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The 5ESS *Switching System:*

Architectural Overview

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This paper presents an overview of the *5ESS*™ system architecture. The administrative, communications, and switching modules are described, together with an overall view of the software architecture. Operations and maintenance aspects and a short discussion of evolutionary trends are covered.

I. *5ESS* SYSTEM ARCHITECTURE

The *5ESS* system architecture was conceived to satisfy the goals set forth in the introductory paper.[1] This architecture incorporates a combination of distributed and centralized control to produce a robust system that will meet present and future switching needs.

The hardware architecture, shown in Fig. 1, has three major components:

- An Administrative Module (AM),‡ which provides systemwide administration, maintenance, and resource allocation.
- A Communications Module (CM), which provides a hub for distributing and switching voice or digital data, control information, and synchronization signals.
- One or more Switching Modules (SMs), which provide local switching and control functions, and the interface to subscriber lines and interexchange circuits.

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‡ Acronyms and abbreviations used in the text are defined at the back of the *Journal*.

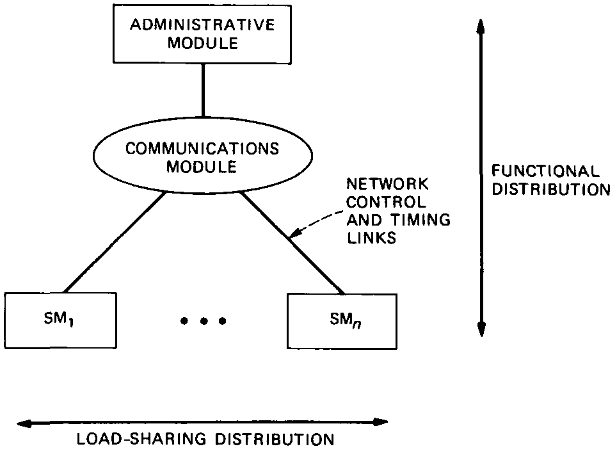

Fig. 1—*5ESS* system distributed architecture.

The following sections describe the functions of these subsystems and their interrelationships. In addition, they discuss the Remote Switching Module (RSM) and the subscriber carrier system.

1.1 Administrative module

The AM provides the system-level interfaces required to operate, administer, and maintain the *5ESS* switch. It performs functions that can most economically be done globally, such as common resource allocation and maintenance control (see Fig. 2). For reliability the Administrative Processor (AP), currently an AT&T 3B20D computer (see Ref. 2), is fully duplicated, and the two processors work in an active/standby configuration. In normal operation the active processor has control and, at the same time, keeps the data in the standby up to date. Thus, when a fault occurs in the active processor, the standby is switched into service with no loss of data.

The AM performs many call-processing support functions, including systemwide craft maintenance access, diagnostic and exercise control and scheduling, software recovery and initialization, and certain fault-recovery and error-detection functions best done on a centralized basis. Within the AM there is error-checking circuitry for detecting and isolating faults. The AM also performs administrative functions and provides software access to external data links and to disk storage.

Today the call-processing functions of the AM consist of routing and resource allocation. Routing involves the determination of the SM on which the terminating line or trunk appears and the selection of an available trunk in a trunk group. The AM also allocates and releases global resources, such as Time-Multiplexed-Switch (TMS) time slots.

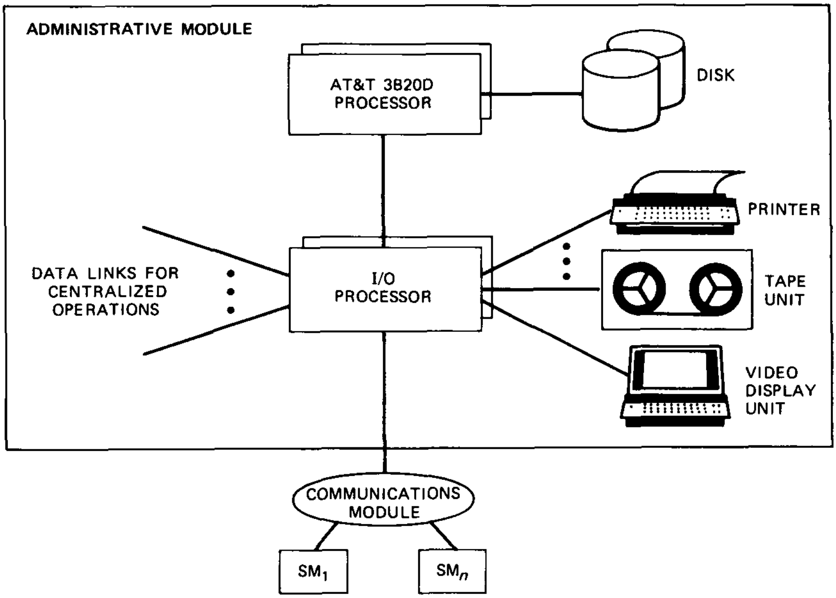

Fig. 2—Administrative module.

A disk memory provides flexible mass storage for programs and data. When needed, these programs and data are transferred to the main memory in the AP or to the memories in the SMs. In the unlikely event of a duplex system failure, the disk also provides rapid program and fixed-data recovery, as well as retention of billing data.

The I/O Processor (IOP) is a subunit of the AM. It is equipped with a scanner/signal distributor, which accommodates functions such as major building and office alarms. Interfaces with operations support systems, video display units, hard copy printers, magnetic tape drives, and a Master Control Center (MCC) are also provided through the IOP.

The MCC provides the human-machine interface for the *5ESS* switch. This includes displaying the system status and providing manual control over system operations. Telephone companies have the option of using (1) a language similar to that used in the 1A *ESS*™ system or (2) the new International Telegraph and Telephone Consultative Committee (CCITT) standard craft interface language (MML). The craft interface also supports an extensive color graphics display of system unit status as well as a menu-based command and control language.

1.2 Communications module

The basic function of the CM is to provide consistent communication between the SMs, and between the AM and the SMs. The Message

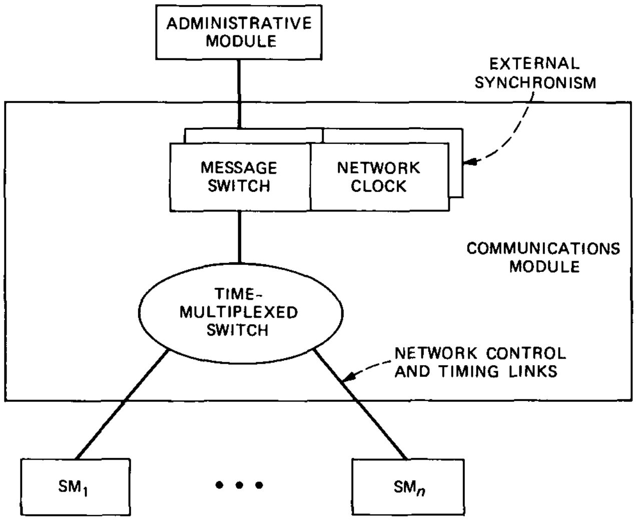

Fig. 3—Communications module.

Switch (MSGS) transfers call-processing and administrative messages between the SMs and the AM, and between any two SMs (see Fig. 3). The MSGS performs a packet-switching function within the *5ESS* switch utilizing CCITT X.25 level-2 protocol to transfer control messages through the CM and its terminating Network Control and Timing (NCT) links. This protocol includes error detection, positive message acknowledgment, and message retransmission in the event of a transmission error. An MSGS can support a combined total of 48 SMs and RSMs. A current development will allow the MSGS to grow and support nearly 200 SMs.

The message interface and clock unit also provides the clock that synchronizes the time-division network. This clock can be synchronized through an external source or run on an internal reference basis with periodic updating. The *5ESS* switching network uses a time-space-time architecture. As illustrated in Fig. 4, a Time-Slot Interchange Unit (TSIU) in each SM performs the time-division switching; the TMS in the CM performs the time-shared space-division switching. At each interface unit the outputs from lines and trunks are converted into 16-bit time slots. These bits are used for signaling, control, and parity, and for binary-coded voice or data. The time slots are switched through the Time-Slot Interchanger (TSI) and time multiplexed into NCT links of the TMS.

The TMS is a single-stage switching network that provides the digital paths for switched connections between the modules and for control messages among modules. The TMS interconnects the modules through the NCT links.

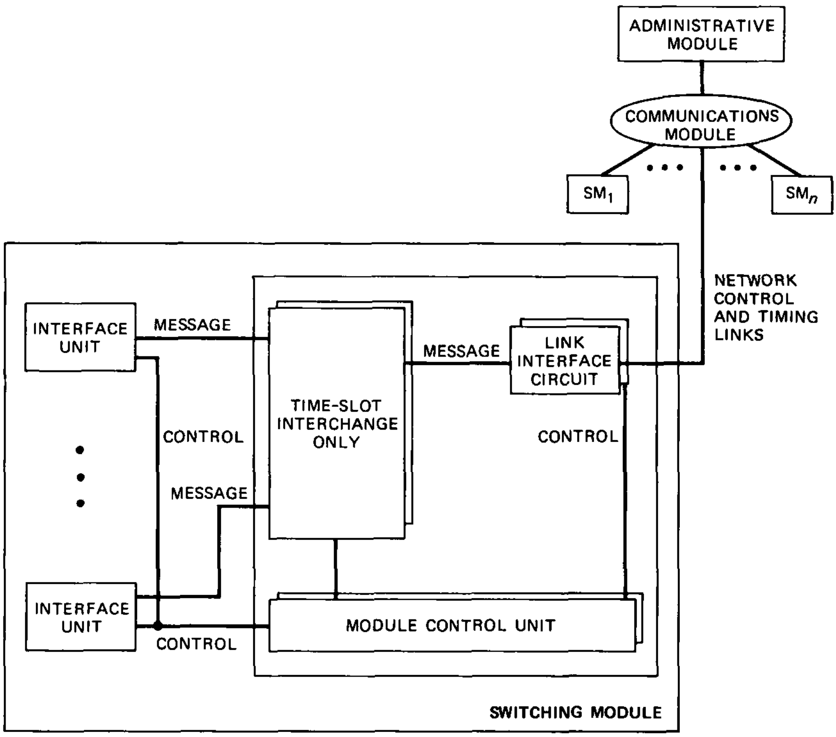

Fig. 4—Switching module.

The NCT links use fiber lightguides. This new technology offers high-data-rate capacity and simple interconnection to switching modules. Compared with conventional cables, the fiber lightguide requires substantially fewer cables to interconnect the various units in the system, simplifying growth procedures. System reconfiguration equipment for maintenance is also reduced. Further, the fiber lightguides are not susceptible to electromagnetic interference and do not create electrical noise.

Each NCT link carries 256 channels (time slots) of multiplexed data in a 32.768-Mb/s serial bit stream. One of the time slots carries control messages, and the remaining 255 time slots carry digitized voice or data. Additional voice/data time slots can be temporarily assigned to the control function in order to transfer large amounts of data. Two NCT links are associated with each module, thus allowing 512 time slots to be routed to and from the TMS. Setting up a path between a line or trunk on two SMs involves finding an idle time slot on one of the NCT links to each SM. A path is then set up through the TMS between these two NCT links on the selected time slot. The TSIU in each SM will establish a path between the chosen NCT time slot and the peripheral time slot associated with the line or trunk.

1.3 Switching module

SMs provide call-processing intelligence, the first stage of switching network, and line and trunk terminals. As a result, the SM is the primary growth unit of the *5ESS* switch (see Fig. 4).

SMs may differ in the types and quantities of interface equipment they contain, depending upon the characteristics of the lines or trunks terminating thereon. Certain equipment is, however, common to all SMs. The common equipment includes a pair of dual-link interfaces, duplicated module processor units, duplicated TSIUs, and a digital services unit. The dual-link interface provides a two-way interface between each SM and the TMS in the CM. The duplicated Module Processors (MPs) control call processing, call distribution, and maintenance functions.

The TSIU contains a signal processor, which handles address and signaling information, and a control interface, which distributes control signals to and from the interface. The TSIU switches time slots between the interface units in an SM and connects time slots from the interface unit to time slots on NCT links. The TSI switches 512 time slots—256 from each of the active NCT links—and 512 peripheral time slots from the interface units. The TSI can connect any of its 512 peripheral time slots to any other peripheral time slot, or to any time slot of either NCT link to the TMS. A local digital services unit provides tone decoding and tone generation capabilities.

A variety of interface units are available in the *5ESS* system. Line units (LUs) provide interfaces to analog lines. Trunk Units (TUs) provide interfaces to analog trunks. Digital Line Trunk Units (DLTUs) provide interfaces to digital trunks and remote SMs, while Digital Carrier Line Units (DCLUs) provide the interface to remote subscriber loop carrier systems. Each SM can accommodate any mixture of these units, with up to 510 channels. Two time slots are used for control.

The LU terminates all of the facilities that are typically categorized as lines, including coin lines and private automatic branch exchange lines. Each terminal can be used for any type of line.

The connection of a line to the *5ESS* system requires the BORSCHT functions: battery feed, overvoltage protection, ringing, supervision, (digital) coding and decoding, hybrid, and testing. Ringing and test functions are provided by high-level service circuits. Channel circuits, which are shared through a concentrator, provide the other BORSCHT functions.

A concentrator, using a solid-state crosspoint network, connects the line terminations and the channel circuits. The crosspoint network consists of newly developed Gated Diode Crosspoints (GDXs) that can withstand the high voltage required for ringing and line testing. As a result, all connections are made electronically, without the use of relays. The concentrator can be provided at 8:1, 6:1, and 4:1 concentration ratios. The concentration ratio can be changed by simply adding or removing plug-in units. These ratios can be mixed within an office if needed. An LU can serve a maximum of 512 lines with an 8:1 concentration ratio.

The TU terminates interoffice trunks, and trunks to operators and to announcement circuits. A TU has 64 data channels and terminates up to 64 voice frequency trunks (that is, trunk traffic is not concentrated). The circuits in a TU are divided into two general categories: trunk circuits and common circuits. Each trunk has an associated trunk circuit, which includes digital coding and decoding, dc signaling, and test access functions. Common circuits are associated with groups of 32 trunks. The functions performed by these circuits include testing, alarming, and multiplexing.

The DLTU provides direct interfacing with digital facilities using 1544-kb/s (24-channel) or 2048-kb/s (30+2-channel) pulse code modulation transmission. A DLTU may terminate up to ten 1544-kb/s digital lines or sixteen 2048-kb/s digital lines.

A DLTU contains a number of Digital Facility Interfaces (DFIs). The DFI is the interface between the digital transmission facility and the *5ESS* switch. Like an analog line or TU, each DFI interfaces to each TSIU by means of peripheral interface control and data buses. The DFI aligns frames; detects alarms, framing errors, and slips; and notifies the module processor when a trouble condition or error threshold is reached.

1.4 Remote switching module

The *5ESS* system can serve remote customers with the same features and services provided to local customers. This capability is provided by the RSM, which can be located as far as 150 kilometers from the host exchange, while still meeting transmission objectives (see Fig. 5). The RSM consists of standard SM hardware augmented by circuits to terminate the digital facilities that connect it to the host exchange. The NCT links at the RSM are converted to T1 data format and transmitted across T1 facilities that terminate on an SM at the host location. The RSM can provide service to a maximum of 4096 lines with a concentration ration of 8:1.

The number of equipped digital lines between the RSM and its host is primarily determined by traffic characteristics. A minimum of two digital lines is presently recommended to provide reliable transport to the host. A maximum of either twenty 1544-kb/s lines with 24 channels

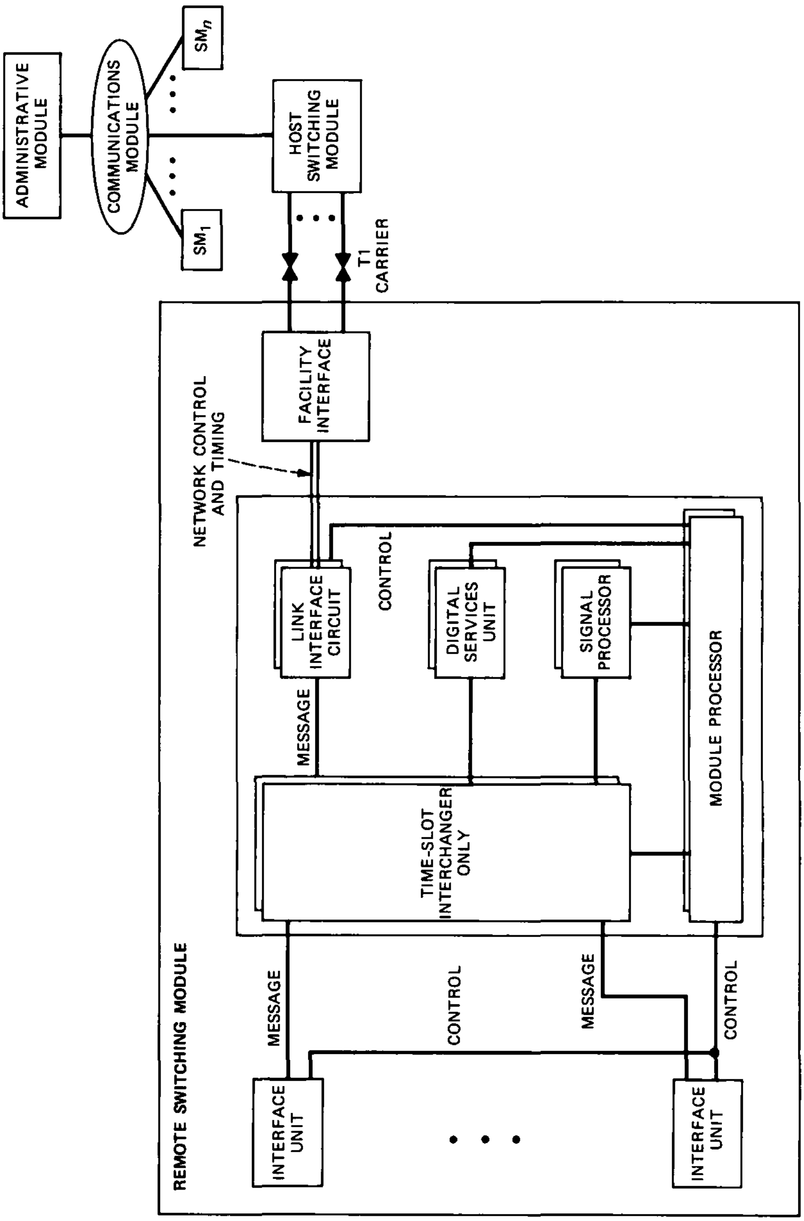

Fig. 5—Remote switching module.

or sixteen 2048-kb/s lines with 30 channels can be utilized to serve traffic between the host exchange and the remote site.

During the normal mode of operation, the RSM is connected by control and data links to its host system. Direct trunks to other offices are also supported. In the rare event of a total transmission failure, the RSM can process calls to lines directly connected to it and over the direct trunks. This processing is called *stand-alone* operation.

During the transition to or from stand-alone operation, intra-RSM calls will be maintained to minimize call cutoffs. Normal dialing patterns will be accepted. When it is not possible to process a request (because the call is destined for lines reached through the host or because features require host resources not available at the RSM), the subscriber will be connected to reorder tone or to a recorded announcement.

In stand-alone operation, the RSM provides access to emergency services, such as police, that normally would be accessed through the host. This provision is implemented independently of the normal links between the RSM and its host.

1.5 Subscriber loop carrier system

The *SLC*® 96 carrier system is a digital loop carrier pair gain system[3] designed as a supplement or replacement for cable. The *SLC* system serves up to 96 subscribers over T1 transmission facilities.

The *5ESS* switch provides a digital interface to the *SLC* 96 system either from an RSM or directly from a local SM. A mechanism for performing spare digital line switching is available in either arrangement. The direct interface between *SLC* 96 system remote terminals and the *5ESS* switch is provided by the DCLU.

II. *5ESS* SOFTWARE ARCHITECTURE

2.1 Software design strategies

For a large software system such as the *5ESS* switch, with its stringent requirements for performance, reliability, maintainability, extensibility, and life-span, it is of paramount importance to define a modular software architecture that exhibits unity of design. The structural integrity of such a software architecture can be preserved by establishing a set of strategies and then using them as guiding principles throughout the design of the software architecture, as well as during the entire life of the system. The most important strategies used in the definition of the *5ESS* software architecture are as follows:

1. Hierarchy of virtual machines—The concept of structuring the software as a set of layers (levels) of abstraction, each defining a virtual (abstract) machine, has been employed in the design of *5ESS*

software architecture. The resulting software structure takes the form of a hierarchy of nested virtual machines.

2. Software modularity—The software implementing each virtual machine is in turn partitioned into modules. A software module is a functionally coherent unit with well-defined interfaces, whose implementation is hidden from all other modules. The changes to its implementation algorithm are transparent to all modules using it.

3. Module portability—The software modules are coded in a high-level language, permitting the object code to run on a variety of target processors. Combining this with the other aspects of the software structure allows modules to be moved among the many system processors (e.g., AP to MP) in order to optimize performance.

4. Distribution of control and data—The distribution of both control and data represents a major software design strategy for implementing the distributed architecture of the *5ESS* switch. Functions and their related data are distributed among the modules providing terminal services (e.g., SMs) and modules providing global services (e.g., the AM).

5. Loosely coupled network—Another important strategy is the design of the *5ESS* switch as a network of loosely coupled modules connected via data links. The processor in each module has its own view of the network and functions consistently with that view. Although loosely coupled, the interfaces among modules are well defined.

2.2 An overview of the software architecture

The *5ESS* software architecture is defined as a hierarchy of nested virtual (also called abstract or logical) machines that spans all processors. The hierarchy is made of a number of virtual machines structured as sequential layers, each using the services of the lower machines and providing additional services for the higher machines. This hierarchy is general, in the sense that a given machine can use the services of any lower machine, not just those of the machine immediately below it. When this view is extended to the entire system, the hardware can be represented as yet another layer at the bottom of the hierarchy, called the physical machine. This layer consists of the processors with their peripherals and is traditionally referred to as the "bare machine" (see Fig. 6).

Most of this software is written in the high-level language C. There are several types of processors controlling each physical module. These include customized microprocessors, an MC68000 chip,[4] and an AT&T Technologies Digital Signal Processor in the SM, an 8086 in the CM, and the 3B20D in the AM. Associated with each control processor is an operating system running on the bare machine and a number of virtual machines that run on the operating system and provide more specialized services.

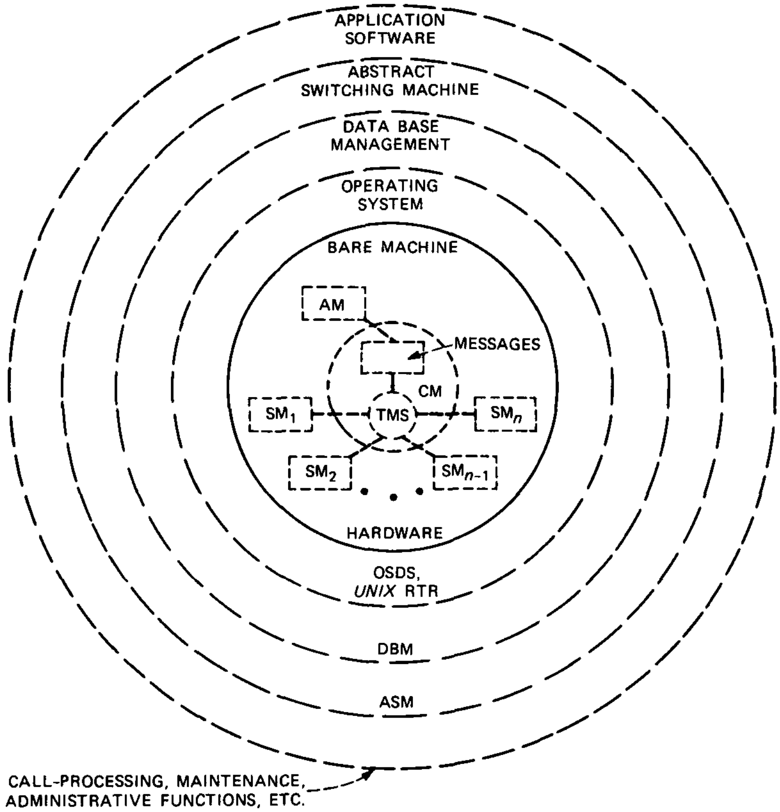

Fig. 6—Software architecture.

The operating system in each processor creates the environment for the concurrent execution of a number of processes by scheduling and synchronizing these processes, providing services in the form of primitives, and managing system resources. The operating system running in the SMs is called Operating System for Distributed Switching (OSDS) and is specially designed for switching applications in a distributed architecture. In the AM there is a general real-time operating system developed for the 3B20D computer, called the *UNIX*™ Real-Time Reliable (RTR) operating system, as well as OSDS, running on RTR in the form of several processes and providing for other "inner" processes an environment similar to that found in OSDS-SM. The OSDS executing in the AM is identified as OSDS-AM. A special interprocess message mechanism is provided in all OSDS environments, allowing processes in different processors to communicate directly. Therefore, the OSDS operating system spans all processors, creating a distributed environment in which processes executing in different processors can cooperate toward the implementation of particular tasks.

The virtual machine just above the operating system in the hierarchy is the Data Base Manager (DBM). The *5ESS* switch does not have a single uniform database but a collection of separate databases with their corresponding DBMs. Some of these databases are distributed among several or all processors.

The next higher virtual machine is the abstract switching machine. It provides a number of logical entities such as terminal, port, connector, and path and a set of operations for manipulating these entities. The software running above this layer can thus provide the switching functions without having to know the detailed implementation of the switching hardware.

Further beyond these virtual machines, the remaining software can be regarded as the application software. It provides major system functions such as call processing, maintenance, and administration by employing the services of the lower virtual machines. The application software is structured as processes running on different processors.

The call-processing application software for the *5ESS* switch also incorporates a highly modular and structured design that is functionally partitioned into several subsystems, such as a feature control subsystem and a peripheral control subsystem. Feature control is responsible for sequencing call-processing actions at a hardware-independent level by sending commands to the peripheral control that manages and controls the switching periphery. This partitioning is applied to the software in both the AP and the MPs. When feature software is separated, new features as well as hardware enhancements can be introduced in a relatively straightforward manner.

Additional software is provided for administrative features in the areas of traffic measurements, plant and service measurements, and charge recording. Trunk and line maintenance, maintenance personnel interface, initialization, fault detection, and overload control are provided by various maintenance software subsystems. All software is supported by the operating system, which manages the computing resources for the *5ESS* switch.

III. OPERATIONS AND MAINTENANCE

All of the operations and maintenance functions can be optionally provided either locally or remotely on a single-office basis, or remotely on a centralized basis serving many offices. The major functions are discussed below.

3.1 Switch maintenance

The MCC is the primary communication medium between maintenance personnel and the *5ESS* system. It displays system status and alarm information, and it provides system control functions, message input and output, and telephone communication with work areas both inside and outside the exchange. Together with the exchange alarms, the MCC offers a complete set of switch and terminal maintenance features. The MCC provides trunk and line maintenance features. Separate Trunk Line Work Stations (TLWSs) are also available for this purpose.

3.2 Line and trunk maintenance

All trunk and line maintenance features can be invoked from either the MCC or an optional TLWS. The optional TLWS is physically identical to the MCC but is restricted to trunk and line maintenance functions. The TLWS performs the following functions: testing subscriber lines, operational testing of trunks, transmission testing of trunks, removing trunks and lines from service, and restoring trunks and lines to service.

3.3 Database administration

The *5ESS* switch stores translation data in a relational database. The *5ESS* Data Base Management System provides database access for maintenance and operations personnel and protects against the introduction of many types of database errors. Data-change and data-retrieval requests made from the MCC or an optional recent-change-and-verify work station add, change, delete, or verify individual records in the database. Automated office-record production is also provided.

3.4 Billing

The *5ESS* switch provides two billing methods: detailed billing and Periodic Pulse Metering (PPM). One billing method may be chosen for all calls, or both methods may be used in the same *5ESS* system for different types of calls (e.g., PPM for local calls and detailed billing for long-distance calls). Billing data may be recorded locally or sent via data links to a centralized recording system.

Detailed billing records are in the form of a standard single entry for each call. PPM pulses are recorded in software registers (a software register can be provided for each subscriber) and, in addition, can be transmitted to the subscriber over the subscriber line.

3.5 Measurements

Traffic measurements give data for the performance supervision of the exchange, for traffic engineering of the network and service circuits, and for long-range exchange planning. To realize this objective, the *5ESS* switch continuously measures exchange traffic and provides appropriate reports. These reports can be produced either on a stand-alone basis or through an operations system.

Other measurements provided by the *5ESS* switch fall into the following categories:

1. Call attempts—These measurements represent the demand for service at the exchange and include traffic distribution (i.e., originating calls, incoming calls, etc.) and the traffic mix (i.e., coin, PBX, and feature calls).

2. Processed calls—These measurements represent the service supplied and include outpulsed and answered calls.

3. Switching system—The measurements in this category are related to the switching system components and include performance measures of the AM, CM, SMs, peripheral units, and service circuits.

4. External periphery—These measurements are related to the performance of other exchanges and trunk groups.

5. Ineffective call attempts—The main objective of these measurements is to determine the cause of ineffective call attempts so that appropriate corrective actions can be taken.

3.6 Centralized operations and maintenance

Centralized maintenance arrangements may be provided either by means of remote work stations or Operations Support Systems (OSSs) that increase the effectiveness of operations and maintenance personnel. Color terminals with pictorial equipment and status displays provide enhanced maintainability. Additionally, menus and standard forms with a cursor-control capability enhance telephone company operations.

Although the *5ESS* switch provides the human interfaces necessary for performing all operations and maintenance tasks, it is also compatible with several OSSs to increase the efficiency of the operations and maintenance personnel.

1. Switching Control Center System (SCCS)—SCCS provides facilities needed for efficient centralized maintenance of stored program control electronic switching systems manufactured by AT&T Technologies and others. It includes a minicomputer that performs real-time and batch analysis of the *5ESS* switch output messages and alerts maintenance personnel if the data show any abnormalities.

2. Remote Memory Administration System (RMAS)—RMAS is a multimicroprocessor system that increases the efficiency of centralized database administration for most types of electronic switching systems. It significantly reduces the time required to enter recent changes and to retrieve data, automates the production of office records, and provides reports that assist in managing both database and the personnel performing this work.

3. Engineering and Administrative Data Acquisition System (EADAS)—EADAS is a minicomputer-based real-time traffic data collection and reporting system. It has the capacity to gather data from up to 48

exchanges. The traffic reports generated for any particular exchange can be routed, via a data link, to a terminal in the exchange, to a central location, or to the printer at the EADAS site. The reports are similar to those provided by the stand-alone *5ESS* switch. A programming capability is also available to develop other types of reports, if desired. EADAS also writes the collected traffic data on magnetic tape for further processing. This provision can be used, for example, to generate weekly, monthly, or busy-season reports for engineering and administrative purposes.

4. Centralized Automatic Reporting on Trunks (CAROT)—CAROT is a minicomputer-based system that controls transmission and operational trunk tests for all exchanges in a particular area that are equipped with comparable remote office test lines and responders. Routine tests are automatically scheduled, performed, and analyzed; the results are automatically forwarded to the appropriate maintenance personnel.

Efforts are now being directed at providing interfaces to the OSSs and data collection systems used by foreign and independent administrations. An early application interfaces with a PDU-10 for United Telephone.

IV. ARCHITECTURAL EVOLUTION PLANS

The modular and distributed nature of the *5ESS* system, in both hardware and software design, allows it to continuously evolve as new technology and new market opportunities arise. Several major areas of architectural evolution are planned:

1. Business and residence custom services—The *5ESS* system will provide a set of features with a number of options to be selected by the customer. This modular feature customization gives the telephone administration greater tariffing options and assignment capabilities to meet the individual differences in customer needs. This mechanism, built entirely in software, can be applied to all customer lines, both individual lines and Centrex lines. It also creates new services by allowing many features to work together that never could before. For example, one service would allow for bridging from a call-waiting arrangement, where the called party talks to two calling parties alternately, to a three-way call in which all the parties can communicate simultaneously.

2. Integrated services digital network services and capabilities—The international community, through CCITT, is developing standards for the integrated services digital network. The *5ESS* system will provide end-to-end digital services via simultaneous circuit-switched voice or data, and packet-switched data, with out-of-band digital signaling. These capabilities will be provided over basic Digital Subscriber Lines

(DSLs), multiplexed DSLs over carrier systems, and primary rate DSLs over T-carrier.

3. High-capacity architecture—The *5ESS* system presently is capable of handling approximately 200,000 peak calls per busy hour, assuming a varied mix of call types and a normal level of maintenance and administrative activities. This will support a typical 50,000-line office, with a maximum of 48 SMs, both local and remote. In the near future the capacity will be expanded to over 300,000 peak calls. Overall, a 100,000-line system will be accommodated. Beyond this large capacity, the *5ESS* system could potentially grow to 500,000 or 1 million peak calls per hour with the continued modular addition of processing power.

4. Larger remote units—The initial RSM for the *5ESS* system is capable of handling 4000 lines. This architecture can be extended to larger line sizes for application in larger office replacements, or with trunking capability as a toll access and routing node. The ability to continuously evolve from a small remote to a large remote to a standalone office offers the telephone administration the flexibility to meet uncertain and fluctuating market demands with a minimum capital investment.

5. Remote units over lightguide facilities—The *5ESS* system currently uses integrated digital T-carrier facilities between the host exchange and remote units. However, the fundamental design of the *5ESS* system uses fiber-optic lightguide facilities as the interconnection mechanism between the CM and the SMs. This mechanism will be extended so that remote modules using direct fiber-optic connections will be a reality. This will be especially important in metropolitan areas, where large demands are making lightguide facilities the economic choice.

6. Integrated special services—A sizable portion of switching equipment and transmission facilities in metropolitan areas are dedicated to special services. Special services distinguish themselves from ordinary telephone service because they typically have more complex transmission and/or signaling requirements, they generate higher traffic loads, and they have more volatile growth and turnover rates. Consequently, installation, provisioning, and testing functions are, in general, more involved, leading to higher operating expenses. The *5ESS* system with its direct digital interfaces to interoffice T-carrier and to subscriber-side *SLC* 96 systems, together with a planned semipermanent connection mechanism (nail-up) for full-time circuits, will allow it to eliminate and reduce many of the problems associated with special services.

V. SUMMARY

The *5ESS* system incorporates sophisticated new technologies in its design. These technologies include GDXs, digital signal processors, fiber optics, and distributed control elements. Its modular, distributed architecture creates a reliable and flexible system for continued evolution of new capabilities and services. The *5ESS* system uses state-of-the-art techniques to provide a modern software architecture built upon layers of carefully structured virtual machines. The resulting software system is implemented using the C language high-level programming language and provides a high degree of modularity and extensibility appropriate for feature additions for years to come.

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