The Evolution of the 4ESS™ Switch

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On January 17, 1976, the first 4ESS™ switch was placed into service, culminating the single largest switch development ever undertaken in the Bell System until that time. When it was introduced, the 4ESS switch was the largest high-capacity digital switch in existence, capable of terminating 107,520 trunks and completing over 500,000 calls per hour. During the next 18 years, the 4ESS switch played a pivotal role in enabling the emerging U.S. long distance market to grow into today's $60 billion industry. The hallmark reliability and capacity of the 4ESS switch set the standard for digital switching. Since then, neither technology nor service needs have stood still. Although the classic digital switch architecture pioneered by the 4ESS switch has passed the test of time, every major subsystem within the switch has gone through one or more technology upgrades to accept new features and reduce costs. This paper describes the evolution of the 4ESS switch, how our customers' investment has been protected, and how new features have been added by selectively upgrading 4ESS switch subsystems.

Introduction

Engineers often dream about designing a new switching system from a clean slate. In reality, however, our customers cannot afford to replace their large capital investment in switching for technological reasons alone. Instead, they (see Panel 1) would like to protect their investment by choosing incremental upgrades. This strategy allows the network provider to adapt the existing network infrastructure to meet the ever-increasing feature and technology needs of the business.[1] The 4ESS switch has evolved[2] to meet these needs in a cost-effective, structured, and well-planned manner.

System Overview

The 4ESS switch[3] is a feature-rich, high-capacity toll and tandem service node used by both interexchange and local exchange carriers. Figure 1 shows a typical network architecture using the 4ESS switch. The classical architecture of the 4ESS switch, shown in Figure 2, includes three main building blocks: the switching processor platform, the switching fabrics platform, and the customer interface platform.

The switching processor platform contains a custom uniprocessor central controller (the 1B processor) supported by a number of special-purpose adjunct processors. The entire processing system is the central intelligence of the system, providing:

- Overall call control;
- Call signaling processing;
- Overall operations, administration, maintenance and provisioning (OAM&P);
  - Craft maintenance;
  - Craft control interfaces;
  - Call data collection;
  - Operations Support Systems interfaces for call-detail reporting and controls;
  - Administration of the call service database;
  - Provision of routing, trunking and call services;

- Overall system integrity;
  - Audits; and
  - System initialization.

Software routines in the 1B processor determine which types of service will be provided, and interface with both the customer interface platform and the switching fabrics platform, described later. The 1B processor also handles overall maintenance for both the switching fabrics platform and the customer interface platform, as well as software audits and system integrity functionality. The *common network interface* (CNI) *ring* is the interface for various common channel signaling links (such as Common Channel Signaling 7 [CCS7] and Q.931 Integrated Services Digital Network [ISDN]). (See Panel 2 for definitions of abbreviations, acronyms and terms.) Call-related signaling received over these links is forwarded to the 1B central controller for processing. The 3B20 processor[4] handles the CNI ring administration, call billing, formatting, disk backup, and general input/output functions for the switch.

As Figure 2 shows, the *switching fabrics platform* contains the space-division *time multiplex switch,* which interconnects many time slot interchange units. The primary digital trunk interface to the switch is through T1 (24-channel) trunks. *Digital interface* units demultiplex T1 trunks to digital signal level 0 (DS0) format and provide basic bit-oriented and in-band signaling functions. They also translate the 64-kilobit-per-second (kbit/s) DS0 information (either voice or data) into the format required by the core switch fabric. The switching fabrics platform includes a *network clock,* to keep the switch fabric synchronized with the network, and various signal processors that enable in-band signaling and system maintenance and control.

The switch fabric is managed by commands received from the switching processor platform. For example, as soon as feature control programs determine the routing number for a call, real-time network routing routines in the switching processor platform select the outgoing trunk to be used for the call. Given the incoming and outgoing trunks, the switching fabrics platform can be instructed to create a DS0 path through the switch fabric to complete the call.

During a call, the *customer interface platform* enables the switching processor platform to interact with end customers. It does this using traditional capabilities, such as touch-tone reception and announcements, and newer capabilities, such as automatic speech recognition. The customer interface platform contains a high-capacity, fault-tolerant, fully switch-integrated Service Circuit System, and an Announcement Administration Processor that remotely records, verifies, and deletes announcements on the Service Circuit System.

Panel 1. 4ESS Switch Customers
Ameritech
AT&T Communication Services
Bell Atlantic
Bell South
GTE
Korea
NYNEX
Pacific Bell
Rochester Telephone
Southwestern Bell
Taiwan
UNITEL
US West

Evolution of the Switching Processor Platform

The switching processor platform requires three basic resources:
- Real-time functioning for call processing and billing data processing;
- Memory for call-related data and service databases; and
- Input/output ports and bandwidth to support signaling links and OAM&P links to Operations Support Systems.

Total switch downtime for all causes cannot exceed three minutes per year per switch, so all processing resources must be extremely fault-tolerant. In the early years, these processing needs could not be met cost-effectively through standard commercial processing components.

As such, the starting point for the processor evolution was the 1A processor, a high-capacity, custom-designed uniprocessor that has proven itself in both the 4ESS switch and 1A ESS™ switch product lines. Although the 4ESS switch with the 1A processor has an advertised capacity of 570,000 completed calls per busy hour, its actual performance often exceeds its advertised capacity. The number of calls completed has exceeded 800,000 per hour (with attempt rates approaching 1,200,000 per hour)

Panel 2. Abbreviations, Acronyms, and Terms

A-I-Net™ — Advanced Intelligent Network
ATM — asynchronous transfer mode
CCS7 — Common Channel Signaling 7
CNI — common network interface
DS0 — digital signal level 0
ISDN — Integrated Services Digital Network
OAM&P — operations, administration, maintenance, and provisioning
ODA — Office Data Administration
ODMS — Office Data Administration System
SONET — synchronous optical network

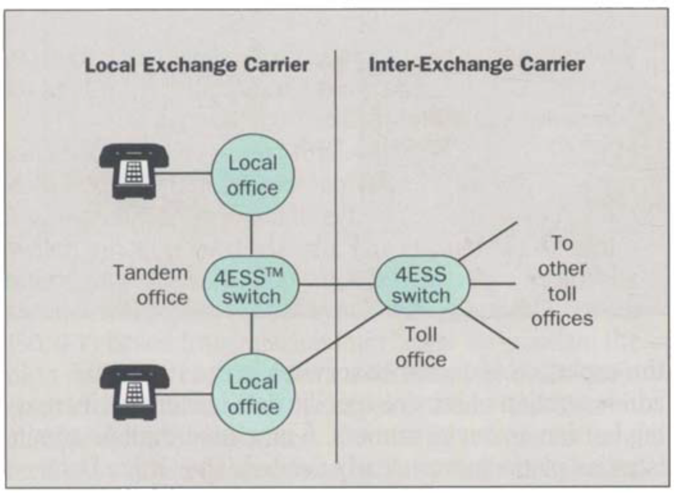


Figure 1. Typical network architecture using the 4ESS switch.

in times of natural disaster, such as floods or earthquakes. Even so, with the ever-increasing complexity of call services, some customers using the 1A processor were going to experience real-time exhaust in the early 1990s.

Call-processing real time can be negatively affected by many factors, including the following:

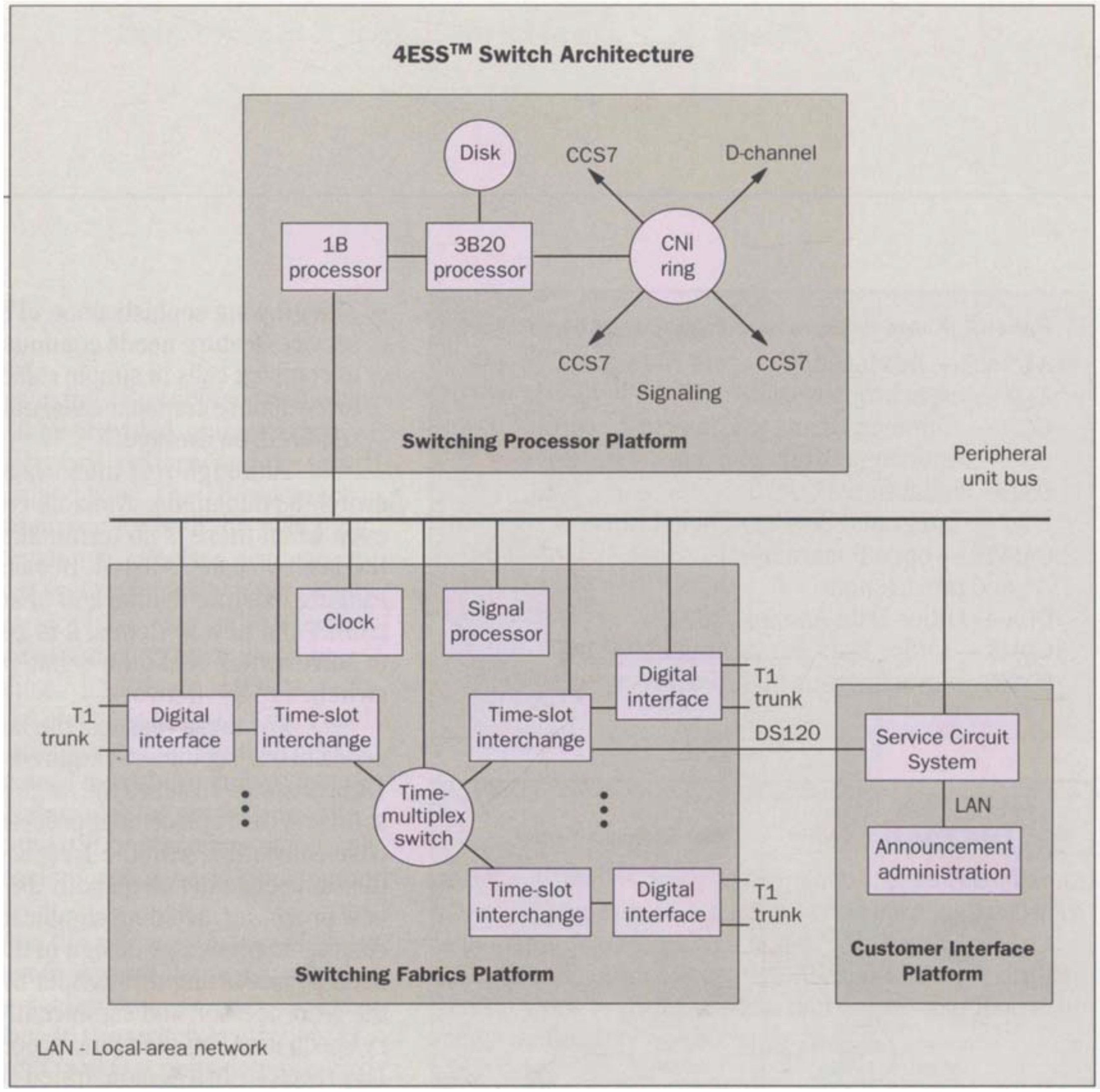
- Growth in call traffic requires growth in the number of trunk terminations and in the number of calls that can be processed during the busy hour.
- New call features implemented on the switch add code to the base call-processing routines, increasing the amount of real time needed to process calls.
- The growing sophistication of end customer service/feature needs continually increases the ratio of complex calls to simple calls. As the call mix tends toward more complex calls, more switch real time is required, on average.

Although real-time usage is a function of switch terminations, available real time will decrease even when there is no termination growth, owing to the last two causes listed. Because of the cost of rearranging existing trunks and of adding new interswitch trunks and new switches, it is generally not economical to solve switch real-time exhaustion by adding more switches to the network.

For these reasons, the increasing real-time needs of our customers required a replacement for the 1A processor. To serve the large existing base of switch software, the replacement processor had to be object-code-compatible with the 1A processor. This would allow the same code to run on both the 1A processor and the new processor, avoiding significant software costs. The custom uniprocessor design of the 1B processor met this need by increasing throughput by 2.4 times more than the 1A processor, and significantly increasing the memory spectrum. The switching processor platform with the 1B processor has demonstrated support for well over 1,000,000 busy-hour calls, even when a high percentage of the calls are complex. In addition, the 1B processor's high-speed interface bus allows it to interconnect efficiently with other high-performance, fault-tolerant processor systems. The first 1B processors were placed in existing 4ESS switches early in 1994.

While the 1B processor addresses the near-term call-processing and memory needs of the switch, it is not the final solution. Trends in traffic characteristics, call mix, and call feature complexity indicate that some customers will again exhaust call-processing real time after the year 2000. In the interim, the need for general processing resources in the switch will increase along with the new info-centric data technology needs of the network. These emerging processor, memory, and input/output needs in the switch can be most effectively met by adding modular, scalable processor resources to the switching processor platform. It is also desirable to take advantage of industry trends in processing capacity by using widely available processing components, such as real-time operating systems, input/output drivers, and software development tools. However, the stringent sys-

Figure 2.
Architecture of the 4ESS switch.



tem availability requirements for switching systems must not be compromised.

These processing needs can be met through incremental evolution of the switching processor platform. The first step in the evolution is the creation of a new multiprocessor high-reliability platform based on industry-standard hardware and software technologies. Using industry-standard components will reduce costs by taking advantage of existing hardware and software technologies. Once the high-reliability platform is connected to the 1B processor's high-speed interface bus, its multiprocessing architecture can be exploited and processing resources can be added as needed. By adding a small number of processor cards, existing functions can be ported to the new high-reliability platform environment. The significant increase in computer power available at the switch will enable it to offer network functions that were never possible in the past. Figure 3 shows the architecture of the current switching processor platform.

Basic call-processing capability did not complete the evolution of the switching processor platform. With the explosion of customer services in the 1980s, the administration of service-specific data became an increasing burden on our customers. A new, modern data administration platform was clearly needed. The Office Data Administration System (ODMS) is expected to be one of the applications that will use the high-reliability platform. The rule-based programming environment of the ODMS provides an integrated approach to data management. Its architecture also separates the user interface, data administration engine, and database interface into separate layers that can reuse applications in different environments. The user interface supports industry-standard graphical user interface windows and character-based applications. The database administration engine performs the data manipulation and applies appropriate integrity checks. The database interface binds the system to the appropriate database media.

The ODMS uses industry-standard hardware technology, operating systems, and software development environments—hardened for increased reliability—to provide the fastest time to market and best price/performance points. The system is specification-driven to directly complement new data structures and rules from the defining specifications in an application-oriented language.

The first application of this technology, an off-line Office Data Administration (ODA) product, provides new and evolved office databases for each generic software release. This ODA application will be reused for data administration in the switching processor platform.

Evolution of the Switching Fabrics Platform

In sheer physical size and cost, the switching fabrics platform dominates the switch. Although there is only one central 1B processor, there can be as many as 129,000 transmission interfaces (trunks). The original 4ESS switch transmission interface was upgraded once in the 1980s. In the early 1990s, the development of a new expanded time-slot interchange offered an opportunity for another significant cost reduction.

The expanded time-slot interchange is a new switch fabric component that replaces both the digital interface and the time-slot interchange, providing a new, high-speed transmission interface and a time-division switch function for the fabric. The expanded time-slot interchange initially supports a DS3 interface for trunks. Later, it will support other synchronous optical network (SONET)-based transmission interfaces. To maintain the high reliability required for a switching fabric, the main control and the fabric of the expanded time-slot interchange are fully duplicated. The DS3 interfaces are protection switched against failures. A DS3 transmission format provides 672 DS0 channels. Each expanded time-slot interchange can support as many as six DS3 interfaces, comprising 4032 DS0 channels. As many as 32 expanded time-slot interchanges can be configured within a 4ESS switch, increasing the switch's termination capability from the original 107,520 to 129,024 channels. Termination capacity can also be expanded incrementally. Adding one expanded time-slot interchange to a switch will increase the number of available DS0 terminations by 4032 and will add 672 terminations to the original 107,520 switch termination limit.

The highly integrated design of the expanded time-slot interchange reduces costs, power, and floor space. In addition, the high-speed transmission interface and capability for integrated echo cancelers can eliminate significant capital investment in associated transmission equipment.

The basic switch fabric in the expanded time-slot interchange is twice as large as its predecessor, the time-slot interchange, allowing it to support such features as per-call switched access to in-line voice/data processing systems without using costly external switch terminations. For example, echo cancelers can be integrated into the expanded time-slot interchange and connected to its switch fabric. The expanded time-slot interchange can then switch to echo cancelers as needed, without reducing the number of terminations available for trunks. This switching capability makes it easy to remove hardware for routine testing, and to reconfigure around echo canceler failures quickly and efficiently.

Technology in the early 1990s also provided service-related opportunities. In particular, digital signal processors were becoming fast enough to operate on multiple speech channels in real time, allowing per-channel digital signal processing functions to be incorporated cost-effectively. Voice enhancement features can now be provided to the end-customers on a network basis.

The *network clock* performs timing for the 4ESS switch time-division network. The accuracy of the network clock determines how long the switch can be isolated from the incoming synchronization signal before transmission problems begin to occur. To maintain accurate, available timing information, the oscillator in the network clock has been quadruplicated and the existing quartz-based oscillator has been upgraded with a disciplined rubidium oscillator. Both the existing oscillator and the disciplined rubidium oscillator are classified as stratum 2 oscillators. However, the disciplined rubidium oscillator is at least ten times more accurate than the quartz-based oscillator, as measured by frequency-drift rate from nominal. The disciplined rubidium oscillator limits the frequency drift during isolation from the incoming synchronization signal, greatly improving the performance of the 4ESS switch. The disciplined rubidium oscillator also has significant maintenance advantages over the current quartz-based oscillator. Its superior temperature stability enables it to be brought into service significantly faster than the quartz oscillator, and it requires no routine adjustments to maintain its accuracy.

The time-multiplex switch is the core space-division *centerstage* (i.e., the center stage of switching, which typically occurs in stages) for the 4ESS switching fabrics platform. It connects as many as 131,072 DS0 paths to as many as 32 expanded time-slot interchanges (or time-slot

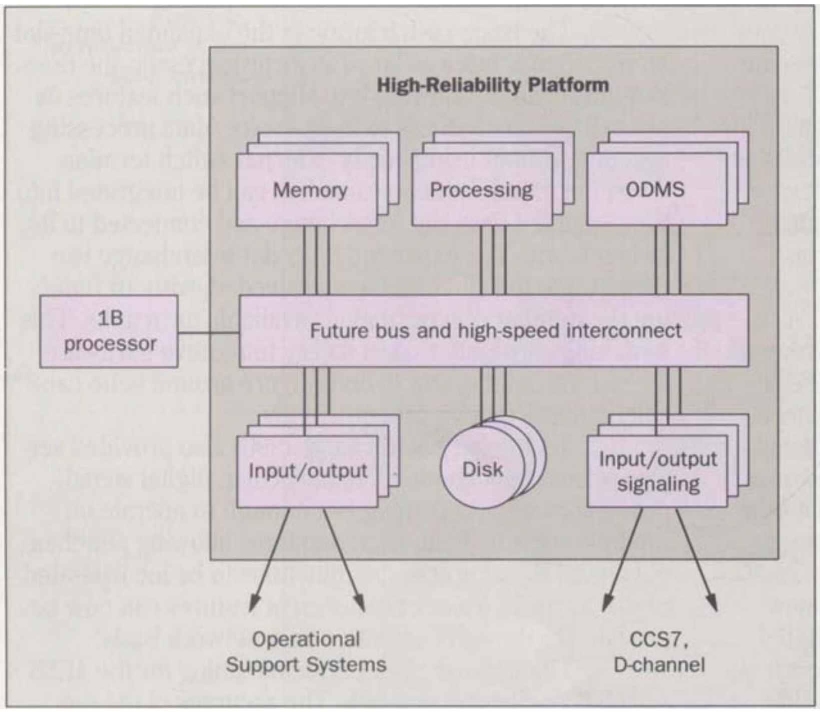


Figure 3. The current architecture of the switching processor platform.

interchanges). With no concentration on the edge of the fabric, the time-multiplex switch effectively limits the maximum number of switch terminations to approximately 129,000. The continuing growth in network traffic requires switches that are capable of terminating more than 200,000 DS0 trunks. Such large switches offer significant network cost advantages and minimize network routing complexity and OAM&P cost. To meet these needs, the switching fabrics platform must evolve to incorporate a new, high-capacity centerstage sometime after the year 2000. This new centerstage must not only satisfy the needs of the existing voice/data narrowband market, but should address the emerging technology needs of broadband ISDN and asynchronous transfer mode (ATM) switching. New services, such as Broadband Multimedia, and trends in voice/data network integration require a highly flexible switch fabric. By using a core centerstage capable of both circuit and ATM switching, the existing base of circuit-switched capital can be preserved while incorporating and integrating new ATM switching capabilities. Figure 4 shows the current architecture of the switching fabrics platform of the 4ESS switch.

Evolution of the Customer Interface Platform

In the early 1980s, end customers communicated with the system in the system's language, i.e., touch-tone tones and simple announcements. Today, systems must communicate with the end-customer in the end-customer's language, i.e., speech recognition and customized announcements of arbitrary length.

The Service Circuit System has general-purpose interactive service circuit ports that can be used by features that play announcements and/or collect digit information. Each port supports as many as 65,000 unique announcements that can draw from more than 1,500,000 seconds of announcement data. The length of an announcement can vary from 1 to 261 seconds. Half-second announcements are also supported to provide individual voiceback of digits or other short utterances. As many as 32 announcements can be concatenated to create a sophisticated, interactive message sequence.

This large announcement capacity demands a robust announcement administration. The Service Circuit System works with a fault-tolerant, network-wide *Announcement Administration Processor* to allow a work center within the central network to manage all the network announcements quickly and efficiently. The Announcement Administration Processor can record, verify, replace, delete, or exchange announcements on a Service Circuit System. To support fast updates, announcements are broadcast to all network switches using individual ISDN links. This enables a remote work center to update announcements for the entire network in near real time. The system's high availability also ensures that critical service announcements can be administered even in the face of network equipment failures.

Automatic speech recognition was originally used on the 4ESS switch via a specialized custom adjunct called the Network Services Complex, which accurately collects isolated digits embedded in speech. In response to a menu-oriented announcement prompt, for example, the end customer may want to indicate the choice "3" back to the network. This information can be sent to the

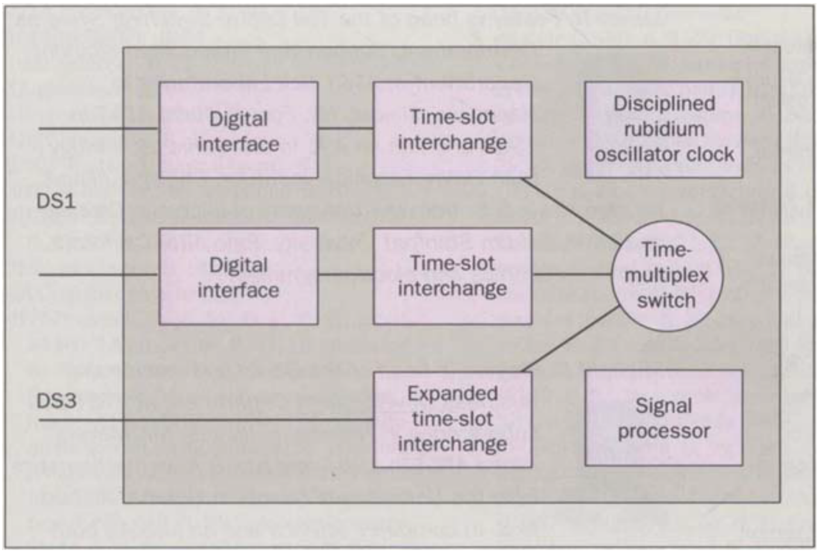


Figure 4. The current architecture of the switching fabrics platform.

switch by pressing "3" on a touch-tone phone. The automatic speech recognition system of the 4ESS switch would also recognize any voice response containing the word "three." This capability allows users to say such phrases as "number three, please" without confusing the recognition algorithm.

In 1995, this speech recognition capability will be integrated into the switch through the Service Circuit System. In addition to integration, the new, enhanced speech recognition platform will be designed to accept arbitrary vocabularies, connected-digit speech recognition, and such specialized functions as voice verification.

Putting It All Together

Added together, the evolution of the 4ESS switch results in a cost-effective, high-capacity, highly reliable, sophisticated call-switching capability. However, our customers need more than just building blocks; they need the ability to interconnect these capabilities easily to create revenue-generating features. The 4ESS switch offers our customers a platform for communication services. With the advent of AT&T Advanced Intelligent Network (A-I-Net™) advanced-services-platform capabilities[5] on the 4ESS switch, along with the integrated Service Circuit System, network providers can offer a wide range of custom-interactive announcement and routing features. Using A-I-Net-dialed number triggers, calls of various types can trigger the switch to query a service control point for customized features. The 4ESS switch is often strategically located in the center of the network, providing easy access to all customers.

Meeting the Challenges of the 21st Century

The 1B processor, with its extensible architecture, sets the stage for possible future phases of evolution. Toward the end of this century, there will be a growing need for call-handling capacity beyond that of the uniprocessor architecture of the 1B processor. The high-reliability platform will enable switching software functionality to migrate gracefully to a multiprocessor environment.

The high-reliability platform architecture will also accommodate new switching fabrics and new service applications as they arise. Ultimately, one can envision a multifunctional switching product using hardware and software components that are common to the industry and to other AT&T Network Systems Switching, Transmission, and Operations Support systems.

Summary

Life does not stand still; neither does technology, nor the needs placed on a system design. Responding to these needs for the benefit of our customers has been the driving force behind the ongoing evolution of the 4ESS switch. Each major element of the switch has been upgraded: the switching processor platform with the 1B processor; the switching fabrics platform with the expanded time-slot interchange; and, the customer interface platform with the Service Circuit System. Alive and well in 1994, the 4ESS switch is positioned for a robust life in the next millennium.

Acknowledgment

The authors gratefully acknowledge the many individuals who have contributed to making the 4ESS switch a success over the years. We extend our thanks both to our customers, who have worked closely with us to evolve the switch to meet their needs, and to the AT&T 4ESS development organization, which has toiled endlessly to fulfill these needs. We thank them all.

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