

# The cdma2000 packet core network

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The packet core network, which is a network architecture being promoted by TIA as the packet-data standard for upcoming third-generation cdma2000 networks, is a collection of logical and physical entities that provide IP-centric packet-data-based registration, roaming, and forwarding services for mobile nodes.

The author describes IP mobility support, which provides much of the basic functionality for proper IP connectivity in mobile contexts, as well as Ericsson's implementation in the cdma2000 PCN, which makes use of a packet data service node, home agents, foreign agents and AAA servers (datacom AAA and telecom AAA).

## Introduction

The first commercial wireline telephone switchboard, an ungainly manual contraption, began operation in New Haven, Connecticut on January 28, 1878. It served twenty-one phones on eight separate lines, so the majority of users had to make do with what was referred to as a "party line." By 1903, the estimated number of independent (consumer/household) telephones in place in the US had risen to approximately two million.

Personal transmission of analog audio data was rapidly becoming a ubiquitous and indispensable feature of the technology

landscape. Jumping ahead to the 1970s, the number of telephones installed, both household and business, had risen to well over 100 million plus all the commensurate infrastructure. With tongue in cheek, one might say that our reliance on access to a dial tone is now only slightly less than that on access to oxygen.

The first North American trial deployment of a wireless cellular phone system took place in Chicago, Illinois, in July 1978. Illinois Bell and AT&T rolled out a ten-cell advanced mobile phone service (AMPS) system that covered 21,000 square miles. A market trial with paying customers began on December 20, 1978. The first truly commercial service, after the dust of the Bell breakup had settled, was once again fielded in Chicago by Ameritech on October 12, 1983. By 1985, there were approximately 204,000 cellular subscribers. Within three years, this base had grown to 1,600,000 (incidentally, 1988 also saw the publication of TIA's IS-41 specification). In 1990, driven by capacity concerns, the US cellular network headed down the digital path with the introduction of IS-54B, or digital AMPS (D-AMPS), a TDMA-based dual-mode cellular standard. Three years later, the subscriber count had swelled to more than 13 million. By 1999, the combined North

## BOX A, TERMS AND ABBREVIATIONS

3GPP/3GPP2	Third-generation Partnership Project	GRE	Generic routing encapsulation	PCF	Packet control function
AAA	Authorization, authentication and accounting	GSM	Global system for mobile communication	PCI	Peripheral component interconnect
ABR	Available bit rate	HA	Home agent	PCN	Packet core network
ADSL	Asymmetrical digital subscriber line	HDL	High-level data link communication	PDSN	Packet data service node
AMPS	Advanced mobile phone service	HLR	Home location register	PPP	Point-to-point protocol
ANSI	American National Standards Institute	HTTP	Hypertext transfer protocol	RADIUS	Remote authentication dial-in user server/service
ATM	Asynchronous transfer mode	IANA	Internet Assigned Numbers Authority	RBS	Radio base station
BSC	Base station controller	ICQ	"I seek you"	RFC	Request for comments
BSD	Berkeley Software Distribution (UNIX)	IETF	Internet Engineering Task Force	RP	Radio packet
CBR	Constant bit rate	IP	Internet protocol	RRC	Radio resource control
CDMA	Code-division multiple access	ISP	Internet service provider	RTT	Radio transmission technology
CHAP	Challenge-handshake authentication protocol	LCP	Link control protocol	SDRAM	Synchronous dynamic random access memory
COA	Care-of address	LDAP	Lightweight directory access protocol	TCP	Transmission control protocol
CORBA	Common object request broker architecture	MAAE	Mobility agent advertisement extension	TIA	Telecommunications Industry Association
CPE	Customer premises equipment	MAP	Mobile application part	TPS	Transactions per second
CTIA	Cellular Telecommunications Industry Association	MIP	Mobile IP	TSP	The server platform
D-AMPS	Digital AMPS	MIPS	Million instructions per second	UBR	Unspecified bit rate
FA	Foreign agent	MN	Mobile node	UDR	Usage data record
		NEBS	Network equipment building standards	UTP	Unshielded twisted pair
		OA&M	Operation, administration and maintenance	VBR	Variable bit rate
				VPN	Virtual private network
				WWW	World Wide Web

American subscriber base of the remaining analog AMPS systems and digital TDMA/CDMA systems was (according to figures released by CTIA in April 2000) in the neighborhood of 86 million. Indisputably the phone, either fixed or mobile, and its services have become a necessary fixture in everyday life.

Roughly contemporaneous with the development of wireless phone service, the growth of the “capital-I” Internet proceeded apace. In 1983, 4.2 BSD UNIX with IP support appeared as the conceptual ancestor to the PC—the workstation. By 1987, there are approximately 10,000 interconnected hosts. This number jumped to 100,000 by 1989. The years 1991-1993 were also very big:

- Tim Berners-Lee “created” the World Wide Web (WWW) by introducing the hypertext transfer protocol (HTTP) for simple, atomic, client-server data requests;
- Mosaic offered an integrated “window” into the Internet (the distinction between the Internet and the WWW began to blur, at least in the popular mind) and overall data traffic grew by 341,634% (!) due to Mosaic-fueled browsing.

As of July 2000, there were over 93 million hosts and over 1 billion indexed Web pages, offering search, commerce, specialty communications, such as ICQ (“I seek you”), and purely informational services. Daily reliance on these services and multimedia data communication features made possible by connection to the Internet, now arguably rivals that on fixed/mobile phone services. However, packet-data network access, as exemplified by the Internet, is still “land-locked.” Most end-users still connect their home systems to the Internet over analog phone lines via modem, or (increasingly) via newer, higher-speed purely digital technologies, such as ADSL or a cable modem. Access to mobile packet-data networks still suffers from two limitations:

- low data rates, which make accessing multimedia content and services an exercise in patience; and
- no support for true mobile packet-data service.

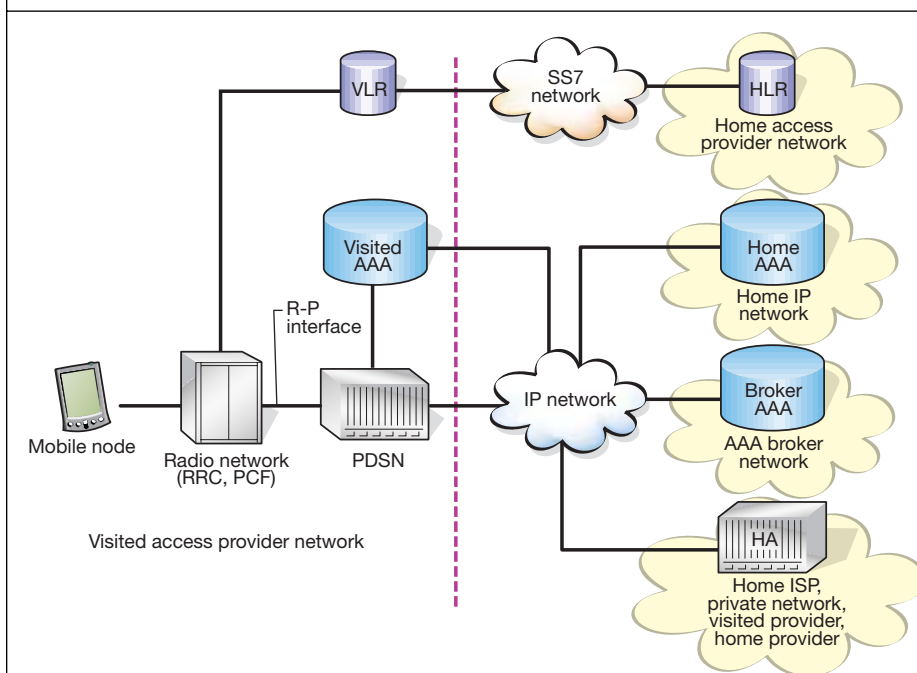
Ericsson’s packet core network (PCN) solution, coupled with the higher data rates provided by their cdma2000 radio base station, heralds the convergence of the mobile circuit-switched and existing packet-switched worlds, to provide seamless voice and data service.

## Background

The wireless evolution to third-generation technologies and services reflects a convergence of the circuit-switched world of “traditional” telephony and the packet-switched world of contemporary computer networks. Hardware and software which belong to packet-data networks and which support IP-centric protocols must be cleanly integrated into third-generation mobile core networks. The proposed architectures for mobile packet-data services are predicated on existing IP-related standards, which—in light of the unique requirements of mobile nodes (which constantly and sometimes rapidly) change their point of connection to a packet-data network—must be extended or completely developed “from scratch” to permit proper IP connectivity and operations.

As implied by its appellation, the packet core network is a collection of logical and physical entities that provide IP-centric packet-data-based registration, roaming, and forwarding services for mobile nodes. At a high level, the packet core network is analogous in operations and entities to an ANSI-41 or GSM mobile application part-based (MAP) mobile core network. The PCN is a network architecture being pro-

Figure 1  
PCN architecture.



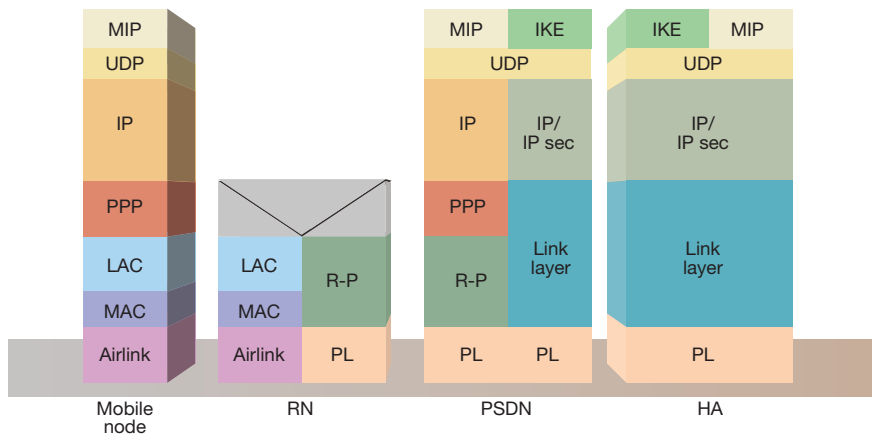


Figure 2  
Protocol reference model for mobile IP control and IKE.

moted by group TR45 of the Telecommunications Industry Association as the packet-data standard for upcoming third-generation cdma2000 networks. The higher bit rates available from the 1xRTT CDMA air interface (up to 144 kbit/s of user data when radio configuration 3 rate sets are available) will permit the use of new wireless multimedia, voice and data applications that were formerly impractical with AMPS or cdmaOne IS-95A technology. In an effort to avoid reinventing the wheel, TIA relied on several existing IETF RFCs in crafting IS-835, the wireless IP network standard. The key RFC, from which was derived most

of the basic functionality of the nodes described in IS-835, is RFC 2002, *IP mobility support*.

## IP mobility

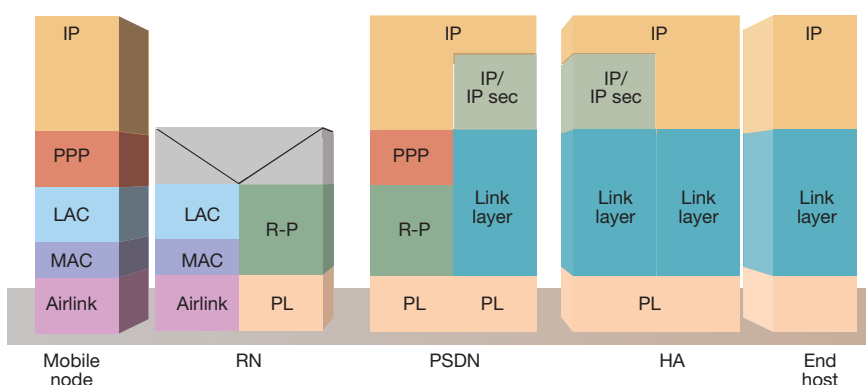
IP mobility support describes the framework of procedures, messages, and message formats that enables a node to change its point of attachment to a network without requiring alteration to its IP address, which would otherwise disrupt layer 3 and higher operations. Peer nodes can respond to the sending node indicated by the IP source address of incoming packets regardless of the IP prefix of the network through which the sending node obtained connectivity. To do this, RFC 2002

- introduces a key distinction between the home address and the care-of address (COA);
- defines three entities—the mobile node (MN), foreign agent (FA), and home agent (HA); and
- delineates the exchanges between the MN, FA and HA that facilitate seamless roaming in layers 3 and above. RFC 2002 also augments the functionality of an existing standard, RFC 1256 ICMP, *router discovery messages*, and extends it to define a mobility agent advertisement extension (MAAE) that enables nodes to advertise their availability to provide foreign agent services in a manner similar to RFC 1256 provisions for the advertisement of routers.

The home address, which is the IP address assigned to a mobile node by its controlling provider, is assigned in much the same way as some Internet service providers (ISP) give a subscriber a fixed Class C address. This address, which can be assigned dynamically, is the source address value in the IP header of outgoing packets. Because the network prefix is the same as that of the network assigned to the controlling provider, this address will probably be topologically incorrect when the mobile node roams into a new network. The care-of address functions as an indirect pointer to the mobile node. It represents the topologically correct and reachable IP address that corresponds to the mobile node's current network attachment, so that the home agent can tunnel packets to it. The care-of address can be located

- in the foreign agent—this is more efficient, since only one address is required to support multiple mobile nodes; or
- in the mobile node itself—this obviates

Figure 3  
Protocol reference model for mobile IP user data.



the need for a foreign agent. In this case, the care-of address is referred to as a co-located COA.

A mobile node is basically any user device which features a TCP/IP stack and supports the added functionality that allows it to register its new location as it roams from network to network. The foreign agent is the critical entity in a (visited) network, making mobility services available to a roaming mobile node. It is also one endpoint of the HA-FA tunnel that is created when a mobile node successfully registers with its home agent for mobile IP (MIP) services. This might be an IP-IP, generic routing encapsulation (GRE), or minimal encapsulation tunnel. The foreign agent advertises its availability for service when a mobile node roams into its network and accepts, processes and forwards a mobile node's registration request to the home agent. The foreign agent also accepts, processes and forwards registration replies from the home agent. The home agent, which is the other endpoint of the FA-HA tunnel, is responsible for attracting traffic destined for the mobile node (based on network prefix) and for tunneling it to the care-of address associated with a given mobile node (presumably an interface on a foreign agent) for further delivery to the mobile node.

The position of the home agent in attracting and tunneling traffic to the mobile node gives rise to inefficiencies in the routing of traffic. If the roaming mobile node and a peer node are geographically very close to each other (in terms of router hops), possibly even on different subnets homed on the same node, packets from the peer to the mobile node must still travel through the mobile node, which may be many additional hops away. Referred to as triangle routing, this is one of the issues in the MIP standard being addressed by a number of IETF drafts collected under the umbrella term of route optimization (Box B and Figure 4).

#### IOS 4.0 and TIA IS-835

IS-835—TIA's wireless IP network standard—lays out the detailed architecture and procedures of the packet core network entities. The standard, which is intended as an implementation document, clearly specifies distinct nodes and their relative areas of responsibility for handling packet data service delivery and mobility management. The interoperability standard (IOS) 4.0 defines

- the radio packet (RP) interface, which is an open interface between the base station

controller (BSC) and packet control function (PCF). A logical division was made, separating the BSC into the radio resource control (RRC) and packet control function (PCF, the "interface" to the PCN); and

- the packet data service node (PDSN), which is a key feature of Ericsson's PCN solution.

As stated above, IS-835 uses existing RFCs as a starting point, so I will focus on four important additions to the general MIP framework described in the document:

- the authorization, authentication and accounting (AAA) server;
- the packet-data service node;
- packet-data-related RADIUS attributes; and
- node-specific mobility-management procedures.

The radio packet interface defines two logical channels: *A11* for signaling, and *A10* for data. Signaling is based on MIP messages (*registration request* and *registration reply*) with two additions: *registration update* and *registration acknowledge*. Data from the mobile node is encapsulated in generic routing encapsulation and tunneled from the packet control function within the base station controller to the PDSN, where it is decapsulated and further processed.

The AAA server, which is based on remote authorization dial-in service (RADIUS), is analogous to the home location register (HLR) of the voice core network. It contains subscriber packet-data-provisioning information and is used to authenticate and de-

#### BOX B, TRIANGLE ROUTING

- The mobile node sends data to its peer node through normal means, using the foreign agent as its default router.
- The peer node sends data to the mobile node indirectly—the home agent intercepts packets destined for the mobile node.
- The home agent encapsulates and tunnels packets to the mobile node via the foreign agent's care-of address. This is inefficient, however, because in theory, a peer node adjacent to the mobile node, either geographically or by network segment, will still have its packets directed through the home agent, which might be located many hops away (see Figure 4).

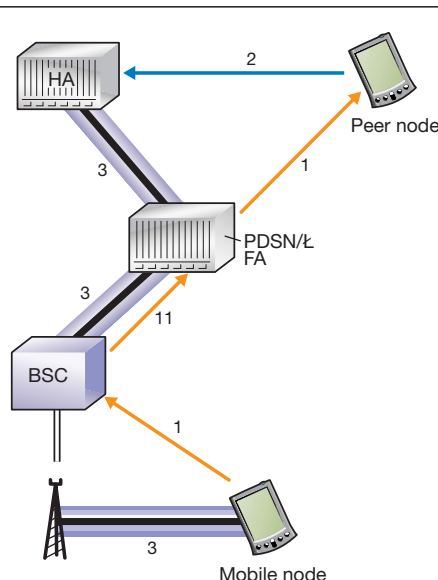


Figure 4  
Triangle routing

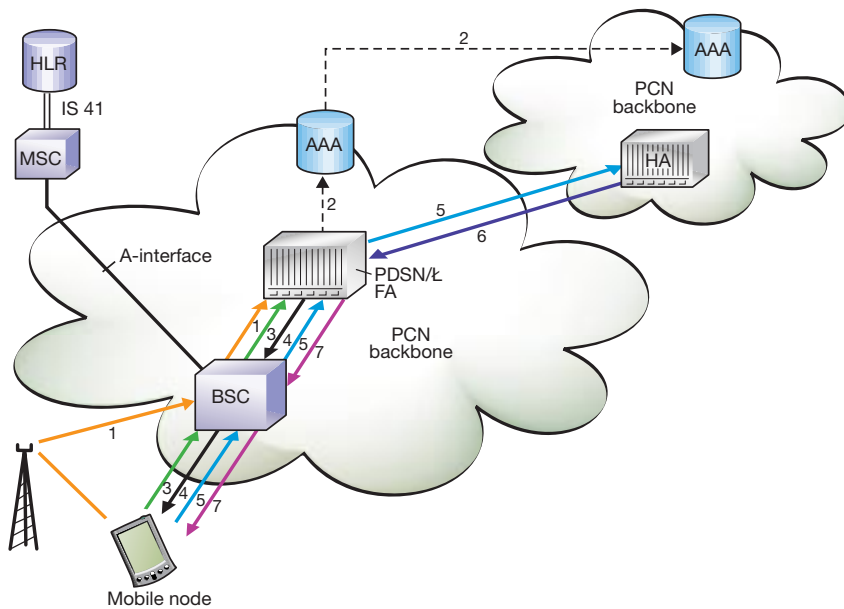


Figure 5  
Mobile IP registration.

#### BOX C, DETAILED MIP REGISTRATION IN ERICSSON'S PCN

- The mobile node (MN) roams into a new (visited) network and sends an origination request to the base station, specifying packet-data service option 33.
- The packet control function (PCF) determines that there is no A10 connection associated with the mobile node and initiates A11 signaling to the packet data service node (PDSN) to set up A10 data connection.
- The mobile node negotiates PPP LCP with the PDSN to establish the data link.
- LCP link parameter negotiation concludes; the CHAP phase begins.
- The mobile node sends CHAP data (CHAP ID, CHAP secret, etc.) to the PDSN, which
  - creates a RADIUS access request, assigning CHAP data to appropriate RADIUS attributes; and
  - sends the attributes to the local AAA server, which proxies the request to the mobile node's home AAA.
- The home AAA returns a positive access accept message through the visited AAA to the PDSN.
- The PPP link is established.
- The mobile node sends agent solicitation to the PDSN/FA looking for an available foreign agent (FA).
- A foreign agent responds with a mobility agent advertisement, listing available foreign agents.
- The mobile node creates a MIP registration request, specifying a willing foreign agent as its care-of address (COA) and forwards the request through the foreign agent to the home agent (HA).
- The foreign agent processes the request and forwards it to the home agent.
- The home agent processes the request and responds with a positive registration reply. It also updates its binding tables with the mobile node's new care-of address association and its remaining lifetime.
- The foreign agent processes the reply, updates its visitor list with a new entry for the mobile node, and forwards the reply to the mobile node.
- A tunnel is established between the foreign agent and the home agent.
- The mobile node can now send packet data using the foreign agent as its default router.
- The home agent can now tunnel traffic sent to the mobile node's home address to the foreign agent, which decapsulates the traffic and transfers it to the mobile node.

terminate the parameters of a subscriber's packet-data session. It is also a store-and-forward point for accounting data in the form of usage data records (UDR) generated by the PDSN.

The PDSN is the mobility anchor point between the mobile node and PCN. The mobile node point-to-point protocol (PPP) data link terminates at the PDSN, and the FA logical entity resides in this same node. The PDSN

- operates as a RADIUS client toward an AAA server;
- is responsible for aggregating accounting information from the radio resource domain via updates sent from the PCF and for combining this data with its own packet traffic information to form complete accounting records; and
- vets subscriber credentials during PPP CHAP activity where the subscriber's information is verified to allow completion of PPP link establishment.

RADIUS attribute extensions have been defined by TIA in IS-835 to enable information on cdma2000 packet data operations to be exchanged within the RADIUS protocol framework. The extensions are of type "26"—that is, they are vendor-specific (3GPP2). The 3GPP2 vendor ID used with them is 5535, as defined by the Internet Assigned Numbers Authority (IANA). The attributes can be broken down further into accounting and service-related attributes, such as session status, session activity, security status, and differentiated services class option. These attributes are exchanged between the PDSN and AAA in, for example, access request, access accept, and accounting request RADIUS messages.

Mobility management defines two roaming scenarios and the procedures to accommodate them. In the PCF-to-PCF handoff scenario (intra-PDSN), the mobile node moves from one base station controller to another, and both BSCs are connected to the same PDSN. This type of handoff might not require the renegotiation of the PPP session between the mobile node and PDSN, since the PDSN can re-associate the PPP state of the mobile node with the new base station controller. In the PDSN-to-PDSN handoff scenario (inter-PDSN), the mobile node (presumably) roams into a new network with a different PDSN. In this case, the mobile node is required to establish a new PPP link to the new PDSN and then perform MIP registration again.

An addendum to IS-835, IS-835-A-1, which is currently under review, attempts to clarify “gray areas” in the initial document, such as handoff optimization, security indications for optimized key exchanges, and the removal of data entities (these have been underutilized in emerging implementations of the standard).

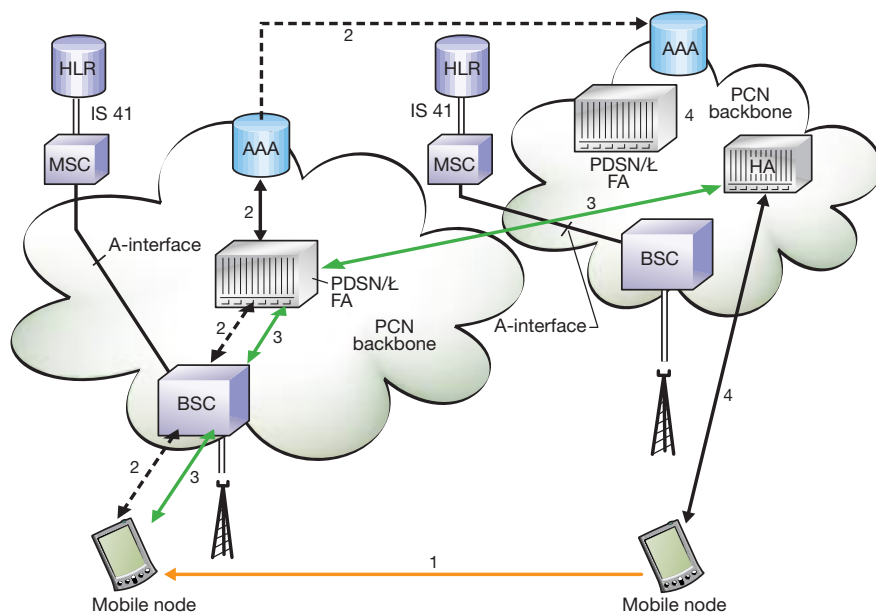
## Ericsson’s packet core network

Ericsson has capitalized on decades of telecom and datacom expertise to deliver a fully open standards-compliant third-generation packet network architecture that incorporates the most recent advances in mobile packet-data transmission technology. The PCN product roadmap includes PDSN, HA and AAA offerings that span the range of subscriber or traffic loads, from equipment that handles from 5,000 to 7,000 simultaneous sessions to platforms that handle up to 400,000 simultaneous sessions typically deployed in a central office.

All Ericsson solutions offer carrier-class network equipment building standards (NEBS) level 3-compliant access platforms for the PDSN/foreign agent and home agent nodes. The AAA server is also NEBS-compliant for use in a carrier operations center.

### PDSN

The first router in the Ericsson PCN family to implement PDSN functionality is the AXC, which has been optimized for small-scale deployment. In PDSN trim, up to 50,000 simultaneous PPP sessions are supported. The AXC provides a PCI-derived 1 Gbit/s packet bus coupled with a MIPS CPU and up to 512 MB of SDRAM, split between packet memory (for packet forwarding) and local memory. Up to 64 MB of flash memory is used for operating system activity, such as maintaining IP routing tables, physical interface tables, and so on. Dual control cards provide support for redundant failover, so that the failure of one control card will result in the backup card taking over—a necessary configuration in high-availability carrier environments. This configuration features 10/10BaseT unshielded twisted pair (UTP) redundant ports for network connectivity and uses asynchronous transfer mode (ATM) interface cards to the base station controller. These high-performance interface boards, which are based on the IDT R4700 processor, support OC-3 and STM-1 155 Mbit/s



**Figure 6**  
Mobile IP handoff.

over single- or multi-mode fiber or CAT-5 STP. Standard ATM service class configurations, such as constant bit rate (CBR), variable bit rate (VBR), available bit rate (ABR) and unspecified bit rate (UBR) and their associated metrics are supported, as well as support for RFC 1483, to enable multiprotocol encapsulation over ATM.

The medium- to high-capacity PDSN platform is the AXI, in seven- or fifteen-slot configurations, supporting up to 200,000 simultaneous PPP sessions.

To the base station controller, each OC-3/STM-1 ATM interface card features four single- or multi-mode physical 155 Mbit/s fiber interfaces. The ATM forwarding engine supports both PPP (RFC 1619, *PPP over SONET*) and HDLC (RFC 1662, *PPP in HDLC-like framing*) encapsulation. All major components (the route processor module, switch fabric modules, fans, power supplies, and so on) are one-to-one (1:1) redundant and hot-swappable for zero-downtime operation.

### Home agent

The home agent is based on the same hardware platforms as the PDSN. It is also pro-

### BOX D, MOBILE IP HANDOFF

- The mobile node roams into a new access provider.
- The mobile node engages in new PPP negotiation with a new PDSN. As before, the PDSN determines the subscriber attributes during the CHAP authentication phase of PPP via an AAA server.
- The mobile node obtains the care-of address (COA) from the foreign agent and registers with the home agent, updating its mobility binding with the new COA (in Figure 6, the mobile node is shown roaming away from its home network). The foreign agent updates its visitor list.
- The previous PPP link is torn down and the foreign agent visitor list entry is deleted after registration lifetime expires.

## TRADEMARKS

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vided on an additional platform, the Fraser, which has been optimized for customer premises equipment (CPE) solutions that target the corporate level (that is, virtual private networks) and supports up to 7,000 PPP sessions. The Fraser features two fast Ethernet ports, an IDT R4700 central CPU, 8 MB Flash RAM for configuration storage, and 16 MB DRAM dedicated packet memory.

### AAA server

A unique design innovation in the Ericsson PCN places all node configuration information in the AAA server. Thus only the AAA

server is provisioned—subscriber and node data is accessed by the PDSN or HA on an as-needed basis. This avoids the redundancy of duplicate provisioning, a situation which arises because IS-835 specifies the data that is required by the nodes for MIP operations but not how the data is to be disseminated. An additional benefit of this approach is the short deployment time for nodes in an Ericsson PCN. If a node currently operating as a PDSN must be rotated out or switched to home agent duty, a reload of the operating system (incorporating appropriate node-specific PCN features) is the only operator activity needed to completely re-provision the node. The remaining provisioning data is retrieved from the AAA server.

### Datacom AAA

The AAA applications feature full RADIUS support with cdma2000-specific attributes (RFC 2138, 2139) as well as AAA extensions for MIP authorization and accounting support. The underlying database systems, which support widely accepted open data

## BOX E, STANDARDS AND RFC'S

### TIA standards

TSB115	Wireless IP Network Architecture
IS-707-A-1.10	Data Service Options for Spread Spectrum Systems: Radio Link Protocol Type 3
IS-707-A-1.11	Data Service Options for Spread Spectrum Systems: cdma2000 High Speed Packet Data Service Option 34
IS-707-A-1.12	Data Service Options for Spread Spectrum Systems: cdma2000 High Speed Packet Data Service Option 33
IS-835	Wireless IP Network Standard
IS-2000-1	Introduction to cdma2000 Standards for Spread Spectrum Systems
IS-2000-2	Physical Layer Standard for cdma2000 Spread Spectrum Systems
IS-2000-3	Medium Access Control Standard for cdma2000 Spread Spectrum Systems
IS-2000-4	Link Access Control Standard for cdma2000 Spread Spectrum Systems
IS-2000-5	Upper Layer (Layer 3) Standard for cdma2000 Spread Spectrum Systems
IS-2000-6	Analog Standard for cdma2000 Spread Spectrum Systems
IS-2001	Interoperability Specification for cdma2000

### RFCs

RFC 1256	ICMP router discover
RFC 1661	PPP
RFC 1662	PPP HDLC framing
RFC 1701	Generic routing encapsulation (GRE)
RFC 1702	GRE in IP
RFC 2002	Mobile IP
RFC 2003	IP in IP encapsulation
RFC 2004	Minimum encapsulation
RFC 2138	Remote authentication dial-in user service (RADIUS)
RFC 2139	RADIUS accounting
RFC 2344	Reverse tunneling
RFC 2401	IPSec security architecture
RFC 2402	Authentication header (AH)
RFC 2406	Encapsulating security payload (ESP)
RFC 2661	Layer 2 tunneling protocol (L2TP)

processing standards, such as the lightweight directory access protocol (LDAP), are fully distributed and replicated (logically, and if so configured, geographically) for zero downtime, should a particular node or office fail. Very high transactions-per-second (TPS) levels can be sustained, which reflects the large subscriber base and high activity rate currently seen in the circuit-switched world.

### Telecom AAA

The telecom AAA node is based on Ericsson's TSP, a multi-CPU and scalable applications platform. The distributed real-time operating system, runs on Pentium boards, each with 512 MB dedicated RAM, and supports open data transfer standards, such as the common object request broker architecture (CORBA). Dual, dedicated UltraSparc boards run operation, administration and maintenance (OA&M) applications, providing access to external databases. The AAA and HLR platforms are derived from the same architecture, providing a single point for packet and telephony subscriber provisioning.

## Conclusion

Two forces have driven the development of the packet core network: the evolving consumer demand for convenient access to multimedia data services, as exemplified by the World Wide Web, and the approaching technological convergence of circuit-switching and packet-switching—a packet-based bearer medium supporting and coexisting with traditional circuit-switched services.

Ericsson's PCN solution introduces three nodes—the home agent, PDSN/foreign agent, and AAA—which support high-speed wireless packet-data operations and provide zero-downtime operational characteristics for demanding telecommunications environments. The nodes are evolved from mature hardware architectures with proven track records, such as the AXC, AXI and TSP platforms. With Ericsson's full support of the open standards radio-packet interface, the PCN can be rapidly and smoothly integrated into any cdma2000 core network.

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