♦ Cellular Digital Packet Data Networks

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Cellular digital packet data (CDPD) is the first wide area wireless data network with open interfaces to enter the wireless services market. Operating in the 800-MHz cellular bands, CDPD offers native support of transmission control protocol/Internet protocol (TCP/IP) and connectionless network protocol (CLNP). This paper presents an overview of CDPD's network architecture, its network performance issues, and wireless data applications that take advantage of CDPD's seamless support of IP and CLNP data.

Introduction

Cellular digital packet data (CDPD) unites two dynamic technologies: internetworking and wireless communications. Designed as an overlay to typical 800-MHz analog cellular (Advanced Mobile Phone System [AMPS]) networks, CDPD seamlessly supports network applications based on Internet protocol (IP) or connectionless network protocol (CLNP). Native support of these popular networking protocols allows mobile data users to run familiar applications and facilitates rapid development of new applications that take advantage of CDPD's anytime, anywhere access to internets and intranets.

The CDPD system specification[1] was developed in the early 1990s by a consortium of U.S. cellular service providers, later organized as the CDPD Forum. Members of the CDPD Forum sought to create an open, nationwide wireless data service. In late 1994, CDPD entered commercial service.

After an initial connection setup procedure called *registration*, CDPD mobile subscribers can send and receive data on demand without additional connection setup delay. CDPD networks were designed to support "pay-by-the-packet" and "pay-by-the-byte" billing schemes. These schemes, shown in **Table I**, combined with attractive pricing packages, make wireless data a cost-effective option for applications that periodically send and receive relatively small amounts of data. For such applications, the cost of making a circuit-switched wireless call for each transaction or of keeping a call established could be prohibitive.

The CDPD network builds on the familiar cellular network architecture shown in **Figure 1**. CDPD includes specifications for an air link, mobility management, accounting, and internetworking.

CDPD Network Architecture

CDPD networks consist of several major components:

- Subscriber devices,
- Infrastructure equipment provided by a cellular operator, and
- Network connections to internets and intranets, as shown in **Figure 2**.

An air link provided by CDPD efficiently supports digital data over 800-MHz cellular frequencies, with each 30-kHz cellular channel capable of serving multiple CDPD subscribers simultaneously. A subscriber registered with the CDPD network may keep a session intact for many hours, regardless of the volume of data sent or received.

CDPD uses different strategies for managing access to the *forward* (data flowing to the mobile user) and *reverse* (data flowing from the mobile user) channels. Base stations continuously transmit CDPD's forward air link, sending control and data signals to mobile units. The mobile data intermediate system (MD-IS) controls the flow of data in the forward direction and sends it serially in the form of link layer frames. A mobile data base station (MDBS) then relays the link layer frames over the forward air link. The CDPD digital sense multiple access control protocol with collision detection (DSMA/CD), discussed later in this paper, governs transmissions over the reverse air link. This Ethernet-like medium access control (MAC) protocol arbitrates reverse air link contention.

CDPD supports both unacknowledged broadcast and multicast services. Transmission of a single packet over CDPD's *broadcast* service efficiently sends the packet to all mobiles in a geographic area. CDPD's *multicast* service transmits messages to a select group of mobile end systems (M-ESs) in an area. Multicast transmissions follow subscribers in the multicast group as they roam. Only one packet is sent over the air for all members of a multicast group registered for receipt of multicast data on a particular CDPD channel, saving air link bandwidth.

Panel 1. Abbreviations, Acronyms, and Terms

AMPS—Advanced Mobile Phone System
CDMA—code division multiple access
CDPD—cellular digital packet data
CLNP—connectionless network protocol
CM-ES—circuit-switched mobile end system
CMD-IS—circuit-switched mobile data intermediate system
CPU—central processing unit
CS-CDPD—circuit-switched cellular digital packet data
DSMA/CD—digital sense multiple access with collision detection
FEC—forward error correction
F-ES—fixed end system
GMSK—Gaussian filtered minimum shift keying
GPS—global positioning system
HDML—handheld device markup language
ICMP—Internet control message protocol
IP—Internet protocol
IS—intermediate system
LAP-D—link access procedures for D (data) channel
MAC—medium access control
M-ES—mobile end system
MDBS—mobile data base station
MD-IS—mobile data intermediate system
MDLP—mobile data link protocol
OSI—Open System Interconnection
PCMCIA—Personal Computer Memory Card International Association
PDU—protocol data unit
POTS—"plain old telephone service"
PSTN—public switched telephone network
PVC—permanent virtual circuit
RF—radio frequency
SNDCP—subnetwork dependent convergence protocol
SREJ—selective reject
TCP—transmission control protocol
TDMA—time division multiple access
TIA—Telecommunications Industry Association
UDP—user datagram protocol
WAN—wide area network

Mobile End System

The CDPD subscriber device, called a mobile end system (M-ES), takes a variety of forms: an integral part of a hand-held mobile telephone, a Personal Computer Memory Card International Association (PCMCIA) card installed in a laptop, or a hardened point-of-sale terminal.

The major components of an M-ES include a modem/radio and a processor running the CDPD protocol stack. CDPD uses Gaussian filtered minimum shift keying (GMSK) modulation[2] and Reed-Solomon[3] forward error correction (FEC) to provide wireless data service in cellular's typically harsh radio-frequency (RF) environment. M-ESs may be full duplex, with separate transmitter and receiver sections in the radio, or half duplex, with a transmitter and a receiver that share major components. Full-duplex mobile units—which, unlike half-duplex units, can transmit and receive data simultaneously—provide superior throughput and service under adverse RF conditions. As with all portable wireless devices, power management is an important function. CDPD mobile units have a range of maximum transmit power levels from 0.6 to 3 watts and dynamically change their transmit power level to conserve power and reduce interference. An optional sleep mode conserves power by allowing M-ESs to power down RF circuitry when they are not transmitting data and to periodically awaken to see if forward data is pending.

The M-ES uses information broadcast over the forward channel to determine when and how to

Table I. High-level comparison of packet- and circuit-switched data networks.

Billing scheme	Network architecture	Latency for initial transmission (sec)	Typical pricing	Typical network usage
Packet data (for example, CDPD)	Connectionless	≤ 1	Based on data volume	Short, bursty transactions
Circuit data	Connection-oriented	5-20	Based on connect time	Larger amounts of data

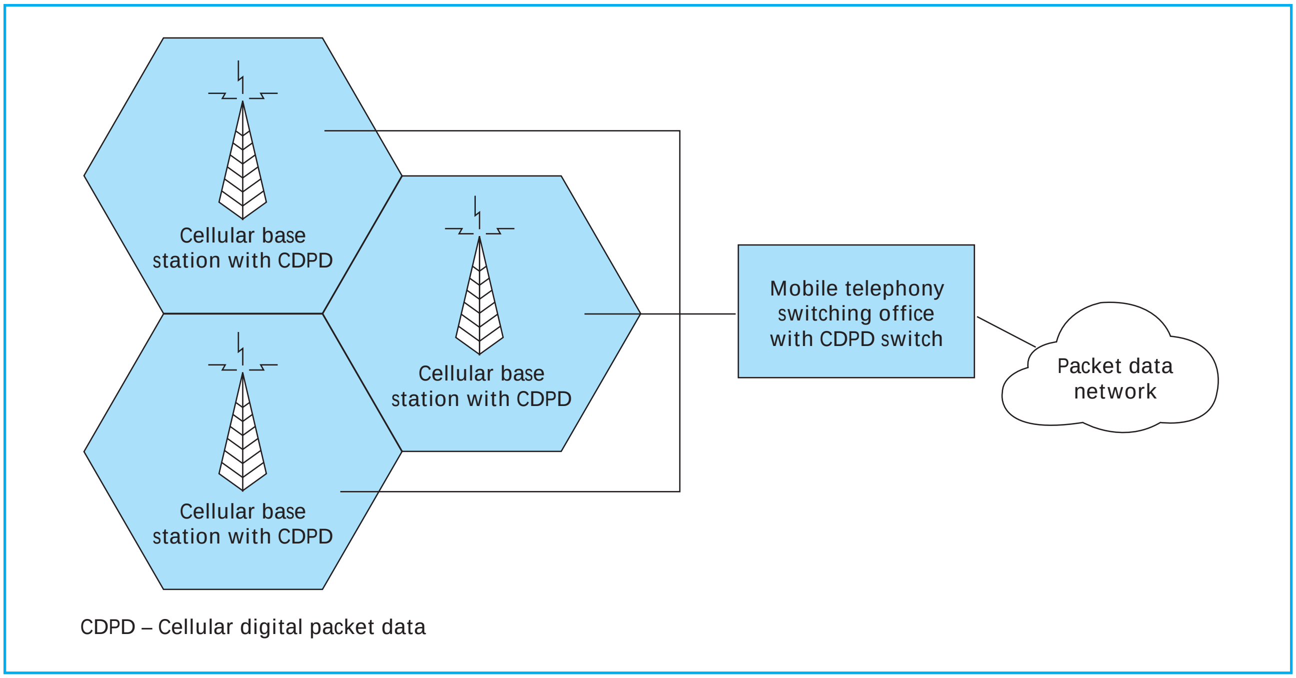

Figure 1.
CDPD as an AMPS network overlay.

search for new RF channels. RF channels may need to be changed when:

- The mobile unit travels between cell sectors,
- The current RF channel experiences fades or interference, or
- Contention with the AMPS network for RF channels triggers channel hopping, as described later in this paper.

Mobile Data Base Station

The mobile data base station (MDBS) resides at the cellular site and typically covers a geographical area of 0.5 to 5 km in radius. On the forward channel, the MDBS transmits status data about its transmit power level, the adjacent sectors' CDPD channels, the decode status of received reverse data, and the activity status (busy or idle) of the reverse channel. The MDBS does not maintain information about registered mobile units, nor does it play a direct role in M-ES mobility.

CDPD often uses the same base station antenna as an AMPS cell and the same cellular voice RF plans. Network planners may configure the RF channels used by CDPD in various ways at the MDBS:

- *Dedicated*. One or more 30-kHz channels are dedicated to CDPD in each sector of the cell site. This is the simplest configuration, but it uses the most RF spectrum.
- *Omnidirectional overlay*. Each cell broadcasts an omnidirectional CDPD signal, overlaid on a sectorized AMPS cell. Fewer RF channels are used for CDPD, with a corresponding reduction in CDPD capacity.
- *Channel hopping*. CDPD radios are dedicated to

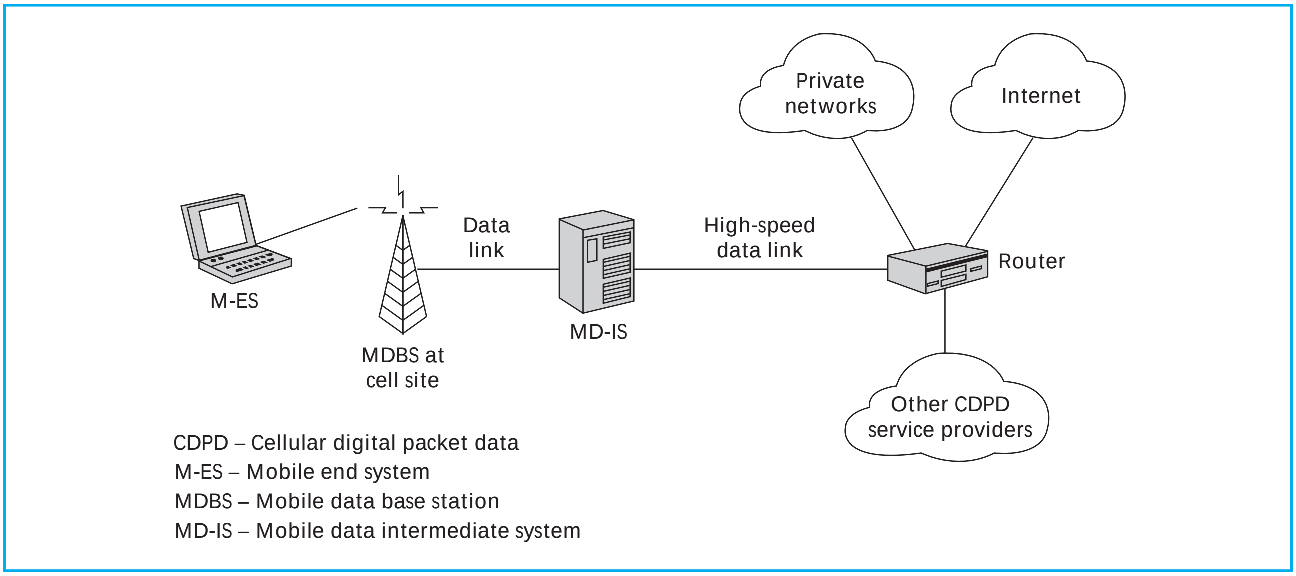

Figure 2.
CDPD network architecture.

each AMPS sector, but CDPD attempts to share 30-kHz channels with AMPS calls, where AMPS calls have priority over data. As described later in this paper, channel hopping works well when AMPS blocking rates are low to moderate.

At the cost of complicating RF planning, different cell configurations can be used in adjacent cell sites, or even within the same cell.

CDPD was designed to coexist with AMPS and to share/reuse many components such as power, enclosures, antennas, and RF amplifiers. Cellular service providers have found it easy to add CDPD equipment to existing AMPS base stations. CDPD is being used in some areas, however, as a standalone data network.

Mobile Data Intermediate System

The mobile data intermediate system (MD-IS), typically located at the mobile telephony switching office, provides:

- Support for CDPD mobile protocols, including transmission of subscriber data. To prevent fraud, M-ESs are authenticated as part of the registration process and are denied CDPD network access if they present invalid credentials. The MD-IS and M-ES share responsibility for ensuring that user data is reliably sent. Data flowing between the MD-IS and M-ES is encrypted to protect it against eavesdropping.
- Mobility management. Mobiles must be tracked as they travel between cells or between channels within a single cell.
- Accounting. The MD-IS records detailed accounting data in a standard format.
- An interservice provider interface. As a mobile roams outside its home area, the mobile unit's home MD-IS must cooperate with the *serving* MD-IS. The home MD-IS must determine if the mobile is allowed to receive service and tunnel forward subscriber traffic from the home to serving systems.
- Connections into wide area networks (WANs). The MD-IS is typically connected to one or more conventional routers that route subscriber traffic towards its destination.

From a network and application viewpoint, CDPD is a wireless extension of the Internet. IP-based applications usually run on CDPD networks with *no* modifications. End users may find it beneficial to make some changes to their applications to improve performance and to lower network usage costs, as discussed later, in "CDPD Applications." The CDPD specification supports conventional IP (IPv4) and Open System Interconnection (OSI) mobile devices. Support of the next version of IP (IPv6)[4] is planned.

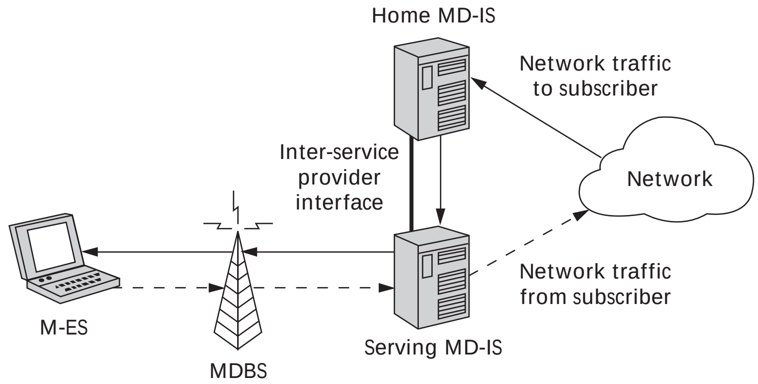

Figure 3.
CDPD mobility management.

The MD-IS is the focal point for mobility management, either within a service area or as the subscriber roams between CDPD service providers. A CDPD subscriber must be registered with the CDPD network to receive service. After the mobile unit has found an appropriate CDPD channel, it registers by sending its network credentials, based on shared secrets. These credentials validate that the mobile unit is authorized to receive CDPD service. In the simplest case, the MD-IS has direct access to a subscriber database for this authentication.

As a CDPD subscriber moves from one local AMPS sector to another, the M-ES scans for and moves to new channels to maintain service. The serving MD-IS tracks these handoffs. When the CDPD subscriber moves outside his or her home service region, MD-ISs from other service providers may be enlisted to maintain CDPD service. An M-ES has a *fixed* network address (typically an IP address), but it may receive service from any CDPD service provider that operates with the subscriber's home system, as shown in **Figure 3**.

The home MD-IS of an M-ES manages roaming by authenticating the subscriber and sending forward data to the MD-IS where the subscriber is currently receiving CDPD service. The serving MD-IS provides the air link, collects detailed accounting data, and operates with the subscriber's home MD-IS.

Circuit-Switched CDPD

During the early stages of CDPD deployment, some AMPS cell sites may not be equipped with MDBSs. In addition, CDPD's usage-based accounting may not be cost-effective for applications exchanging large amounts of data. Both situations are addressed by introducing circuit-switched CDPD (CS-CDPD).[5] Although CDPD's air link is not used, its mobility model and subscriber management are. CS-CDPD works using a dedicated connection between the subscriber and service provider. A CS-CDPD session, shown in **Figure 4**, requires a circuit-switched connection that includes, for example, a cellular data call using an AMPS-specific modem, a land-line public switched telephone network (PSTN) call using a conventional 28.8-kb/s modem, or an integrated services digital network (ISDN) data link.

Today, CDPD service is available in most metropolitan areas. When subscribers travel to an area without CDPD coverage, they can use the same applications, the same IP network address, and typically the same modem to establish a CS-CDPD cellular connection.

Although CS-CDPD shares much with CDPD, such as accounting, encrypted subscriber traffic, and

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