

The AT&T Switching Evolution Challenge

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The 1B processor represents one of the largest single investments in new network technology ever made by AT&T. The effort to make the 1B processor a reality encompassed organizations throughout AT&T, requiring, from all involved, the highest levels of commitment and teamwork to meet an aggressive schedule. This paper provides an overview of the scope and complexity of the entire project, from requirements through field deployment. It focuses on the significant role that the 1B processor plays in the long distance network, the stringent reliability requirements imposed on it, and the technical and organizational challenges that were successfully met. Also included are a high-level summary of the 1B processor's capabilities, and a discussion of the business directions that helped to define them. Finally, this paper sets the stage for the detailed papers that follow, providing perspective on how each effort fits into the overall scheme.

Introduction

The backbone of the AT&T switched network is the 4ESS™ switch. This switch and the 1A processor that controls it have served the network extremely well since 1976. However, increases in both traffic levels and call complexity eventually demanded an increase in capacity. In the late 1980s, network planners realized that the growth of basic traffic, a shift in traffic mix toward calls that required more real-time computer resources, more complex routing and billing schemes, and the desire to incorporate new technology would require more processor real time and memory, exceeding the availability of those resources in the 1A processor. It was clear that a vehicle was needed to support new network technology and increased service needs.

Several alternatives were studied, including:

- Adding more 1A processor-based 4ESS switches to the AT&T switched network,
- Adding adjunct processors to reduce the load on the 1A processor,
- Implementing separate business unit net-

- works for specific types of traffic,
- Developing a completely new switch from the ground up,
- Replacing the entire 4ESS switch with a 5ESS® switch, and
- Developing a new central processor for the existing 4ESS switch.

Only the last alternative appeared to be both feasible from a business standpoint and technically adequate. Subsequently, local exchange carriers (LECs) that have a 4ESS switch also found this approach highly valuable. Their purchases of the new central processor in the competitive marketplace confirm that this option is an attractive value.

A number of advantages could be gained by taking this approach. The 4ESS switch is feature rich as a result of heavy past investment in software development. Replacing the central processor allowed this large embedded software base, as well as much of the embedded capital base, to be reused. It also provided more memory, faster real-time performance, and a means for supporting new technology in the future.

Because only the central processor was being replaced, the development and deployment could be done on a reasonable time scale, providing relief to the network before 1995, when the real-time problems and lack of sufficient memory were expected to become critical. These issues are discussed in detail by C. E. Betta et al. in "The Evolution of Switch Intelligence: An AT&T Network Perspective."

To support the continued introduction of new features, the new central processor—christened the 1B processor—was designed to provide twice the memory and 2.4 times the real-time capacity of the 1A processor. It included not only a path for evolution to a 32-bit processor and the ability to expand the memory, but also a high-speed interface that can accommodate adjunct processors. This interface makes evolution of the switch possible in areas such as distributed processing, service creation, and local databases. The 1B processor's central control implements the 1A processor's instruction set in a new design, which includes a three-stage instruction execution pipeline. This allows simultaneous execution of segments of three different instructions, increasing the speed of the processor's operation. The central control of the 1B processor is a fully duplicated design that can detect faults by using in-step instruction matching. The memory subsystem is also fully duplicated and can be configured in 1-megaword units that are self-powered and independently configurable.

The central processor is the "brain" of the 4ESS switch. Application software running inside the central processor controls all call connections, collects data for billing, allows subscribers to access special features, and monitors the general health of the switch. If a fault occurs, the central processor collects data, reconfigures the switch to maintain service, and generates requests for maintenance. The complexity of these functions made replacing the 1A processor with the 1B processor a risky activity. The entire project, from development through field deployment, demanded the highest level of dedication and teamwork from many organizations spread across AT&T.

The Challenges

The 1B processor project represents one of the largest single investments in new network technology ever made by AT&T. The project encompassed organizations throughout AT&T, which presented many challenges in achieving cooperation despite organizational boundaries

and different local cultures. The deployment schedule was faster than for any previous product. The reliability requirements were extremely stringent. Taken separately, each issue was enough to make the project a risk. Taken together, these issues made the ultimate success of the project an amazing achievement.

Aggressive Schedule. After an early prototyping phase established feasibility, the plan for the entire project was finalized in 1990. It allocated four years to developing and testing the 1B processor, and one year to deploying it in 134 AT&T central offices and several non-AT&T LEC offices. This deployment schedule was three times faster than those used for any previous product, with four offices cutting over on a typical weekend. The four-year development and testing interval required concurrent engineering of hardware, software, and documentation.

Generating a set of system requirements for the 1B processor was a critical step in the early stages of the process. These requirements served both as a specification for hardware and software development and as a guideline for product verification. In addition, they set customer expectations for 1B processor performance. To reduce the overall project interval, the generation of these specification documents overlapped the hardware and software development processes. The challenges encountered in accomplishing this initial step under intense scheduling pressure are described by E. Baral et al. in "Requirements for a Brain Transplant for AT&T's New 1B Processor."

High Reliability. The reliability objective for the 1B processor can be simply stated: The 1B processor should be at least as reliable as the 1A processor. Complicating this objective was the fact that the 1A processor had been tuned to reach this outstanding level of reliability over a period of 15 years of service. The 1B processor was expected to achieve that same level of reliability by the end of its deployment phase—one year after its first office application. This general objective translates into specific requirements for system reliability, hardware reliability, software reliability, and procedural reliability. The intent of the requirements is to ensure that introducing the 1B processor into the AT&T long distance network is transparent to customers. These requirements called for an intense focus on reliability during the design and development stage of the project. D. C. Dowden et al.

describe the design and development effort required to achieve these reliability goals in their paper "Improving on the Best: 'Like a 1A, Only Better.'"

Because of the size and complexity of this project, extensive testing programs were executed to verify that customer requirements were fulfilled. In particular, careful attention was paid to demonstrating that software and procedural requirements had been met. The scope of the testing effort and the strategies used to test such a large platform effectively are described in detail by M. A. Hillis et al. in "An Improved Approach to Product Quality Through Testing."

Meeting the hardware requirements necessitated more testing in the factory than has ever been done for a system product. Stress for life (STRIFE) testing, in which the entire system is tested under extreme conditions to determine design limits, was performed early in the development program. Individual circuit packs underwent environmental stress testing as part of the circuit pack functional test. This aggressive testing involved temperature cycling from -20°C to $+80^{\circ}\text{C}$ while field-generic software was being run. Every circuit pack in the 1B processor was tested this way. After each 1B processor was completely assembled, but before it was shipped, a final factory systems test was performed at $+50^{\circ}\text{C}$. In their paper, "Manufacturing of the 1B Processor," L. A. Flynn and T. M. O'Leary describe these manufacturing challenges and how they were met.

Project Management and Staff Issues. Because of the project's sheer size and the complexity of its schedule, project management for the 1B processor project was a great challenge. The intense level of activity caused by the short overall schedule and the necessarily rapid deployment of the 1B processor flowed through the entire product realization process, affecting each one of the areas in turn. Managing this project successfully required many aids, including extensive staff training and the use of Best Current Practices and quality gates. Formal audits were made repeatedly, including three management audits in 1990, a Switching Architecture Review Board audit, one management audit in 1991, and one manufacturing audit and one deployment audit in 1992.

Dedicated teams were assigned separate functions, with individual departments focusing on either 1B processor development, manufacturing, testing, or documentation and training. While this helped to foster a

sense of ownership for each function, it increased coordination and communication problems. These teams were new and formed specifically for the 1B project, but they drew, as much as possible, from staff with relevant experience. One common thread running through the whole project was customer involvement. Customers from the Network Services Division were members of all teams and participated as equal partners in all decisions.

The number of separate dedicated teams could have become an insurmountable barrier if not for the strong executive support shown for this project. This support was manifested as executive advocates, adequate funding, and a determination to prevent interorganizational issues from getting in the way of overall project accomplishments.

Technical Issues. The major technical issue faced in the 1B processor project was the requirement that the 1B processor be "like a 1A." System architects chose to implement the 1A instruction set in new hardware to preserve the 1A assembly language code. When the 1B project was begun, most of the experts who had developed the 1A processor 15 years earlier were gone. A large effort was devoted to understanding what the 1A processor actually does, so that those functions could be duplicated in the 1B processor.

Recruiting trained software staff to work on the project was difficult because the software development environment and programming languages used in the 1A environment contained technology unique to the 4ESS area of AT&T. New staff members could not be expected to contribute quickly. In fact, it took from six months to a year to train software developers who were added to the project.

Hardware design was made more complex by a decision to use established, proven technology to lower the reliability risk. The technology selected—medium-scale integration/small-scale integration silicon implementation with through-hole assembly processes—not only restricted the designers' choice of components, but also made it harder to achieve the technical improvements that the 1B processor was designed to provide. Without improvements such as increased call processing capability, extendable memory spectrum, and the ability to add adjunct processors, the 1B processor was not a good investment. The hardware development community had to walk a fine line to meet these technical challenges

within the chosen technology universe. D. C. Dowden et al. also discuss these technical issues in their paper.

Risk Management. One of the most difficult challenges faced during this project was risk management for the long distance network. Deploying the 1B processor involved installing and retrofitting the new processor in a live, fully operational 4ESS switch, with no interruption of service. The actions taken to ensure that the 1B processor would be deployed flawlessly throughout the network are described by G. S. Bullard et al. in "1B Processor Deployment: Leading the Way to Flawless Execution."

The Successes

The project plan, written in 1990, established a series of *quality gates*, significant milestones spanning the entire project, from requirements to field deployment. AT&T's Network Services Division and AT&T Network Systems thoroughly reviewed major milestones to ensure that detailed requirements for each milestone were satisfactorily met. All milestones were indeed met within the prescribed schedule. In fact, the final review was held several weeks ahead of schedule, a reflection of extremely high quality and customer satisfaction.

Field deployment of the 1B processor has proceeded smoothly according to the planned aggressive schedule. As many as six 1B processors have been brought into service in the 4ESS network in a single weekend, with few calls lost. The number of problems encountered was so small that the cutovers continued even during the peak holiday calling season, a time when the long distance network is normally untouched.

With most of the 1B processor installations completed, the reliability data collected indicates that the extensive attention focused on this area has paid off handsomely. The reliability requirements specified in the feature specification document have been exceeded. The performance of the 1B processors now in service is better than that of the embedded base of 1A processors that have been in the field for 15 years.

These extraordinary achievements in schedule and performance are a tribute to the men and women in many AT&T organizations who worked so diligently to deliver the 1B processor, from requirements definition to field deployment. Taken together, the papers on the 1B processor in this issue provide an in-depth look at how the many challenges were met.

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