Cellular and PCS Digital-Mobile-Services Switching Center

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The AT&T 5ESS®-2000 switch's distributed modular architecture provides an excellent mobile-switching-center platform for digital cellular and personal communication services (PCS) wireless applications. The high-quality, multi-application product line has been proven in the field, and it meets the wireless market demand for central-office (CO) reliability. The continuous evolution of the 5ESS-2000 switch allows cellular service providers to ride the technology "wave." Additionally, this platform provides the ability to evolve rapidly into the PCS arena. This paper explores the use of the 5ESS-2000 switch in key wireless applications throughout the world, and it illustrates how the 5ESS-2000 switch is used to meet these demanding requirements.

Introduction

The 5ESS®-2000 switch wireless application covers the three major Digital World Cellular Standards:
- Advanced mobile phone service (AMPS);
- Global system for mobile communication (GSM); and
- Japan personal digital cellular (PDC).

Each of these standards was created to address the growing subscriber challenges cellular service providers face worldwide; namely, to increase capacity and improve voice quality over the available radio spectrum.[1] While these digital standards solve most cellular service provider needs, other wireless service providers have distinctly different requirements.

Local exchange carriers (LECs) and international service providers, currently limited to supplying wired service, are interested in jumping on the "wireless bandwagon" by providing wireless end-user services. The LECs and international service providers have been struggling with how they will provide wireless services—using their existing equipment and networks—and still differentiate themselves from the cellular industry. One area that has received considerable attention is the U.S. personal communication services (PCS), because the FCC is planning to auction PCS licenses by the end of this year.

LECs, international service providers, and cellular companies are anxious to pursue these PCS licenses, because many believe this is where the future of telecommunications lies. The LECs and international service providers are approaching the PCS arena in a different fashion than the cellular providers. While U.S. cellular providers are struggling with the decision of using time-division multiple access (TDMA) or code-division multiple access (CDMA) technology with the current cellular-network infrastructure, the LECs are exploring the use of land-line technology to provide similar services. A comparable approach is being taken in Japan, with the personal handy phone system (PHS).[2]

Two types of PCS networks are being proposed: a *low-mobility network architecture* and a *high-mobility network architecture*. The low-mobility network is intended for pedestrian traffic, and utilizes existing integrated services digital network (ISDN) technology in the central offices (COs) of the LECs and international service providers. The high-mobility network utilizes cellular network characteristics—for example, intelligent base stations—to handle fast-moving traffic, and it is designed for cellular service providers.

The common thread between all these proposed PCS network architectures is

Panel 1. Abbreviations, Acronyms, and Terms
AMPS — advanced mobile phone service
ATM — asynchronous transfer mode
BRI — basic rate interface
CDMA — code-division multiple access
cell cluster — groups into which radio frequencies
    are organized
CO — central office
CS — cell site
DCS — digital cellular switch
DFI — digital facility interface
FDMA — frequency-division multiple access
frequency planning — a process by which a cluster
    of channels is assigned to one cell but not to its
    neighboring cells
FRPH — frame-relay protocol handler
FS-CE — frame-selector to channel-element,
    a protocol
GSM — global system for mobile communications
high-mobility network — a cellular system designed
    for fast-moving traffic, such as motor vehicles
ISDN — integrated services digital network
LEC — local exchange carrier
low-mobility network — a cellular system designed
    for pedestrian traffic
MS — mobile station
PCM — pulse-code modulated
PCS — personal communication services
PCSC — PCS switching center
PDC — personal digital cellular, a wireless system
    used in Japan
PHA — protocol handler for ATM
PHS — personal handy phone system, a wireless
    telecommunication system used in Japan
PHV — protocol handler for voice
PSTN — public switched telephone network
PSU2 — packet-switch unit 2
TSI — time-slot interchange
rake receiver — a device that combines multipath
    radio signals for improved signal-strength char-
    acteristics
RF — radio frequency
RP — radio port
RPCU — radio-port control unit

smaller, lighter, and less expensive PCS mobile hand
sets, lower PCS per-call prices, intelligent-network-like
services, and personal mobility.

This paper discusses these PCS network propos-
als, and also how the LECs will use low-mobility networks
to provide common characteristics. In addition, it
explores how CDMA will help the cellular service
providers compete in this emerging PCS market, and how
the 5ESS-2000 switch can be used in any PCS network
alternative, in order to meet—cost-effectively—the needs
of PCS service providers.

Low-Mobility PCS Network Architecture

The LECs, international service companies, and
Bell Communications Research (Bellcore) are propos-
ing using ISDN-like interfaces from cell sites to COs, in
order to supply PCS or, as it is called in Japan, PHS ser-
vice. PCS would be provided using a radio-frequency (RF)
technology similar to that deployed for use in today's
typical cellular service. The only difference is that PCS
would use smaller cell-radio coverage areas. PCS cell-
radio coverage would have a radius of approximately 100
meters, and it would connect to the COs of LECs or inter-
national service providers using ISDN basic rate inter-
face (BRI). Figure 1 illustrates the proposed Bellcore PCS
low-mobility architecture.

The PCS cells would be small, hardened radio
ports (RPs) mounted on telephone poles, street lights, in
shopping malls, train stations, airport terminals, and on
top of pay-phone booths. Both the small PCS antenna and
RP unit can easily be placed in inconspicuous locations,
giving PCS a deployment advantage over the larger cell-
site towers used in cellular systems. Groups of RPs would
be connected to a centralized radio-port control unit
(RPCU). The RPCUs would be owned and operated by the
service providers, and connections could either be
leased or available as private facilities. The RPs could be
owned by non-LECs, and revenue could be collected on a
per-call basis from the LECs.

The PCS hand set would work at home and in the
work place in a fashion similar to today's cordless phone.
Such functionality would allow an end-user to operate a
PCS hand set as a land-line phone at home, and as a
mobile phone elsewhere. PCS technology would have
low-mobility characteristics; that is, it would be designed
to accommodate pedestrian traffic. It would not support
fast-moving (vehicular) hand-offs between cells, because
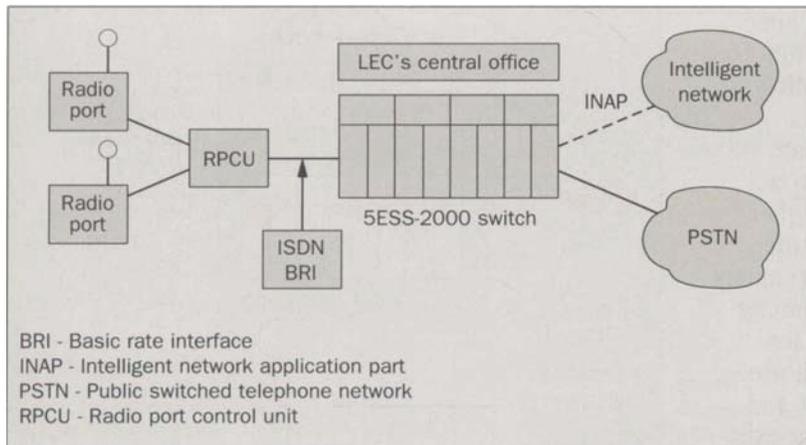
Figure 1. This drawing represents the proposed PCS low-mobility architecture. The use of ISDN-like interfaces from cell sites to central offices has been suggested. PCS would be provided using a radio-frequency technology similar to that deployed for use in today's typical cellular service. The only difference is that PCS would use smaller cell-radio coverage areas for this low-mobility application.

BRI - Basic rate interface
INAP - Intelligent network application part
PSTN - Public switched telephone network
RPCU - Radio port control unit

PCS cells are much smaller than traditional cells, and hand-offs between cells would occur too frequently. The low-mobility architecture, with ISDN BRI access, would not effectively handle the signaling load produced by fast-moving vehicles.

PCS hand sets will be lower in cost, however, as compared with typical cellular phones, because they will require less power to transmit and receive within the smaller PCS cells. They will also be smaller in size. Lower power consumption will result in longer battery life, permitting mobile usage similar to today's cordless telephones. PCS hand sets can also be used for wired service in the home, thus sharing the cost load with wired home-phone equipment. The LECs and international service providers view this scenario as a distinguishable advantage over their cellular competitors.

By using ISDN BRIs as the fundamental interface between RPCUs, LECs, and international service provider COs, the embedded land-line service providers can benefit from using an already existing base of public switched telephone network (PSTN) COs and local-loop equipment installed in homes and offices, thus keeping initial PCS entry costs low. Additionally, LECs can take advantage of an ISDN technology that has been, for the most part, dormant since it's inception in the early 1980's.

The hope is that moderate entry costs will allow the LECs to maintain low per-call and monthly charges and to avail themselves of already expansive CO ISDN services. This situation should provide some incentive for existing cellular phone customers to switch to PCS, especially those who do not normally use their phones in fast-moving vehicles.

Several LECs have performed PCS trials in the United States during the past year. One trial[3] currently has approximately 160 PCS RP cells in a residential area. The antennas and RPs are placed in various locations—on street lights, in gas stations, shopping malls, train stations, parking garages, and in buildings. These PCS RP locations were chosen to best serve the area's pedestrian traffic patterns. This three-phase trial is currently in its second phase, with the final phase supporting hand-offs between RP cells.

Bellcore has developed several technical advisories—TA-NPL-000145, TA-INS-001412, and TA-TSV-001411—that propose PCS network architectures, interface specifications, and PCS services. Figure 1 illustrates the suggested Bellcore PCS network architecture targeted at low-mobility or low-speed traffic.

Low-Mobility 5ESS-2000 Switch PCS Architecture

The PCS low-mobility architecture is easily added to the 5ESS-2000 switch, because it is based on a mature 5ESS-2000 ISDN product that has been in service since the early 1980's. Additionally, the RPCU messaging atop the ISDN BRI that supports the personal communication services is easily incorporated into the 5ESS-2000 switch, because it is based on already existing wireless software.

High-Mobility PCS Network Architecture

A high-mobility PCS architecture is being proposed to handle fast-moving traffic, such as vehicles. This architecture involves a PCS switching center (PCSC) having an incorporated access manager. The architecture uses a base station for the PCS mobile radio inter-

face, and is similar to current cellular-network architectures. It is designed for carriers planning to offer full-service mobile networks. Figure 2 is a representation of the proposed PCS high-mobility architecture.

End-user call rates and monthly charges are expected to be slightly higher than PCS, due to the fact that high-mobility network equipment requires higher powered RF equipment, and often does not utilize the embedded network. Mobile size and power requirements will be higher due to larger cell sizes, thus contributing to higher end-user costs. This architecture offers features that the low-mobility network cannot offer, however, including accommodation of fast-moving traffic and wider geographical coverage. It will be possible for existing cellular service providers to add components to their established network, thereby lowering the initial, high-mobility PCS network investment required. This will help the cellular service providers compete against new, non-LEC companies in the PCS market.

In addition, CDMA technology promises to solve some of the technical issues associated with high-mobility networks. The next section explores CDMA technology and describes how it will be developed on the 5ESS-2000 switch.

Code-Division Multiple Access

CDMA technology is easily incorporated into the PCS high-mobility architecture. In particular, the cellular industry is excited about using CDMA to solve its capacity needs, and it is anticipating moving into the PCS arena to compete with the low-mobility networks of the LECs and international service providers. The next section introduces CDMA technology and concepts, and explains how the 5ESS-2000 digital cellular switch (DCS) is configured to handle the advanced mobile phone system (AMPS) CDMA standard (CTIA IS-95 standard). Figure 2 shows how the 5ESS-2000 DCS is used in a typical wireless network.

CDMA is one of three multiple-access schemes used to divide the RF spectrum covered by cell-site (CS) and mobile-station (MS) radios for cellular telephone service. The two other access methods are frequency-division multiple access (FDMA), used in today's analog cellular networks, and TDMA (defined in CTIA IS-54 standards, GSM standards, and Japan's PCS standards). Figure 3 graphically depicts the three AMPS RF access methods.
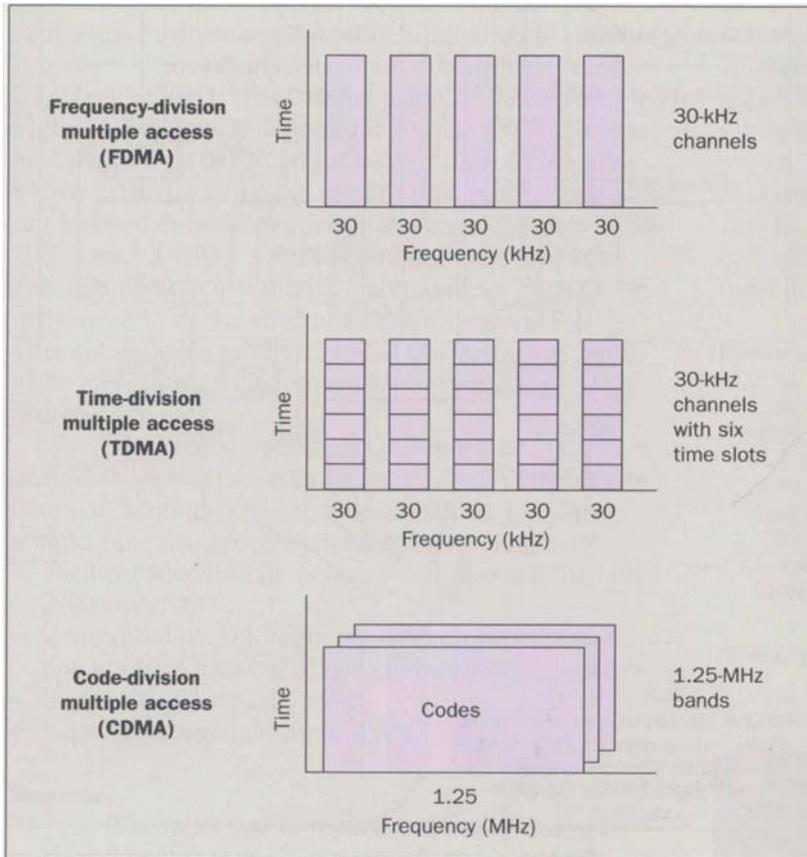
CDMA uses spread-spectrum technology, in
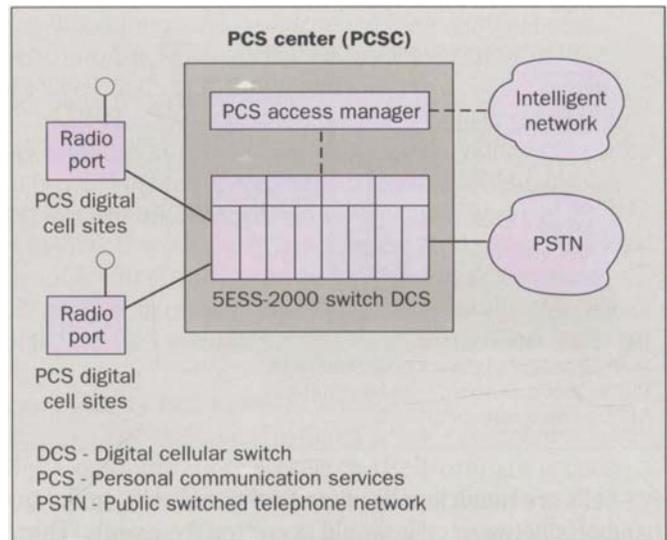
Figure 2. A high-mobility PCS architecture, shown in this illustration, is being proposed to handle fast-moving traffic, such as vehicles. This architecture includes a PCS switching center having an incorporated access manager. The architecture uses a base station for the PCS mobile radio interface, and it is similar to current cellular-network architectures. It is designed for carriers planning to offer full-service mobile networks.

which the radio signals associated with a call are spread across a single, broad frequency spectrum (1.25 MHz for initial CDMA applications). These radio signals are differentiated from other calls in that spectrum by assigning unique codes to each call's signal. This process allows multiple vehicles to share the same 1.25-MHz frequency band. At the receiving end (mobile or cell), the specific call's signal is isolated by decoding the entire received signal using the code assigned to that signal. All other electronic "noises," or signals that don't match the assigned code, are ignored. Additionally, multipath signals are combined, using a *rake receiver*, to provide even stronger signal reception at each end (mobile and cell).

The CDMA frequency-access method allows a cellular service provider to reuse the same frequencies in adjacent cells. A unique, assigned code is used to decipher the signals. Therefore, signals in the same frequency, but with different codes, appear as noise to the receiving end.

interference problem, a cluster of channels is assigned to one cell but not to its neighboring cells. This assignment process is called *frequency planning*. It turns out that frequency planning reduces the actual number of usable channels in an analog cell by a factor of seven. CDMA, however, does not suffer from these frequency-planning limitations. By its nature, CDMA uses codes to decipher signals, and it effectively has a reuse factor of one.

Conceivably, a cellular service provider could have a cell supporting hundreds of channels in a CDMA cell surrounded by other cells supporting the same channels. Additionally, CDMA gains capacity by splitting the cells into sectors (sectorization). Moving from one to three sectors approximately triples the amount of capacity offered by a CDMA cell. Because of the frequency planning and reuse issue, this is not true for an FDMA cell. Thus, the factor of seven (due to no penalty for frequency planning) and the factor of three (gained by sectorization) are the reasons CDMA can, theoretically, provide improvements of up to 20 times over that provided by analog capacity.

CDMA mobile power levels are controlled by the network, and power levels are kept to a minimum during transmission, which conserves battery life. Therefore, CDMA mobiles consume less power and, as a result, use smaller batteries that are lighter in weight. This design will allow cellular service providers to compete with the small-size PCS phones.

Though FDMA and TDMA do allow RFs to be reused, the separation between cells containing the same frequency must be large enough so that co-frequency interference can be kept below acceptable levels most of the time. Frequencies are organized into *cell clusters* for TDMA and FDMA, and cluster size is determined by the number of cells per cluster and the radius per cell.

For example, an FDMA analog network has 395 duplex voice channels available (including expanded spectrum) that can be mapped into a cell. All such channels are not really usable, however, because neighboring cells on the same channels would interfere. To avoid this

5ESS-2000 Switch CDMA Call Architecture

Figure 4 diagrams a CDMA call-flow through the 5ESS-2000 switch, highlighting the key components. In order to handle CDMA, there are four new components that have been added to the 5ESS-2000 switch. They are the:

- Frame-relay protocol handler (FRPH);
- Protocol handler for voice (PHV);
- Protocol handler for ATM (PHA); and
- Packet switch unit 2 (PSU2).

Figure 4. The transmission trunk between a CDMA cell site and the 5ESS-2000 switch is called a packet pipe. A packet pipe is defined as a collection of 64-Kbits/s pulse-code-modulated trunks. It can be set from two to eight DS0s (128-512 Kbits/s), depending on CDMA cell-site radio configurations. The purpose of the frame-relay protocol handler in the packet-switch unit is to terminate the packet pipes to and from the CDMA cell sites, as illustrated in the drawing.

The transmission trunk between a CDMA cell site and the 5ESS-2000 switch DCS is called a *packet pipe*. A packet pipe is defined as a collection of 64-Kbits/s PCM or 56-Kbits/s trunks and can be set from 2 to 8 DS0s (128-512 Kbits/s), depending on CDMA cell-site radio configurations. For instance, a four-DS0-wide packet pipe can handle a maximum of 14 CDMA calls, while an eight-DS0-wide packet pipe can handle a maximum of 30 CDMA calls. The purpose of the FRPH in the PSU2 is to terminate the packet pipes to and from the CDMA cell sites, as illustrated in Figure 4.

Packet pipes provide for very efficient utilization of trunks between cell sites and the 5ESS-2000 switch DCS. Packet pipes permit a service provider to deploy fewer trunks—and handle more calls—at far less transmission cost. Because a four-DS0-wide packet pipe can handle 14 CDMA calls simultaneously, a service provider realizes a better than three-to-one trunk-utilization factor over other cellular traffic.

The 5ESS-2000 switch DCS can support many different size packet pipes simultaneously, to and from the CDMA cell sites. For example, a service provider can deploy many different size packet pipes to a cell site and, thus, engineer packet pipes and sizes based on CDMA traffic at a cell site. This procedure permits easy and cost-efficient CDMA cell-site packet-pipe configurations and future growth.

Using a 64-Kbits/s or 56-Kbits/s PCM trunk per call, transmission trunking between the 5ESS-2000 switch DCS and other network entities remains the same.
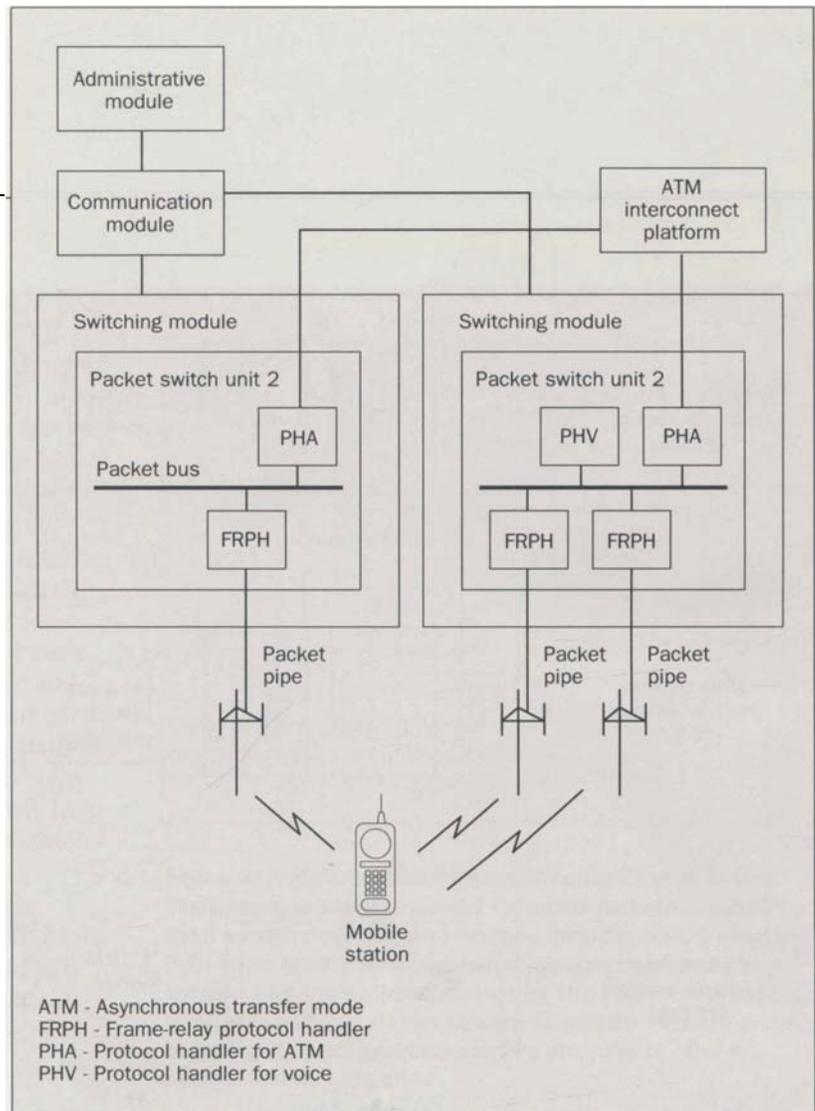
The function of the PHV is to receive packets from the MS, select the best packet (as determined by a criteria specified in the frame-selector to channel-element [FS-CE] protocol), convert the variable-length packets into 64-Kbits/s or 56-Kbits/s circuit-switched pulse-code-modulated (PCM) voice, and send it (by means of a time slot) through the time-slot interchange (TSI) to the PSTN. The PHV can receive packets from multiple cell sites during a soft hand-off by means of separate packet pipes and FRPHs.

In the reverse direction, the PSTN PCM voice is received through the time-slot interchange at the PHV and converted into variable-length packets. The PHV then sends the packets to the cell sites (potentially, multiple cell sites during a soft hand-off) through the FRPH and digital facility interface (DFI), terminating that cell site's packet pipe (or through potentially multiple FRPHs during a soft hand-off) by means of the PSU2 packet bus.

If a CDMA 5ESS-2000 switch DCS requires more

than one PSU2, then a PHA is required to support inter-PSU2 connectivity. The PHA can be configured in either of two ways: by means of an asynchronous transfer mode (ATM) center-stage interconnect platform (shown in Figure 4) or in point-to-point mode. The ATM interconnect platform is designed for large, CDMA, 5ESS-2000 switch DCSs (for example, greater than eight PSU2s) and can be used to interconnect PSU2s across multiple 5ESS-2000 switch DCSs. A point-to-point option is also available that allows customers to interconnect PSU2s directly from a PHA in one PSU2 to a PHA in a second PSU2. This option helps minimize initial CDMA start-up costs while still allowing customers to migrate into the ATM center-stage option.

The preceding discussion about the CDMA 5ESS-2000 switch DCS architecture further illustrates its inherent flexibility and versatile infrastructure. The architecture also provides many benefits, including:

- Facility concentration between cell sites and the 5ESS-2000 switch DCS;
- Centralized packet switching, which eases the evolution to CDMA data traffic and ISDN network interfaces;
- Increased call capacity; and
- Support for multiple applications.

Summary

It is important to realize that numerous network architectures are being considered in order to solve the many PCS questions. This paper demonstrates how the LECs and international service providers are exploring ways to take advantage of their existing network base to keep service entry costs low, while still maintaining a viable PCS product that can compete with the existing cellular industry. The AT&T 5ESS-2000 switch provides the PCS foundation and flexibility required for the LECs and international service providers in their migration toward PCS.

Challenges face the cellular industry in its efforts to implement and deploy PCS service, and the consumer market is changing rapidly. The AT&T 5ESS-2000 switch DCS CDMA product offers many advantages and benefits that allow service providers to reach their individual goals.

The flexible and modular architecture of the 5ESS-2000 switch offers PCS service providers (LECs, international service companies, the cellular industry, and non-LECs) a comprehensive range of PCS solutions to be used in any fashion they choose. The LECs and international service providers can share the versatile 5ESS-2000 switch between land-line service and the new PCS users, helping to keep network and service costs at a minimum. Cellular providers can use the 5ESS-2000 switch to provide CDMA service and still explore other alternatives, such as wired service or other PCS solutions. And finally, the 5ESS-2000 switch can serve non-LECs exploring other PCS solutions (for example, DCS-1800) to meet their specific needs

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