The 5ESS® Wireless Mobile Switching Center

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The growing market for wireless telecommunications services is resulting in a strong movement toward digitizing these services. Currently, three digital wireless standards are specified. Each includes a mobile switching center (MSC) as the centralized network switching and call control entity. The MSC must be adaptable to a variety of network and service environments, and must support a broad range of sophisticated end-user services. AT&T's 5ESS® Switch supports the MSC function for two of the three digital wireless standards, and is an integral component of the AT&T MSC product for the third standard. Reuse of the existing hardware platform, designing wireless functionality as incremental extensions of the existing software architecture, and support of intelligent network (IN) capabilities on the 5ESS MSC, results in a uniquely matched solution for providing wireless services in a wide variety of network environments and applications.

Introduction to Wireless Radio

Advances in digital radio technology are expected to dramatically increase the capacity of wireless networks while driving down costs. This, combined with increasing levels of network intelligence, and the emergence of standards for system and network interconnection, promise to bring the vision of wireless personal communication services (PCS) into reality. At the same time, wireless networks already offer a viable alternative to fixed landline networks in many applications. In addition, wireless technology is expected to play an increasingly important role in the local loop as the technology evolves.

These trends are driving digital switching systems to support wireless services as part of a ubiquitous, high-capacity wireless telecommunications network. These switching systems must be adaptable to a variety of network and service environments, and must support a broad range of sophisticated end-user services. AT&T, as a leader in the information movement and management industry, is addressing these market demands by integrating wireless capabilities into the features and applications already available on the 5ESS® Switch.

Digital Wireless Advantages

The digital wireless standards grew out of the experiences with analog wireless systems and the desire to support national and international "roaming," or interconnect, services between different service providers. Specific improvements over the analog systems include increased capacity on the same bandwidth, better fraud protection through mobile user authentication, and increased privacy with encryption on the radio interface. This increased capability is supported by the digital radio interface with message-based signaling protocols, such as AT&T's signaling system 7 (SS7) service.

National and international roaming services are provided by intelligent network databases, which are queried by MSCs to authenticate subscribers, provide supplementary services, and route calls.

Wireless Network Overview

All major wireless standards share a common underlying network structure. The network elements (as shown in Figure 1) are:

Cell Site Complex. Provides the radio resource central to wireless operations. This complex is usually divided into two functional

Panel 1. Acronyms Used in This Article

AM — Administration module
AMPS — Advanced Mobile Phone Service
ANSI — American National Standards Institute
ASM — Abstract syntax machine
AUC — Authentication center
CM — Communications module
DBM — Database management
DFI — Digital facility interface
DLTU — Digital line trunk unit
DMNI/RCR — Digital Mobile Communications Network Internode/Radio Center for Research
ECP — Executive cellular processor
EIA — Electronic Industries Association
EIR — Equipment identity register
GSM — Global Systems for Mobile Communications
HLR — Home location register
IN — Intelligent network
IS — Interim standard
ISDN — Integrated services digital network
ISUP — ISDN users part
LU — Line unit
MSC — Mobile switching center
MTP — Message transfer part
OA&M — Operations, administration and maintenance
OSDS — Operating System for Distributed Switching
PCS — Personal communications services
PH — Protocol handler
POTS — Plain old telephone service
PSTN — Public-switched telephone network
PSU — Packet-switch unit
RCR — Radio Center for Research
RTR — Real-Time Reliable
SCCP — Switching connection control part
SM — Switching module
SMP — Switch module processor
SS7 — Signaling system 7
STP — Signal transfer point
TIA — Telecommunications Industry Association
TSI — Timeslot interchanger
TTC — Telecommunication Technology Committee
WGSM — Wireless global switching module
WSM — Wireless switching module

elements:

- Radios—Radio transceivers, channel coders/decoders, etc.
- Controller—Manages the radio resources, provides the control interface to the network, etc. One controller is often associated with many radios and cells.

Mobile Switching Center (MSC). Provides switching, call processing, and supplementary services support for wireless calls. Mobility management, often with the support of intelligent network nodes, is included in the MSC.

Intelligent Network Nodes. Provides database systems accessed by other entities in the network that support three main functions:

- Home location register (HLR)—Provides a centralized store for subscriber data;
- Authentication center (AUC)—Provides a secure system for authenticating subscribers' identification codes transmitted from mobile phone equipment; and
- Equipment identity register (EIR)—Screens for stolen or fraudulent mobile phone equipment.

Wireless MSC Goals

The design of AT&T's 5ESS mobile switching center was guided by a set of fundamental goals, based on extensive discussions with customers about their current and future needs, the evolution of international wireless standards, and AT&T's own vision of the future of wireless communications and personal communications services.

International Wireless Standards. As mobile communications matured, users and network providers began to demand increasingly sophisticated inter-system and inter-network features and capabilities. It was apparent that standards were needed to ensure conformity and consistency between multiple networks, network elements, and countries. Strong standards efforts, such as the Pan-European Global Systems for Mobile Communications (GSM) and the initiatives of the American National Standards Institute (ANSI), the Electronic Industries Association (EIA), and the Telecommunications Industry Association (TIA), emerged in response to this

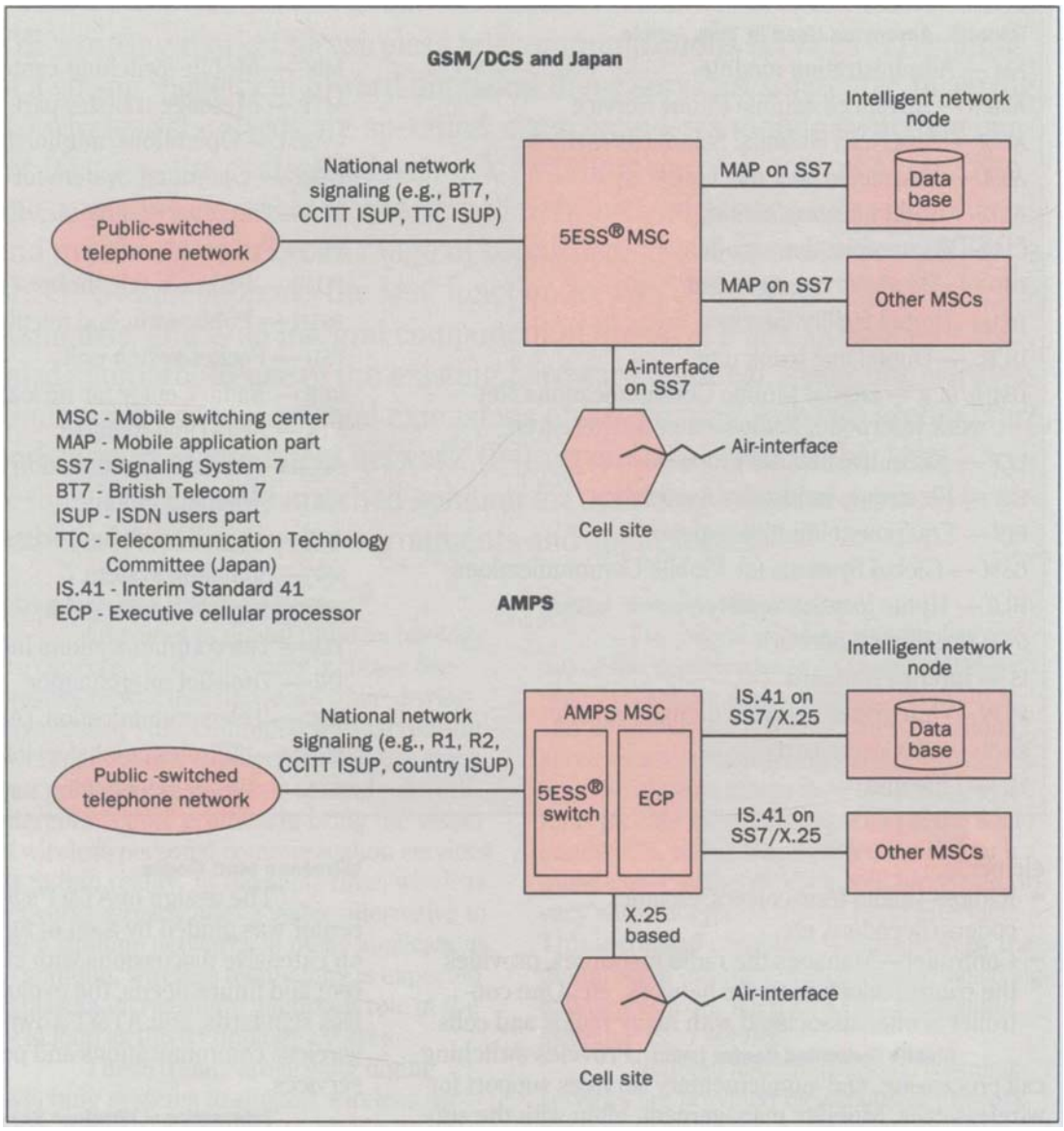

Figure 1. The common underlying structure of a wireless network includes: *Cell site*—Provides radio resources, such as transceivers, coders/decoders, and controller; *Mobile Switching Center* (MSC)—Provides switching, call processing, and other services for wireless calls; *Intelligent network nodes*—Provides the centralized store for subscriber data, authentication of subscriber codes, and a screening process to identify stolen or fraudulent mobile phone equipment; and the network signaling links that connect the systems together.

need. While these initiatives have been successful in defining a consistent set of standards within large segments of the market, there is as yet no single, worldwide standard for wireless systems.

Nevertheless, AT&T is committed to providing its customers with wireless products that conform to all major international standards. These include:

- Global System for Mobile Communications (GSM)[1] —for European and other countries,
- Digital Mobile Communications Network Internode/Radio Center for Research (DMNI/RCR)[2] —for Japan, and
- AMPS (Advanced Mobile Phone Service)[3]—for North and South American and other countries.

The 5ESS Switch acts as the complete MSC for the GSM and DMNI/RCR standards. The AT&T AMPS MSC consists of a 5ESS Switch and an adjunct processor, which is responsible for subscriber data and mobility management

Support for Open Interfaces. The AT&T wireless product line is a vertically integrated, complete solution,

including the cell-site complex, MSC, and intelligent network elements. However, the standards specify open interfaces, GSM and DMNI to a greater degree, and AMPS to a lesser degree, between network elements (as shown in Figure 1). AT&T's commitment to open interfaces has been maintained in the wireless product line, with support of all defined open interfaces between network elements.

National Network Standards

The digital wireless market is emerging in virtually every country, but is dependent on each country's existing infrastructure and regulations. In some situations, wireless service will be integrated into the current public-switched telephone network, while in others, wireless will exist in a separate network. Therefore, the MSC must fit gracefully into a variety of network configurations. It must support interworking with a variety of country-specific signaling protocols, including national versions of signaling system 7. It also must support a variety of customer-specific billing formats, operations support systems interfaces, and operations, administration and maintenance (OA&M) interfaces. Since the 5ESS Switch is present in many markets throughout the world, it supports many country-specific signaling protocols and customer-specific billing formats. Furthermore, the switch is designed to allow easy modification to incorporate new, market-specific signaling types or billing formats.

Multiple Applications on a Switch. Wireless services are often provided in conjunction with land-line services, either to substitute for wire loop or because the alternate service provider is in both wireless and land-line businesses, such as toll or operator services. When this is the case, it is advantageous to offer 5ESS Switch wireless capabilities on the same switching hardware that supports other 5ESS Switch applications, such as gateway, local/toll, integrated services digital network (ISDN), or operator services.

Platform for Continued Evolution. Wireless standards continue to evolve and new applications, services, and interfaces continue to be defined. The digital wireless market is in its infancy, and wireless service providers will identify new product needs as they gain experience with this new application. In addition, one of the most important areas of evolution is in subscriber growth. The 5ESS MSC, with its modular architecture and full range of existing applications, is a flexible, growable platform designed to evolve to meet changing market needs.

Wireless Switching Challenges

Modern wireless networks present unique switching challenges. The traditional connection of subscribers to specific hardware facilities no longer exists, as subscribers are free to move between cells and between switches. The use of common channel, message-based signaling between all network elements—as well as to all subscribers—puts a heavy load on many system resources. The integration of intelligent network capabilities with sophisticated supplementary services requires a high degree of flexibility as well as distributed control.

There are three major extensions required for switching systems to support wireless applications:

- Wireless Signaling—This involves signaling between the switch and cell sites, as well as mobile telephones, which is via message-based, common-channel signaling, with specific protocols varying among the three major standards (GSM, DMNI/RCR, and AMPS). In addition to traditional signaling associated with call setup and teardown, message-based signaling is used for mobile location updates, allocation of cell-site radio resources, call handover between cells, and queries and updates to intelligent network databases.
- Mobility Management—This refers to the tasks required to deal with the inherent mobility of subscribers: locating, paging, and identifying subscribers in the network; validating subscribers and mobile phone equipment; allowing subscribers to "roam" between cities, networks, or countries; and maintaining databases of subscriber information independent of location.
- Wireless Call Control—This refers to setting up, routing, and tearing down calls to or from wireless subscribers; support of supplementary services, such as call forwarding or multi-way calling; and allowing calls to be handed off between physical facilities, as subscribers move from cell to cell throughout the network.

5ESS MSC Architecture

The 5ESS Switch is designed to handle many international applications over a full range of office sizes and with a wide variety of customized services. Its modular hardware and software architectures form the base for incrementally building mobile switching center capabilities onto the switch's existing distributed architecture.

As outlined in Figure 2, the 5ESS Switch has a

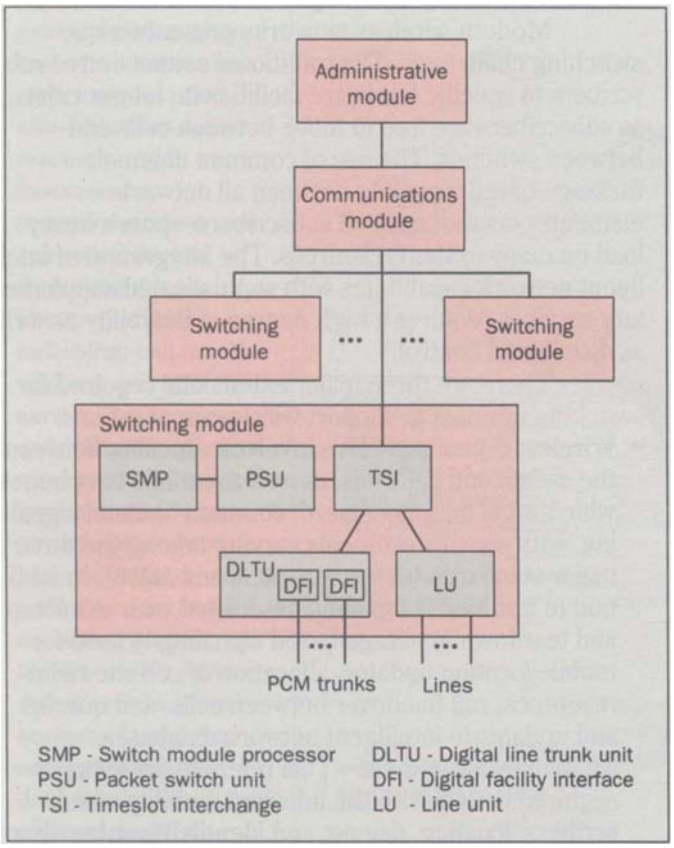

Figure 2. The 5ESS® Switch has a fully distributed architecture comprised of modular hardware and software. The switch consists of the *administrative module (AM)*, which manages all global switch resources; the *switching modules (SMs)*, which interface with customer lines through line units (LUs), and customer-leased and interoffice fiber- and copper-based trunks through digital facility interfaces (DFIs); and a *communications module*, which interconnects the other modules together.

fully distributed architecture comprised of modular hardware and software components. The hardware modules consist of switching modules (SMs), a communications module (CM), and an administrative module (AM). The switching modules contain most of the call-processing and signaling software. The communications module provides switched paths between switching modules, and the administrative module provides global services, such as interfacing to operations systems.

5ESS Wireless Switch Hardware Architecture. The MSC connects to the following wireless components:

- Cell site complexes,
- Intelligent network nodes, and
- Other MSCs.

All of these interfaces are based on signaling system 7. Since the 5ESS Switch already supports SS7 signaling, no new hardware is necessary to add the MSC functionality to the base 5ESS Switch architecture. See Figure 3 for a diagram of the common channel signaling architecture on the 5ESS Switch. Additional software was added to the administrative module, and switching module software load, to add wireless capabilities to the 5ESS MSC. Two types of switching modules are used to support the wireless application on the 5ESS MSC (as shown in Figure 4).

- Wireless Switching Module (WSM)—Terminates facilities from the cell-site complexes. The WSM is a switching module that handles wireless call processing and mobility management.
- Wireless Global Switching Module (WGSM)—Terminates all SS7 signaling links and handles the routing of wireless messages to the appropriate WSMs. Within the WGSM is a packet-switch unit (PSU) containing an engineerable number of protocol handlers (PHs). Protocol handlers are microprocessor-based units that implement the message transport part (MTP) and switching connection control part (SCCP) layers of the SS7 protocol. The WGSM can also act as a signal transfer point (STP) for SS7 signaling between other wireless network elements, or to the public-switched telephone network.

While the WSMs and WGSM are able to handle wireless operations, they need not be dedicated to wireless. Both modules can support a mix of functionality, such as analog POTS, ISDN lines, or trunks in a public-switched telephone network. The number of subscribers and call capacity on the MSC is an engineerable quantity based on the number of WSMs in the switch.

5ESS Base Software Architecture. The 5ESS switch software architecture is structured as a hierarchy of modular systems, each with clearly separated functions, and with hardware details isolated from application software.[4,5]

Figure 5 shows the 5ESS software architecture schematically. The operating system manages the switch's computing resources, supporting all software systems. A database management system provides a

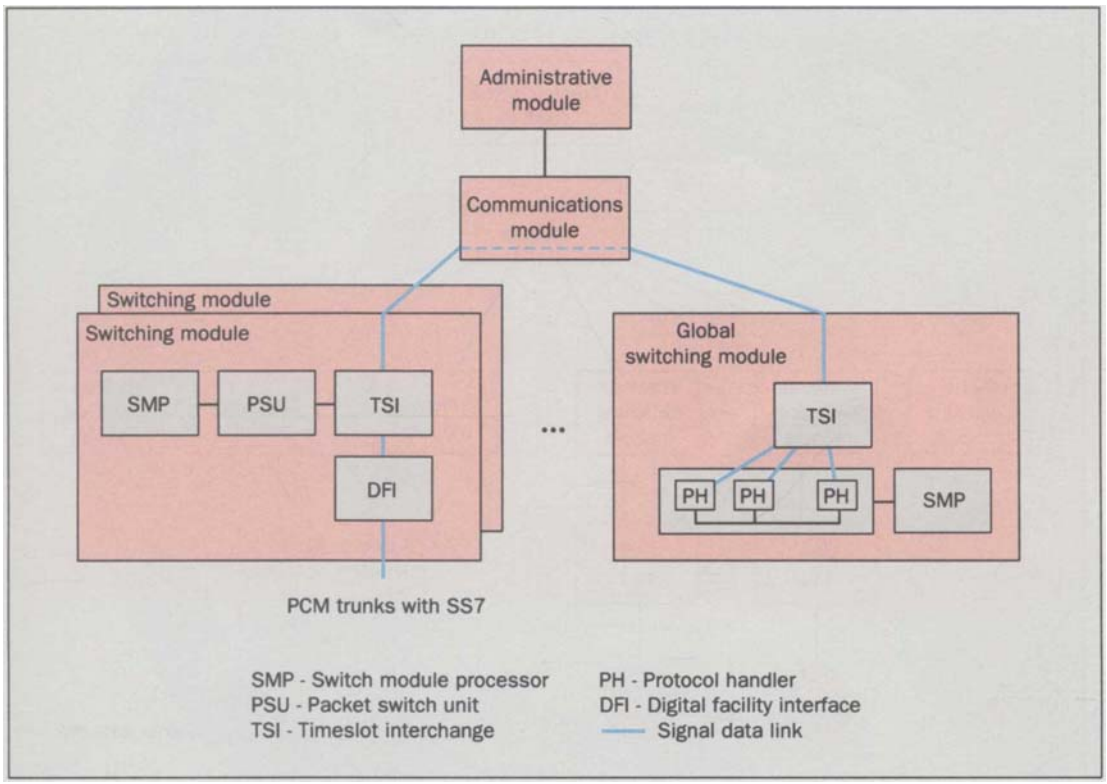

Figure 3. Signaling between 5ESS modules is via common channel links called network control and timing links. These data links, over high-speed fiber optic cables, support call setup and teardown of customer channels between switching modules, and messages between the administrative module processors and the communications and switching module processors.

general, but switch-specific, distributed relational database for all application-related data. An abstract switching machine design provides a constant view of the hardware, yet hides hardware details from the application software. The application software—the highest layer in the hierarchy—provides system functions, such as call processing, maintenance, and administration, by using the services of the lower software systems. Operational software for applications is distributed among the various processing elements of the system: protocol handlers, switching modules, and administrative module.

Wireless Software Architecture. Just as the 5ESS MSC uses the existing 5ESS hardware architecture, the MSC software architecture is based upon the existing 5ESS software architecture. Extensions to the base architecture were made to support wireless signaling, mobility management, and call control.

Wireless Signaling. The existing international 5ESS signaling architecture[6] provides an established, robust base that was easily extended to support wireless. Protocol handlers in the WGSM provide message transfer part and switching connection control part signaling protocols. The abstract switching machine provides a standard, protocol-independent view of signaling channels. Message distribution to the switching modules is achieved via the communication module for application software.

Mobility Management. The implementation of mobility management for the GSM and DMNI/RCR standards on the 5ESS MSC takes advantage of the 5ESS Switch's distributed database management capabilities. In landline applications, subscriber data is distributed across all the switching modules in the switching office, with an associated directory number and/or port to the subscriber. Likewise, in a wireless application, the subscriber data is distributed across switching modules, with an associated directory number and/or mobile identity to the subscriber. This allows the subscriber base of a single MSC to expand to 300,000 mobile subscribers by adding switching modules to the office.

Wireless subscriber data is implemented using an object-oriented approach that supports a well-defined set of access and update software primitives for the logical data entities, while hiding the details of the underlying physical data. This allows the 5ESS to play a variety

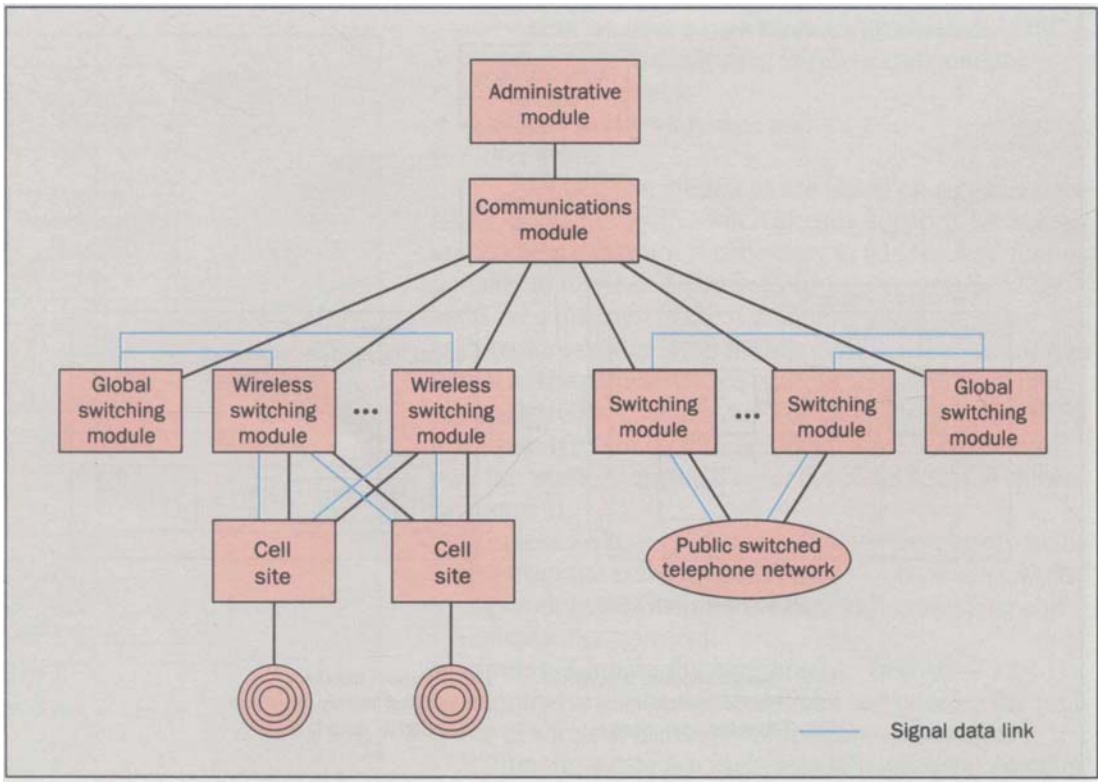

Figure 4. Two types of switching modules support wireless applications on the 5ESS Switch. The *Wireless Switch Module* (WSM) terminates facilities from the cell site complexes. The *Global Wireless Switch Module* (GWSM) terminates all SS7 signaling links, and handles the routing of wireless messages to the appropriate WSMs.

of roles, depending on the wireless network architecture the customer desires:

- It can serve as a stand-alone wireless system, with the home location register, the authentication center, and the equipment identity register data residing locally on the MSC.
- In a multiple-MSC network, it can serve as an home location register, authentication center, and equipment identity register database for other MSCs, either as a dedicated intelligent network node or as an integrated MSC/intelligent network.
- It can retrieve subscriber data from the remote home location register, authentication center, and equipment identity register databases. These can be either other MSCs in the network, or they can be dedicated intelligent network systems.
- It can serve as a wireless network gateway. When calls from the public-switched telephone network or other personal communications services networks come into the network, the switch can perform remote home location register queries, and deliver calls directly to the network location currently serving the terminating subscriber.

The ability to make MSC, home location register, authentication center, and equipment identity register capabilities available on the same platform provides the wireless network provider with a number of advantages. It reduces network startup costs for capital, facilities, training, and administration, while providing maximum flexibility in network configuration. And, when combined with support for open interfaces, it also provides a wide variety of network evolution paths.

Mobility management functions—such as attach/detach, as a result of turning the mobile device on or off; locating the device in a service area; and authenticating the device—are performed by the switching module on which the subscriber data resides. The authentication center functionality (which involves computation-intensive encryption algorithms) is offloaded to protocol handlers in the packet-switch unit. This approach takes advantage of the distributed architecture of the 5ESS Switch. It spreads the processing load among multiple processors and allows mobility management and call control tasks to be performed in parallel, thus both

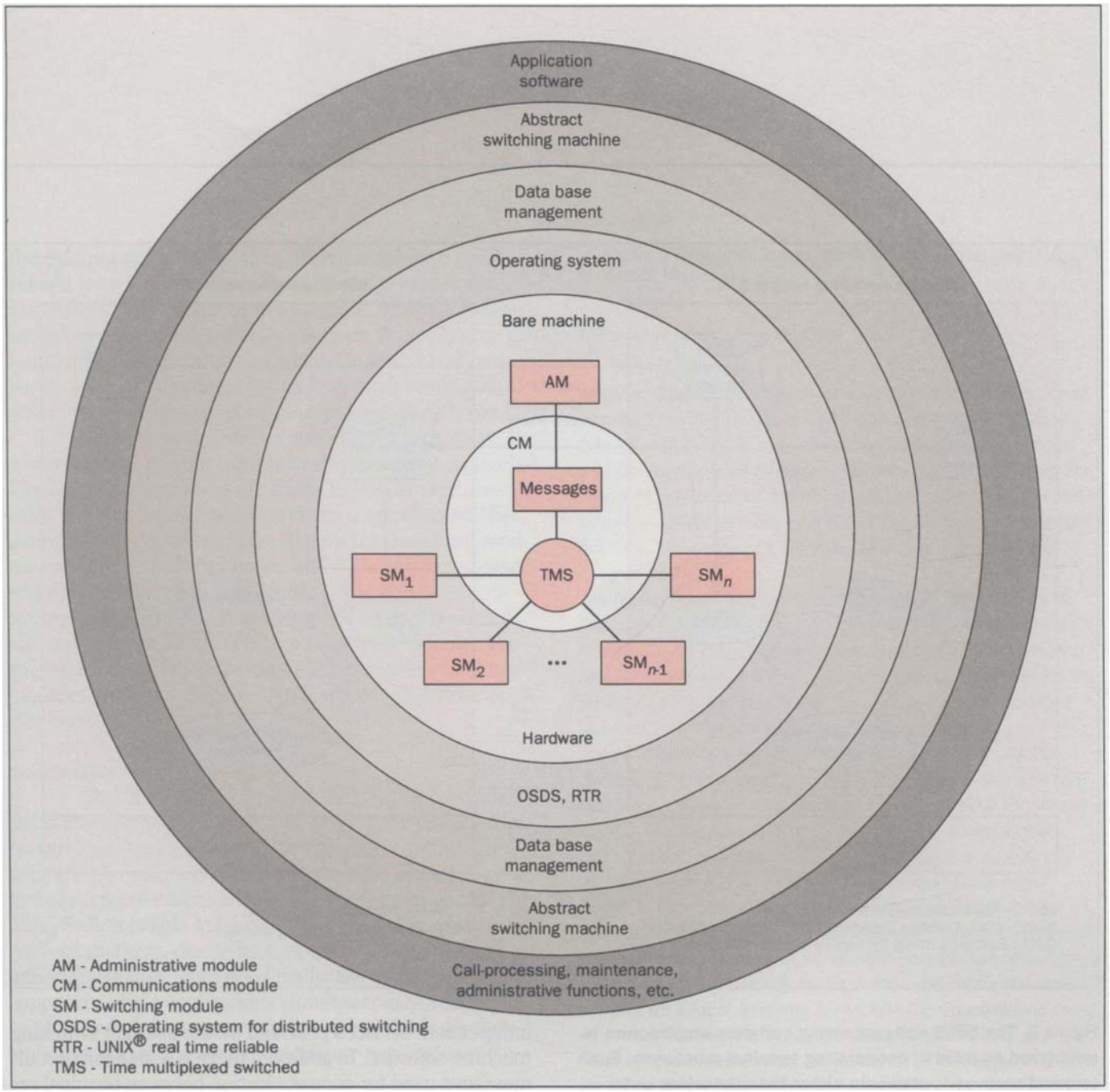

Figure 5. This illustration shows the 5ESS software architecture schematically. The *operating system* manages the switch's computing resources, supporting all software systems. The systems are UNIX® Real Time Reliable (RTR) and the Operating System for Distributed Switching (OSDS). A *database management system* provides a general, but switch-specific, distributed relational database for all application-related data. An *abstract switching machine* design provides a constant view of the hardware, yet hides hardware details from the application software. The *application software,* the highest layer in the hierarchy, provides system functions, such as call processing, maintenance, and administration, by using the services of the lower software systems. Operational software for applications is distributed among the various processing elements of the system: protocol handlers, switching modules, and administrative module.

increasing system capacity and reducing call setup delay. It also prevents any part of the system from becoming a system or network bottleneck.

Wireless Call Control. The 5ESS call processing software architecture is structured as pairs of cooperating *terminal processes*[7] (see Figure 6). Each terminal process implements either the originating or terminating half of the call, allowing call processing to be distributed

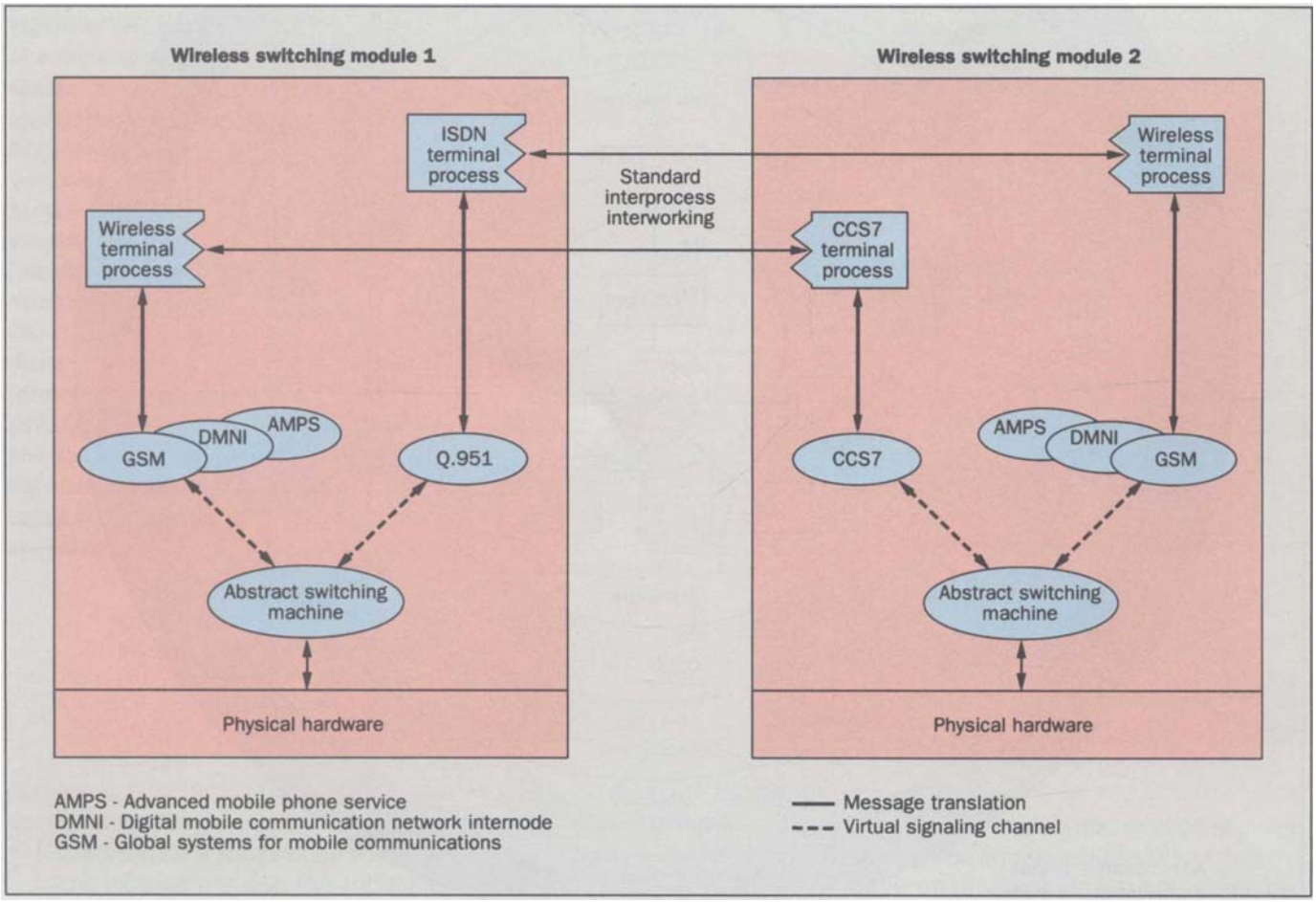

Figure 6. The 5ESS call-processing software architecture is structured as pairs of cooperating terminal processes. Each terminal process implements either the originating or terminating half-call, allowing call processing to be distributed across different switching modules. The terminal process communicates with the physical hardware (lines, trunks, data links, etc.) via a standard set of hardware-independent services provided by the abstract switching machine. In addition, there is a standard set of messages used for communication between terminal processes that allows a diversity of different call-processing applications, such as ISDN, intelligent network, common channel signaling, or POTS, to interwork with one another.

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Because they both share an underlying message-based, signaling system model, wireless call control is built upon the ISDN application software.[5] The abstract switching machine provides the application with a transparent interface to the cell-site signaling channel. Application-specific message translation software converts protocol-specific messages coming in on the signaling channel into a standard internal call-processing message set, then delivers them to the application software. Use of standard internal messages allows the majority of

the existing call-processing application software to be reused for wireless call processing, and provides wireless subscribers access to the wealth of existing features, including ISDN supplementary services. And, because terminal processes communicate via standard interfaces, wireless terminal processes can interwork easily with a wide variety of other applications and signaling types.

The wireless terminal process runs on the WSM, where the voice trunk from the cell terminates, minimizing interprocessor message traffic to handle wireless calls. When a call is handed off from one cell to another, a new terminal process is created on the switching module serving the new cell trunk, and call control responsibility is transferred to that process. The subset of subscriber data required for ongoing call control is copied into temporary data on this new switching module. The voice path is switched transparently between switching modules, using capabilities originally developed for operator services.

Conclusion

The 5ESS MSC is a robust, full featured, wireless switching system. It supports all three international digital wireless standards, and is designed to continue to support the evolution of those standards, as well as new global personal communications services standards. The 5ESS Switch is able to be quickly deployed in many international markets, due to its support of a large number of national signaling systems. Finally, the 5ESS Switch can support multiple applications simultaneously, making it an ideal switch for service providers with both wireless and other, more traditional, telephony applications.

References

1. Special Mobile Group, *"GSM Recommendation"*, Version 3.
2. NTT/IDO/DDI, *"Digital Mobile Communication Network Internode Specification"*, Version 2.0, June 4, 1991.
3. ANSI IS-54/IS-41.
4. D. L. Carney, J. I. Cochrane, L. J. Gitten, E. M. Prell, R. Staehler, *"The 5ESS Switching System: Architectural Overview"*, AT&T Technical Journal, Vol. 64, No. 6, July-August 1985.
5. D. L. Carney, E. M. Prell, *"Planning for ISDN in the 5ESS Switch"*, AT&T Technical Journal, Vol. 65, No. 1, January-February 1986.
6. T. W. Benko, J. H. Horwedel, L. P. Pautler, P. N. Turcu, *"A Distributed Architecture for Common Channel Signaling Number 7 to Meet Diverse Application Requirements"*, Submitted to ISS '92.
7. J. P. Delatore, R. J. Frank, H. Oehring, L. C. Stecher, *"The 5ESS Switching System Operational Software"*, AT&T Technical Journal, Vol. 64, No. 6, July-August 1985.
8. L. G. Anderson, C. H. Bowers, D. L. Carney, J. J. Kulzer, W. W. Parker, *"Distributed Systems Tradeoffs"*, ISS '87, Phoenix, USA, March 1987.

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