Service over ATM, denoted DS,
- the ATM Transfer Service, denoted ATM,

according to the reference configuration shown in figure 3.

The LAN interconnection service is implemented in the Cisco router, acting as an inter-network relay. The Access Point to the service (LANI/AP) is located within the workstations connected to BETEL.

The Data Service is an SMDS\(^4\) like service. This connectionless data service is based on E.164 addressing. Although an SMDS provides valuable facilities like sender authentication, group addressing and address screening, these facilities were not available inside BETEL. The Data Service makes use of AAL 3/4 functions that are well suited to support a connectionless service over ATM. Given the small number of connections in BETEL, the connectionless service is provided as a "Connection Oriented Data Service (C0DS)" using direct ATM connections between the four sites, rather than a "ConnectionLess Data Service (CLDS)" using a connectionless data server. The Access Point to the Data Service over ATM (DS/AP) is located inside the Cisco router which uses the ConnectionLess Network Access Protocol (CLNAP) to invoke DS service functions. The DS service is supported by the ATM Terminal Adapter (TA) which uses the ATM transfer service to convey the data units into ATM cells.

The ATM transfer service offers the transparent transport of ATM cells through the ATM based network. It is structured in two levels, each of them being supported by a separate logical network, as follows:

\(^4\) SMDS stands for Switched Multimegabit Data Service and is a trademark of Bellcore
In order to guarantee the quality of service (QoS) of the technology used in BETEL and other first generation ATM switches, the maximum load of the ATM cells of (48+5):53 bytes each (i.e. 159 bytes) are necessary to convey a 64 bytes IP packet. With ATM, LLC_SNAP (8), CLNAP(32), AAL3/4 (8+4/44), ATM(5/48] which basically means that three ATM cells of (48+5)=53 bytes each (i.e. 159 bytes) are necessary to convey a 64 bytes IP packet. With the technology used in BETEL and other first generation ATM switches, the maximum load of the ATM link is limited to 80% of the transmission payload, in order to guarantee the quality of service (QoS) of ATM.
the individual VPs. In practice, taking into account all the overheads listed above, this means that the maximum bandwidth available to the IP user of the LAN Interconnect service cannot exceed 22 Mb/s for large packets (i.e. 9188 bytes), 20 Mb/s for medium size packets (i.e. 1000 bytes) and 8 Mb/s for small packets (i.e. 64 bytes).

IV. BETEL applications

The three BETEL applications, all using the Internet Protocol (IP), were:

- teleteaching/BETEL.
- paw/BETEL.
- shift/BETEL (distributed meta-computing).

PAW stands for "Physics Analysis Workstation" and provides a "packaged" environment to typical physics users, in order to ease the interactive analysis and visualization of physics data events.

PAW is extremely flexible in that it allows one to decouple the location of the CPU server (i.e. where the actual computation is performed), the location of the disk or tape server holding the data, and the location of the user (i.e. where the user's graphics terminal is physically located).

- shift/BETEL (distributed meta-computing).

Figure 5: shift/BETEL platform

V. shift/BETEL: A Meta-Computing Facility

V.A. SHIFT Overview

In order to exploit the cost/performance advantages of RISC processors and SCSI disk technologies, CERN has developed a new architecture called SHIFT as a substitute to conventional, mainframe based, batch job submission services.

The SHIFT concepts have been used to build a very large computing facility out of high power
UNIX workstations. All together, SHIFT, the Scalable Heterogeneous Integrated computing Facility, is a "multi-GIPS" (Giga Instruction Per Second) assembly of CPU servers from various manufacturers, namely DEC, HP, IBM, SUN and SGI, providing access to over 1 Terabytes of online disk space through disk servers and to the whole CERN tape library, part of which is under tape robot control, through tape servers.

V.B. shift/BETEL goals

A prime goal of BETEL was to identify and demonstrate distributed computing applications with sustained high I/O requirements over a high speed long distance link, without particular concern being initially given to the long term economic viability of these applications.

The SHIFT platform at CERN having been specifically engineered for intensive I/O bound jobs (tasks) it was extremely natural to attempt to run the SHIFT class of applications across the BETEL platform.

More specifically the goals of shift/BETEL were:

- to demonstrate distributed computing, with intensive Input/Output (I/O) requirements, over a high speed ATM/WAN connection.

- to prove that the SHIFT architecture, originally foreseen, although not constrained, to being used over high speed LANs, could also be applied over suitably fast (i.e. 8 Mbit/s minimum, 34 Mbit/s or higher speed) wide area links.

- to build a "meta-computing" facility providing nearly transparent access to a "distributed file store" including the magnetic tape libraries at CERN and IN2P3 (i.e. many Terabytes of data), in a location independent manner.

V.C. shift/BETEL functionality

The functionality of shift/BETEL was:

- batch jobs executing on a cpu server at IN2P3 could make use of disk or tape servers located at CERN and IN2P3.

- batch jobs executing on a cpu server at CERN could make use of disk or tape servers located at IN2P3 and CERN.

V.D. shift/BETEL adaptations

SHIFT uses a client/server model for accessing files. RFIO, the Remote File I/O system, is the name of this highly optimized I/O package.

Tape access for every SHIFT CPU and disk server is provided via a tape copy utility program, the Remote Tape Copy Utility (RTCOPY) which allows tape access across the network.

The main difficulty came from the fact there is no uniform name space for identifying the users at the different sites (i.e. CERN & IN2P3 in the BETEL case).

A user is defined as a triple \((\text{username}, \text{uid}, \text{gid})\), where \text{uid} is the Unix User-ID and \text{gid} is the Unix Group-ID.

The problem can be stated as follows:

- In the original RFIO implementation, file access is protected through a uniform user name space organization. A user \((U, u, g)\) must be the same on the client and the server machine.
With shift/BETEL and more generally with the use of inter-site RFIO, it is unlikely that the same user (U,u,g) exists at both sites or even designates the same person.

To make the problem worse, no "superuser" can obviously be trusted remotely.

The technical solution implemented in shift/BETEL is to perform RFIO operations through "mappings" of remote computers and users onto local user(s). The mappings are under control of the server site.

In addition, there were also problems specific to RTCOPY (Remote Tape Copy Utility) in order to make sure that the proper tape is mounted at the correct site. The solution chosen was to define a new flag (-Remote) to differentiate between local and remote tape operations, and to write a new server, such that different local tape servers may be used.

For example, at IN2P3 there was an interface to the local tape robot via the, so called, "zstage" facility, which was well proven and predated the installation of SHIFT. The use of "zstage" was therefore preferred to the other solution of installing an RS/6000 based, SHIFT tape server at IN2P3.
VI. A perspective on shift/BETEL

VI.A. full integration vs partitioned mode of operation?

One original goal of shift/BETEL was that the combination of shift/CERN & shift/IN2P3 would look to the users as "one meta-computing factory" whose resources could be accessed in a "nearly transparent and location independent manner". As it quickly became apparent that this goal was too ambitious, the effort was placed on interconnecting two separate SHIFT platforms rather than to make the two platforms appear as a single one.

In order to better understand the various options, let us quickly review the various elements from which a SHIFT platform or SHIFT sub-system is built:

- CPU server(s),
- Disk server(s),
- Tape server(s),
- Local or Wide Area TCP/IP Network.

Whereas the client and the server may well be co-located on the same system (e.g. CPU and Disk), they may also be physically remote and, in any case, the communication between the client and the server is done via the RFIO package, itself running on top of TCP/IP sockets.

The user is presented with a Batch Job Submission interface, called NQS, and the different set of CPU servers are grouped by Job Queue names.

In practice, every large group of users at CERN has their own set of CPU and Disk servers in a shared Local Network infrastructure (a mixture of FDDI rings interconnected via a Gigaswitch and a proprietary LAN from Ultra) provided by CERN. In addition, CERN provides access to the central tape library via a set of Tape Servers. One reason for decoupling the resources in this manner is that it
simplifies many organisational problems, in particular, the allocation of CPU time and Disk space on a
shared computing facility and it also allows CERN to optimize and to evolve the various building blocks
independently of each other.

shift/BETEL was therefore no different, namely: yet another SHIFT sub-system, this time at another
location than CERN, with shared access to a common networking infrastructure, namely that of BETEL,
and to Tape servers at both sites.

Another possibility would have been to augment one subsystem with the resources of the other centre
(e.g. 2 CPU servers, 2 Disk servers in CERN, 2 CPU servers, 2 Disk servers in IN2P3, plus shared access
to the Tape servers at both sites). This "full integration scenario" was not retained because it implied a
more expensive hardware deployment and, in particular, the availability of a test platform at CERN
which was not the case. It also implied that NFS, used locally to mount the home directory of the users,
be also available between CERN and IN2P3 which, for security reasons, was not the case.

The "full integration scenario" has many attractions but is probably not realistic as wide area links
are, at present, very expensive in Europe and there are no signs that this state of affairs will change
anytime soon! Furthermore, even a full speed 34 Mb/s BETEL link would have quickly become a
bottleneck, the right speed being more in the range of 140 or 155 Mb/s. There are also many political
constraints that would make the sharing of resources paid out of different national funds and, sometimes,
for different purposes than pure HEP a rather risky exercise!

VI.B. partitioned vs periodic reservation mode of operation?

In the "partial integration (i.e partitioned) mode of operation" used in shift/BETEL the only shared
resources, in practice, were the tape servers, although the SHIFT disk servers at CERN were also
accessible. This meant that once a remote tape had been staged across the BETEL link, I/O intensive
disk operations between the local CPU and Disk servers would then go on for some hours before the
need to stage another remote tape might occur again.

In order to overcome the potentially very low utilisation of very expensive wide area links, we rather
suggest to explore another mode of operation having the capability to make use of periodic reservation
mode, i.e. to queue tape requests until the time where the network becomes available and then transfer
as many tapes as quickly as possible, in order to minimize communication costs. Ideally, dynamic
reservation mode should be available, which implies some form of signalling with the network.

It is worth noting that the proposed mode of operation bears some similarities with the one used in
the CHEOPS\textsuperscript{5} project, despite the fact that the network platforms, the applications and the protocols
are quite different. What is proposed here is variable allocation of bandwidth between a minimum of, say
2 Mb/s, and a maximum of 20 Mb/s.

A variant of the partitioned mode of operation is to interconnect dissimilar platforms via a gateway,
with the advantage that the two platforms can evolve independently of each other but the disadvantage
that a gateway needs to be developed and maintained and that performance risks to be seriously degraded.

VII. Performance issues

A first concern was to identify the specific requirements of shift/BETEL from the underlying network
and the main problem addressed was whether the performance of standard TCP/IP implementations
would match the performance needed by shift/BETEL, in order to make such a deployment meaningful.

\textsuperscript{5} CERN & HEPnet project involving the use of 8 Mb/s switched channels on the European Space Agency
Olympus satellite for the dissemination of bulk physics data in Europe
A secondary concern was to foresee possible problems related to the use of TCP/IP on "high speed and long delay links" such as those that will be present in the context of the European ATM pilot\(^6\) and other similar public networking infrastructure where a hierarchical, therefore potentially sub-optimal, topology is preferred to a meshed topology derived from the actual user needs.

VII.A. Are the performances of standard TCP/IP implementations adequate?

There are particular problems related to the use of TCP on "high speed and long delay links" which have been analyzed by Van Jacobson from LBL\(^7\) and specific solutions have been proposed like the Extended TCP (ETCP), but also the Xpress Transport Protocol (XTP)[5] or the Cheops Data Protocol (CDP)[2] in the case of the Olympus satellite experiment at CERN.

TCP (Transmission Control Protocol) is a reliable transport protocol running over the IP (Internet Protocol) layer, a connectionless network layer. Over the years TCP has been improved such that it can operate in the rapidly evolving and complex Internet environment involving many "hops" and a mixture of slow and fast links (i.e. typically from 64 kb/s to 45 Mb/s). TCP was also designed with bandwidth sharing in mind so that, unlike UDP (User Datagram Protocol), no user is allowed to monopolize expensive resources for private use. In order to achieve these objectives "sliding window" and "slow start" algorithms have been implemented by which the "Round Trip Time" (RTT) of the "pseudo link" or path between the source and the destination hosts is measured and monitored so that the optimum size of the actual "window" (i.e. the number of unacknowledged bytes) can be determined and used. Many other refinements have also been proposed like: fast retransmit, fast recovery, extended windows (i.e. Extended TCP), however very few host TCP implementations do support these, yet!

VII.A.1. short vs long packets, store & forward vs pipelining

A paradox of "sliding windows" algorithms is that, in order to minimize the round-trip time and therefore the window size, short TCP segments would be preferable to long TCP segments which take longer to transmit. However, it is also well known that the resulting load on the end systems of generating many small segments rather than few long segments, is unacceptably high, hence the need for a trade off between long segments which are acknowledged slowly and small segments which would put too much load on the end systems and on the routers.

In the end, it seems that an MTU size of approximately 4 Kbytes used on both FDDI and SMDS is a suitable compromise. A related problem, however, is that standard TCP/IP implementations use a default IP packet size of 576 bytes when the source and destination hosts are not located on the same IP network, which is the normal case on wide area networks. Fortunately, some implementations allow us to define all subnets as being "locals" and/or to specify the MTU size for each destination which is an inconvenient but required way to bypass this problem until "dynamic MTU path discovery" mechanisms are more widely implemented.

There are several other dimensions to this problem, namely the effect of packet loss due to transmission errors, congestion in the routers and/or in the ATM switches. In the case of ATM, it has also been shown earlier than the mapping of IP packets over ATM cells was extremely inefficient for small packets and that packet sizes of, at least, 1000 or 1500 bytes were therefore recommended. Another ATM specific problem is that a single ATM cell loss entails the loss of the complete IP packet. Thus, a 1% ATM cell loss/drop rate and 100 ATM cells per IP packet might lead to 0% communication if the losses were

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\(^6\) A European wide ATM trial involving 18 PNO's and scheduled to start on July 1, 1994 for a minimum duration of 12 months.

\(^7\) Lawrence Berkeley Laboratory
evenly distributed!

Given the maximum theoretical size of 64 kbytes for the TCP window and a practical size of up to 32 or 56 kbytes, one can easily demonstrate that there are serious performance limitations on terrestrial fiber optic links operating at 34 Mb/s and above, over "not so long" distances, as shown in table 1 (propagation of 5 microsecond per kilometer assumed, i.e. 5 millisecond per 1000 kilometers). The TCP Round Trip Time (RTT) is the time it takes for a packet of size "p" to be transmitted at a given link speed and for the TCP Acknowledgment to come back.

The minimum window size derived from the RTT is:

\[(\text{link speed/8}) \times \text{RTT} \]

The basic RTT computation is:

\[2 \times \text{propagation delay} + n \times (\text{time to send packet of size } "p") + m \times (\text{time to receive 64 byte Ack}) \]

Where "n" is the number of significant hops on the forward path and "m" is the number of significant hops on the return path (typical values for n and m are 4 to 6 and 1). The end to end logical "link" is made out of a series of physical "segments" (e.g. Host to Router, Router to Terminal Adapter (DSU), Terminal Adapter to ATM Switch, etc), possibly involving Connectionless servers. A hop is considered to be "significant", that is contributing to the total delay, whenever there is little or no overlap between the sending and the receiving of a packet at both ends of a segment and when the time to generate a packet is meaningful with respect to the propagation delay. In other words, the propagation delay is mostly significant when long distances are involved (e.g. 1000 km or more), whereas the store and forward delay is mostly significant for large packets at low speeds and/or average distances (e.g. 4000 bytes, 10 Mb/s, 1000 km).

On BETEL significant differences (i.e factor 2) were noted between "the computed and the measured RTTs" whose effect would have been to make visible the "long fat network (LFN) syndrome" if the "diameter" of the network had been bigger. In practice, this was not a real issue; however, the need for a very careful engineering of the communications path between the various partners of a high performance networking application was clearly established. One known reason for the extra delays measured on BETEL was the fact that the ATM Terminal Adapters were functioning in "store and forward" rather than in "pipe-lining" mode, i.e. with no overlap between the receiving of an IP packet and its segmentation into ATM cells.

It is feared that this problem may become untractable on public infrastructures, e.g. that of the European ATM pilot, where the network topology is not directly derived from the needs of the users (e.g. the distance between Geneva and Lyon will become 1500 km instead of 200 km because of a detour via Zurich & Paris) and where many connectionless servers may be involved whose likely effect may be to further increase the number of "significant store and forward hops" and therefore the real RTT.

<table>
<thead>
<tr>
<th>MTU size (bytes)</th>
<th>effective speed</th>
<th>packets per second</th>
<th>Computed RTT (misecond)</th>
<th>min. window size (bytes)</th>
<th>max. TCP perf.</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>8 Mb/s</td>
<td>15625</td>
<td>20.1</td>
<td>20100</td>
<td>100%</td>
</tr>
<tr>
<td>512</td>
<td>18 Mb/s</td>
<td>4394</td>
<td>21.5</td>
<td>48375</td>
<td>100%</td>
</tr>
<tr>
<td>4000</td>
<td>21 Mb/s</td>
<td>656</td>
<td>29</td>
<td>76125</td>
<td>84%</td>
</tr>
</tbody>
</table>

Table 1: Maximum TCP performance for 34 Mb/s SMDS/ATM link over 2000 km distance
VIII. shift/BETEL results and experiences

The main result of shift/BETEL was that SHIFT could indeed work in a distributed manner with NO visible degradation to the end user.

One of the major difficulties met in shift/BETEL was the use of a production environment on the CERN side, which essentially precluded the use of "state of the art" solutions like Extended TCP (ETCP) on those platforms where this could have been feasible (e.g. Silicon Graphics) and also made the gathering of reliable measurements extremely difficult.

The value of a pilot project is to gain experience and to possibly uncover unforeseeable difficulties early enough, it would have been a big disappointment, in fact, if no lessons had been learned from the real scale deployment of shift/BETEL. Indeed, problems have been found at many levels which reinforced our belief that piloting of networking applications is essential even when the speeds appear to be fairly commonplace.

Here is a list of the problems encountered:

- SHIFT hang up.
- SHIFT lock/step mechanisms.
- stability of FDDI ring.
- Cisco throughput in SMDS mode.
- Alcatel ATM Terminal Adapter throughput.

At the end of the project all problems had either been resolved or, at least, well understood with bypasses available.

The only real disappointment to report is that, because of the unexpected series of problems mentioned above, our original expectations that shift/BETEL could be turned quickly into an "experimental production facility" did not really materialize.

IX. Conclusions

What initially appeared to be a fairly conservative project turned out to be an extremely challenging one and posed many technical problems, some of which have still not been completely resolved. The lifetime of the project was definitely too short and it is therefore our hope that "BETEL like" projects will continue in 1994 and beyond 1994, so that some unexplored aspects of shift/BETEL (e.g. multipoint mode, use of periodic reservation mode, real user needs, etc) can be studied in more detail and that new applications (e.g. distributed computing and multi-media) can also be piloted over real broadband networks.

The style of cooperation seen in the BETEL project is not new in the USA, where one frequently sees Telecom Operators, manufacturers from the Information Technology and Communications Industry, and academic and research institutions collaborate in testbeds (e.g. Gigabit testbeds), but has been very rare in Europe. We strongly hope that this trend will change and we are placing many expectations on the European ATM pilot that is due to start operating from July 1st, 1994 and which can be seen, in

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8 Internal Betel report by J.M. Jouanigot, part of which may be found in BETEL Deliverable D02, "Test Report"

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some ways, as the successor of BETEL, though on a much wider geographical scale and with many more users, but without substantially more bandwidth overall and therefore much less bandwidth per set of users, unfortunately!

X. Acknowledgements

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XI. Abbreviations

AAL: ATM Adaptation Layer
ATM: Asynchronous Transfer Mode
B.UNI: Broadband User Network Interface
CLNAP: ConnectionLess Network Access Protocol
CPE: Customer Premises Equipment
IP: Internet Protocol
HSSI: High Speed Serial Interface
LAN: Local Area Network
LLC SNAP: Logical Link Control Sublayer Network Access Protocol
RTT: Round Trip Time
SAR: Segmentation And Reassembly
TCP: Transmission Control Protocol
VC: Virtual Channel
VCC: Virtual Channel Connection
VP: Virtual Path
VPC: Virtual Path Connection
WAN: Wide Area Network

XII. References

[1] Jalal Samain et al, Overall Definition of BETEL Demonstrator (BETEL-D01)
[5] Copies of XTP Protocol Description may be obtained by contacting Protocol Engines, Inc.

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XIII. Author Information

Olivier H. Martin graduated from Ecole Superieure d'Electricite (SUPELEC) in 1964 and joined CERN, the European Laboratory for Particle Physics, in 1971, where he became leader of the CDC 7600 and IBM software support teams. He is a member of the communications group since 1983 and has been in charge of the external networking team since 1989.