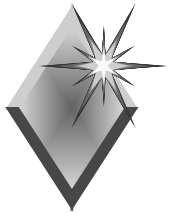
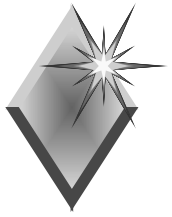


Course Overview

- Introduction and History
- Regulatory Issues
- Fundamentals of Cellular Systems
- AMPS and CDPD (Cellular Digital Packet Data)
- GSM (Global System for Mobile communication)
- Mobile IP
- TCP over Wireless Link
- Issues in Mobile Application Design
- Outlook and Conclusions

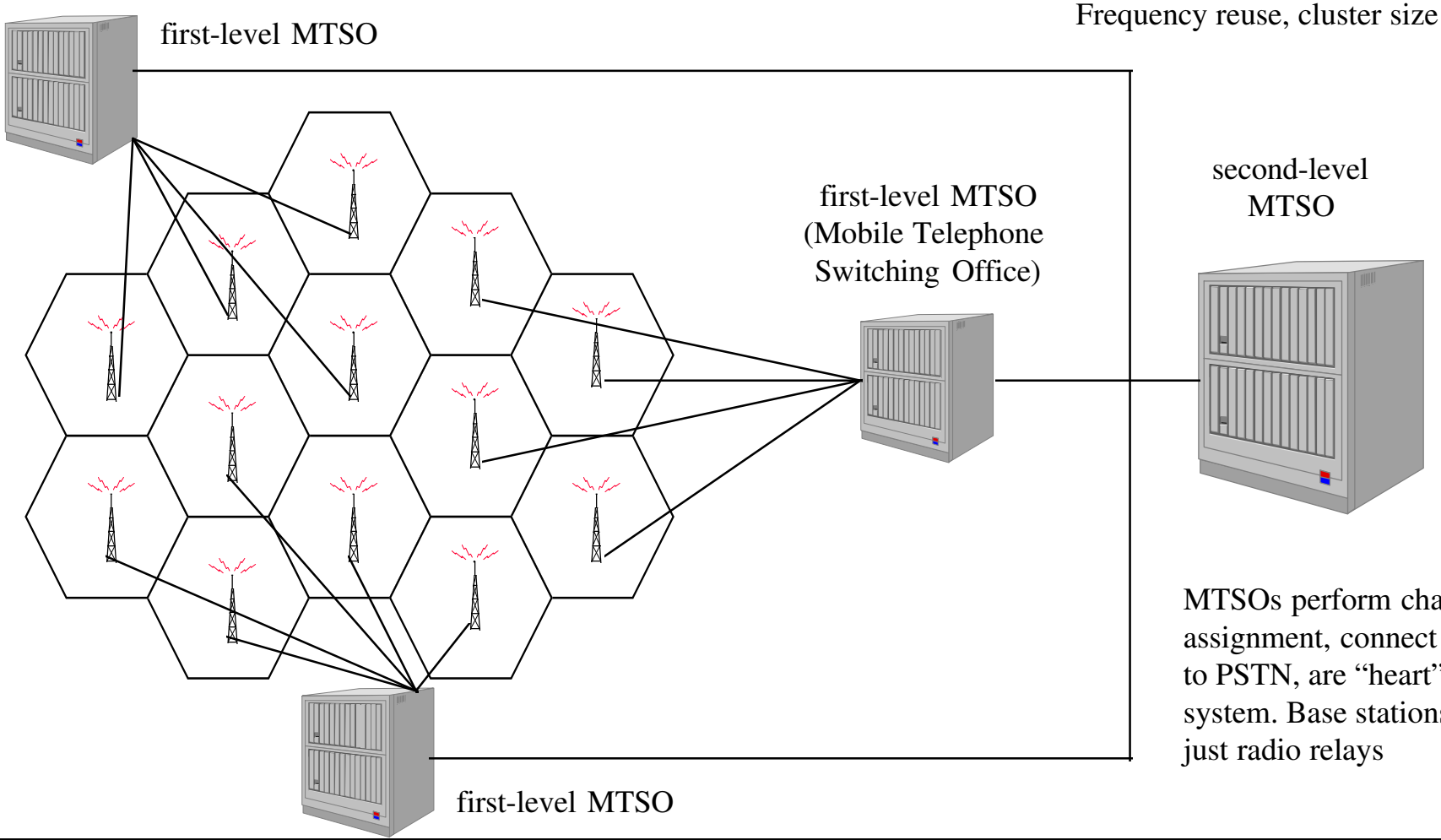


AMPS: History

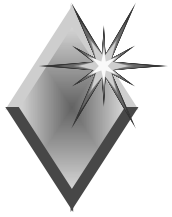
- FCC allocated spectrum space in the 800 MHz spectrum and issued licenses for test systems in Chicago and Washington, D.C.
- first commercial systems available 1983, available in all major cities in US in a few years
- AMPS result of extensive research by Bell Labs in 1960s and 1970s
- 800 MHz band was compromise
  - lower frequencies occupied by FM and TV systems
  - higher frequencies were deemed too unreliable (information loss due to weather conditions, multipath fading, etc.) with existing technology

AMPS Architecture

Cells: typically 10-20 km across
Phones transmit at 0.6 watts
Frequency reuse, cluster size = 7

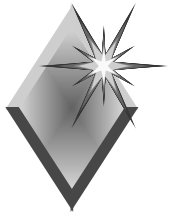


MTSOs perform channel assignment, connect AMPS to PSTN, are "heart" of the system. Base stations are just radio relays



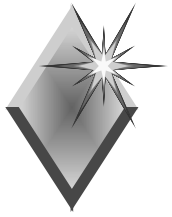
AMPS Spectrum and Channels

- AMPS is narrowband channel structure, supporting 3kHz analog channels, modulated into 30kHz channels
- occupies parts of spectrum ranging from 824 MHz to 894 MHz, split into two categories
  - Band A:
    - Transmit 824-835 MHz and 845-846.5 MHz
    - Receive: 869-880 MHz and 890-891.5 MHz
  - Band B:
    - Transmit: 835-845 MHz and 846.5-849 MHz
    - Receive: 880-990 MHz and 891.5-894 MHz
  - 312 useable RF pairs divided by 7 (reuse factor) = roughly 45 channel pairs per cell



AMPS Spectrum and Allocation

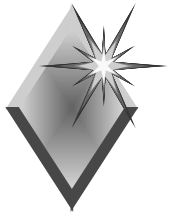
- A band set up for independent carriers
- B band set up for traditional wireline carriers, such as the Regional Bell Operating Companies (RBOC)
- idea was to ensure competition in all markets, while restrict potential proliferation of companies that would complicate spectrum allocation/management
- today, many independent carriers bought by RBOCs, so it is not uncommon to have one company operating in Band A in one market and Band B in another market
- channels always come in pairs, spaced 45 MHz apart



AMPS: Channel Numbers and Frequencies

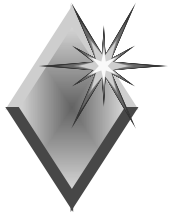
System	Mhz	# of channels	boundary channel number	transmitter center frequency, mobile	transmitter center frequency, base
Not used		1	(990)	(824.010)	(869.010)
E-AMPS	1	33	991	824.040	869.040
			1023	825.000	870.000
A	10	333	1	825.030	870.30
			333	834.990	879.990
B	10	333	334	835.020	880.020
			666	844.980	889.980
A’	1.5	50	667	845.010	890.010
			717	846.480	891.480
B’	2.5	83	717	846.510	889.510
			799	848.970	883.970

E-AMPS, A’ and B’ added later, A’ and B’ may optionally use 5 MHz
Channels 313-333 and 334-354 are control channels, provider is free to use them in any manner deemed appropriate



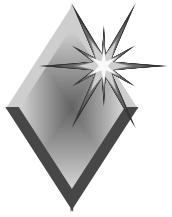
AMPS Identification Numbers

- three identification numbers are used:
  - mobile station's serial number (SN)
    - 32-bit binary number
    - uniquely identifies a cellular unit
    - established by manufacturer at the factory
      - 8-bit manufacturer code, assigned by FCC to manufacturer
      - 6 bit reserved (currently all 0)
      - 18 bits serial number, assigned by manufacturer
    - should not be easily alterable, burned into ROM
  - system identification number (SID)
    - 15-bit binary number, uniquely identifies cellular system
    - FCC assigns SID
    - mobile station in the cell must transmit the SID
  - mobile identification number (MIN)
    - digital representation of mobile's 10-digit telephone number



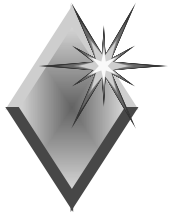
AMPS Call Management

- when phone is switched on, scan known list of control channels for most powerful signal
  - phone can be set to scan Band A only, Band B only, Band A first, Band B first, depending on services customer subscribed
- learn number of paging and access channels from control channel, broadcast 32-bit SN and 34-bit MIN
- all control information is sent in digital form, multiple times, and with error-correcting codes
- when base station hears announcement, it tells the MTSO (Mobile Telephone Switching Office), which records existence and tells home MTSO
- mobile phone registers about once every 15 minutes



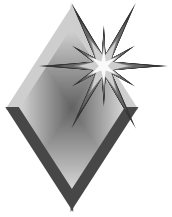
AMPS: Call Initiation

- user enters number and presses SEND
- phone sends number to be called and own identity on access channel (random access channel), retry in case of collision
- MTSO looks for idle channel (if caller is customer of MTSO's company or one of its partners) and sends back channel number on the control channel
- mobile phone switches to the selected voice channel and waits until the called party picks up the phone



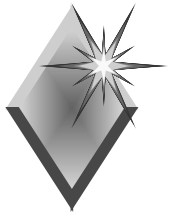
AMPS: Call Reception

- idle phones continuously listen to the paging channel to detect messages directed at them
- when someone initiates call to mobile, message is sent to home MTSO to find out where mobile currently is
- a packet is then sent to base station in current cell, which pages the mobile on the paging channel
- if mobile replies, base assigns channel number and sends it to mobile
- mobile switches to this channel and starts making ringing sound



AMPS: Security

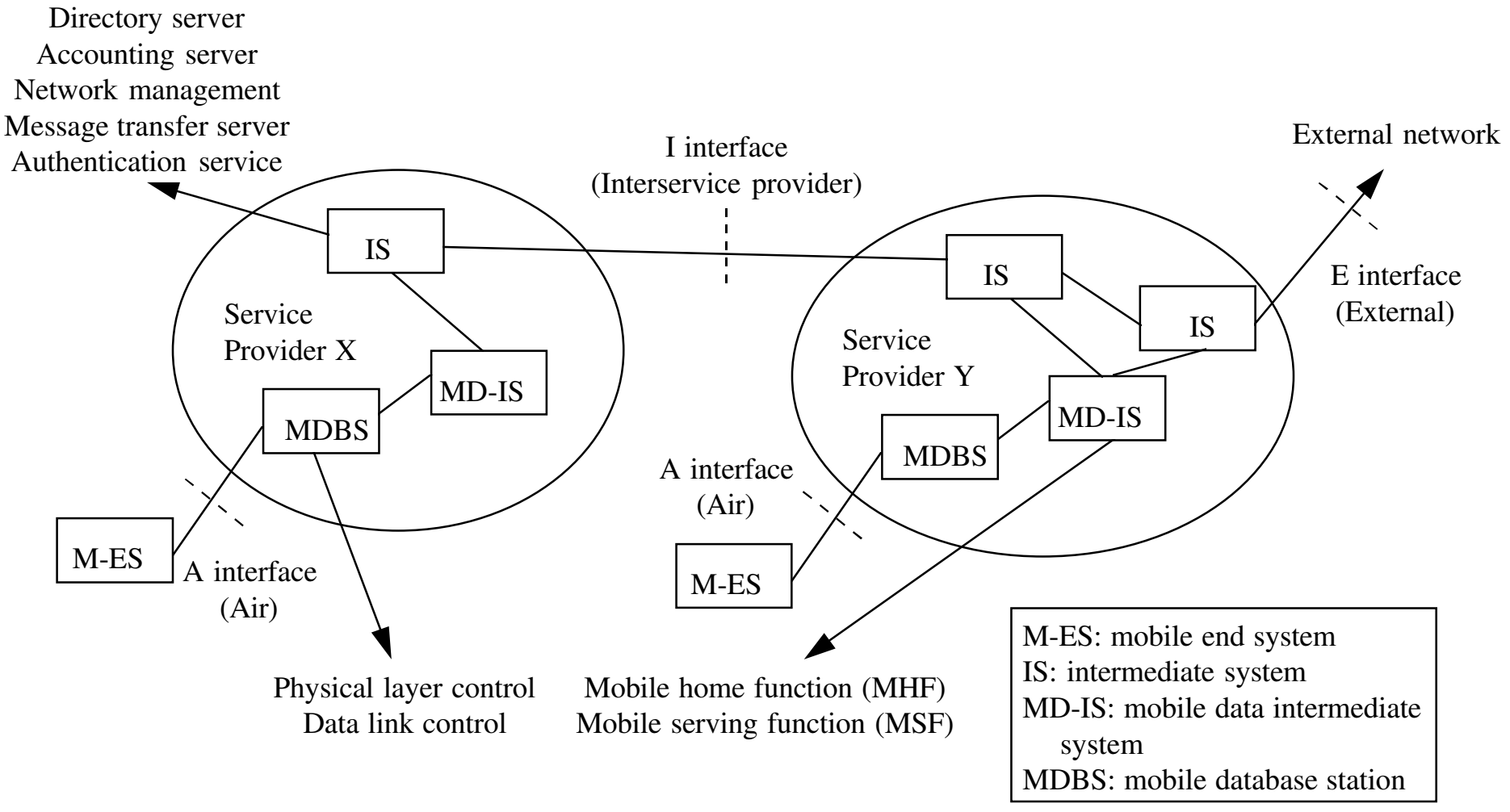
- analog cellular phones are completely insecure
  - anyone with all-band radio receiver can tune in and listen, just ask the British Royal Family
  - also, combining all-band receiver with a computer, one can monitor the control channels and record all 32-bit serial numbers and 34-bit MINs (kind of like monitoring Ethernet for password in clear text, except that intrusion here is even easier)
  - once SN and MIN are know, use them to reprogram cheap phones and viola: all your calls will be charged to unsuspecting victim, who will only notice weeks later, when phone bill arrives (big scam in New York).
- also an issue of vandalism and damage to antennas and base stations (similar to damaged public phone booths)

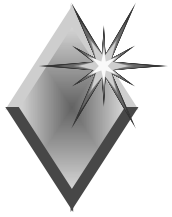


CDPD

- CDPD: Cellular Digital Packet Data
- idea: “steal” unused channels from AMPS to transfer packet data
- first specification published by several mobile carriers in 1993 (version 1.1 appeared January 1995):
  - Ameritech Mobile Communications, Inc.
  - Bell Atlantic Mobile Systems
  - Contel Cellular, Inc.
  - GTE Mobile Communications, Inc.
  - McCaw Cellular Communications, Inc.
  - NYNEX Mobile Communications, Inc.
  - PacTel Cellular
  - Southwestern Bell Mobile Systems

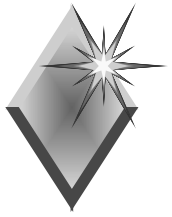
CDPD: Architecture





CDPD: Architecture

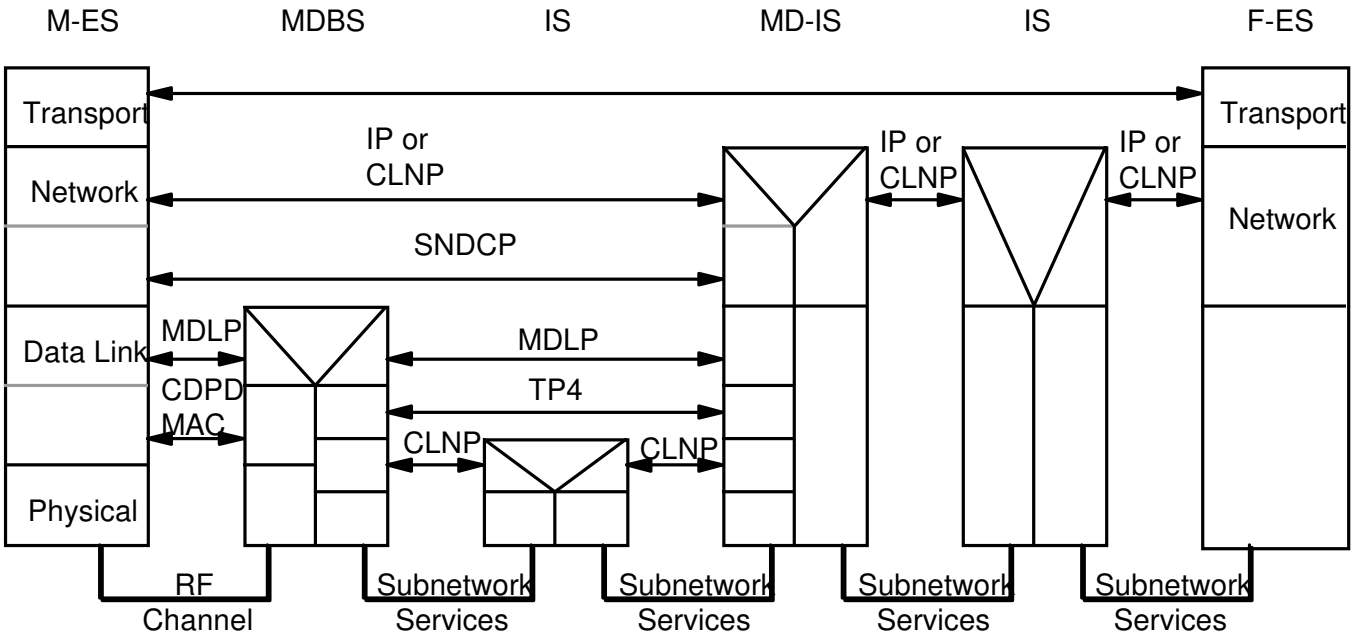
- M-ES: user device, mobile, identified by at least one globally unique Network Entity Identifier (NEI)
- IS: basically a router, might provide additional services
- MD-IS: only entity that has knowledge of mobility, runs MNLP (Mobile Network Location Protocol):
  - each M-ES belongs to a fixed home area, MHF keeps track of this information
  - MSF handles packet transfer services for visiting M-ES
  - requires that M-ES register with serving MD-IS when roaming
- MDBS: supports air interface to M-ES
  - resides at the AMPS cell
  - uses AMPS transmit and receive equipment



CDPD: Protocol Stack

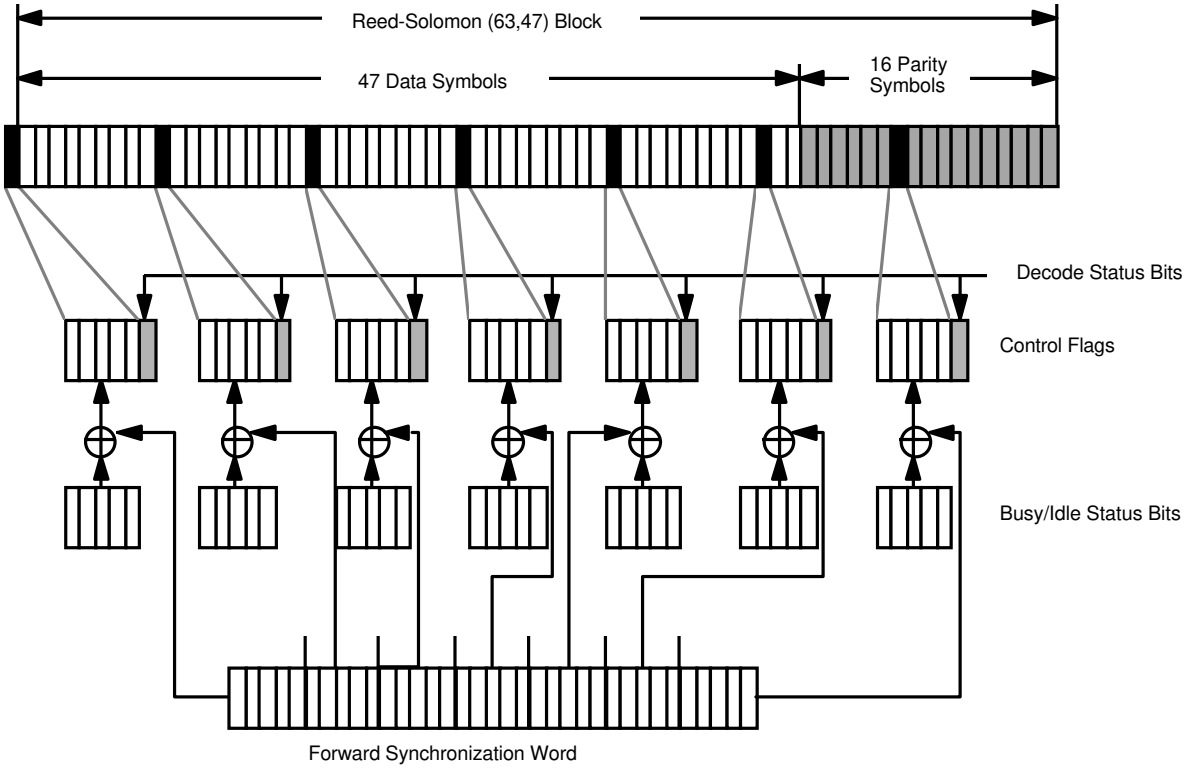
- follows OSI stack
- CDPD basically specifies physical layer and data link layer protocols only
- nominal channel rate: 19.2 kbps, maximum throughput after coding & framing, ignoring contention, is 11.8 kbps on downlink (to mobile), 13.3 kbps on uplink
- standard specifies support for CLNP (ConnectionLess Network Protocol) and IP (Internet Protocol) at layer 3
- higher layers can be TCP or TP4
- CDPD also specifies a wide variety of upper-layer protocols (directory management, electronic messaging, etc.), based on OSI and Internet services

CDPD: Protocol Stack



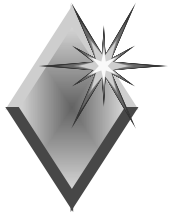
MAC: Media Access Control
MDLP: Mobile Data Link Protocol, modified LAPB (Link Access Protocol B, CCITT standard under X.25)
SNDCP: SubNetwork Dependent Convergence Protocol (compression, segmentation, encryption)
F-ES: Fixed End System (provide higher layer services)

CDPD: Channel Coding



RF link-layer frame segmented into blocks of 282 data bits (6*47). Each 6-bit symbol participates in a (63, 47) Reed-Solomon block code: can correct up to 8 6-bit symbol errors. Total block length is 378 bits.

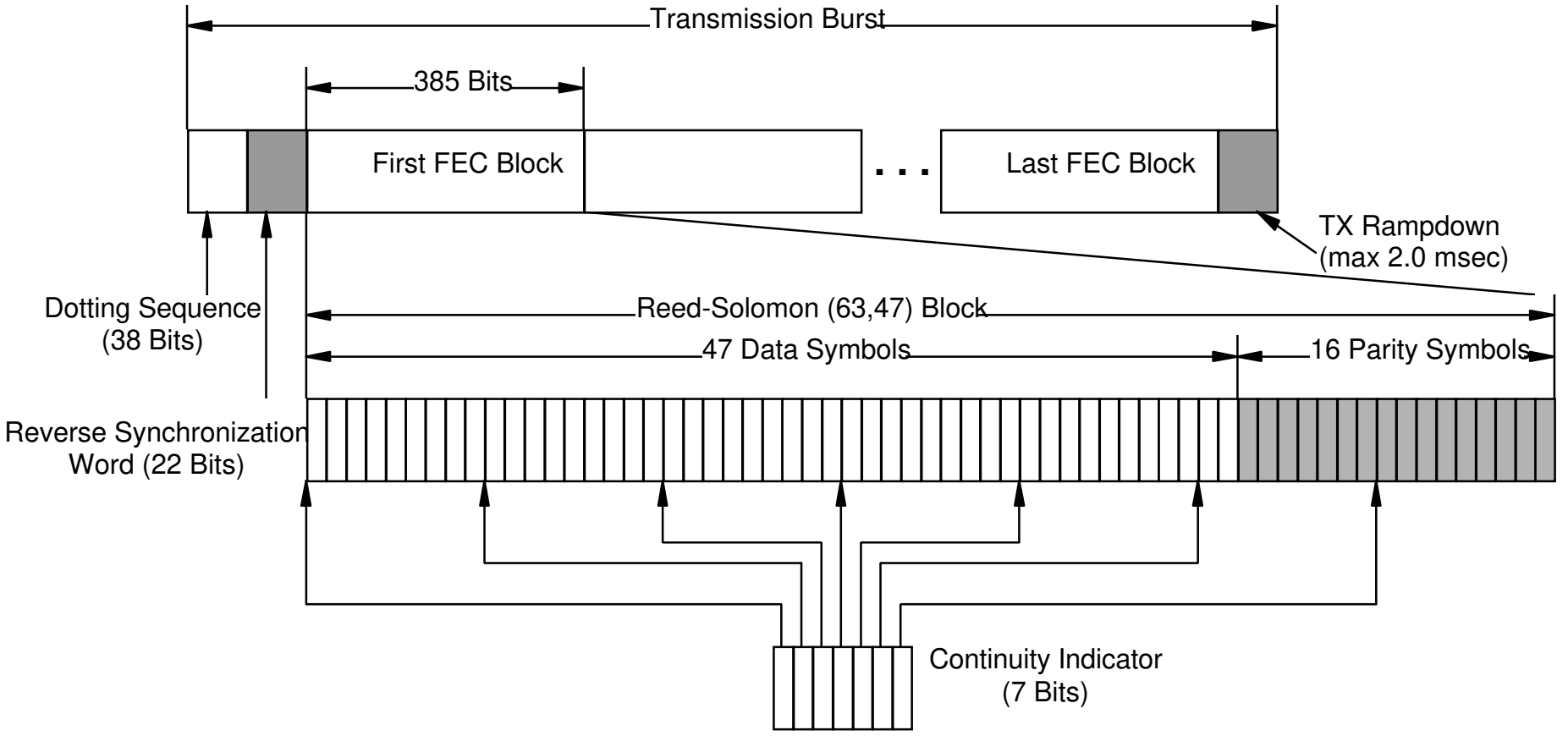
Every 10th 6-bit symbol is used to spread busy/idle flag and decode status flag, monitored by mobiles. Each flag is 5 bits, modified by forward synchronization word.



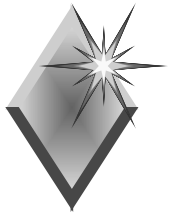
CDPD: Forward Channel

- forward channel is continuous, contiguous series of blocks, interleaved with sync. and control flags
- forward synchronization word
  - marker for FEC block boundaries and timing references
  - binary value: 11101 00001 11000 00100 11001 01010 01111
  - each group of five bits XOR-ed with one 5-bit busy/idle flag
- control flags
  - busy/idle status flag: signals status of reverse channel
    - channel busy = 00000, channel idle = 11111
  - block decode status flag: could received block be decoded (burst errors and collision both prevent successful decoding)
    - success = 00000, failure = 11111
    - transfer 6 or 7 bits, but ignore extra bits (flag is one 5-bit word)

CDPD: Channel Coding

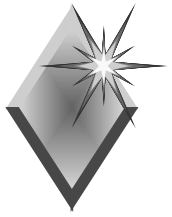


Contention on up-link: each 378-bit block followed by “continuity” or EOT indication requesting subsequent block reservation if necessary. Default maximum number of block: 64



CDPD: Reverse Channel

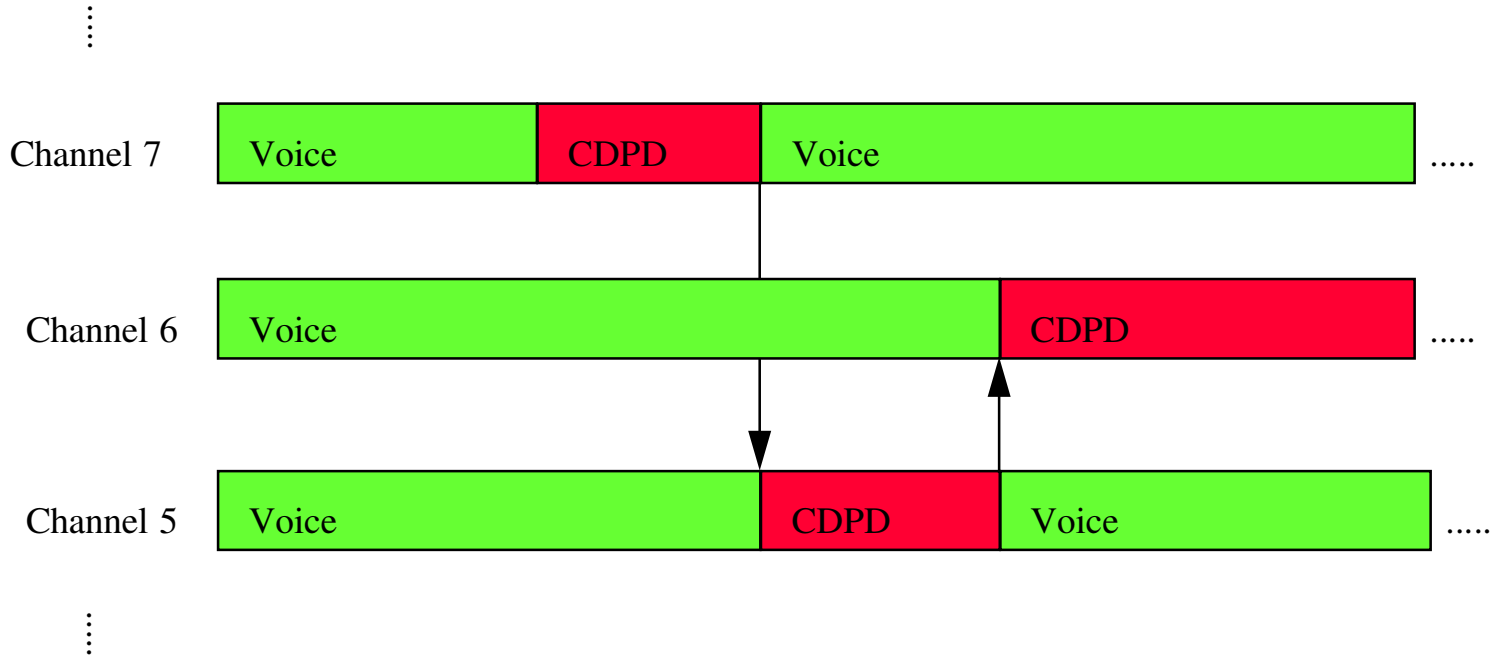
- not contiguous, but in bursts
- 38-bit dotting sequence:
  - allows MDBS to detect bursts and recover bit times
  - value: 1010 1010 1010 1010 1010 1010 1010 1010 1010 10
- 22-bit reverse synchronization word:
  - used by MDBS to determine block beginning
  - value: 1011 1011 0101 1001 1100 00
- 7-bit continuity indicator:
  - signals whether reverse transmission burst is complete
  - final block = 0000000, more blocks = 1111111
- transmitter rampdown period: transmit binary 0 while powering down for 2.0 milliseconds (38 bit times)

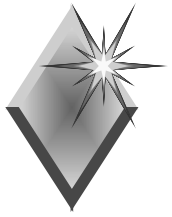


CDPD: MAC Protocol

- downlink/forward channel: no contention, only one sender: the MDBS. All frames are broadcasted, each M-ES picks out the ones destined for it or for everyone
- uplink/reverse channel: contention is a problem
  - access to channel follows a DSMA/CD protocol:
    - uses time slots of 60 bit times (see structure of forward channel)
    - “digital sense”: watch forward channel to determine whether reverse channel is busy or idle (busy/idle flags every 60 bits)
    - if busy, skip a random number of slots and try again. If still busy, wait for longer period (statistically twice as long) and retry
    - if idle, start transmitting
    - “collision detection”: decode flag in forward channel indicates with delay whether there was a collision
    - keep sending until collision is detected or until maximum number of slots is set or until MDBS tells M-ES to shut down

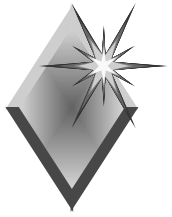
CDPD: Sharing AMPS Channels





CDPD: Sharing AMPS Channels

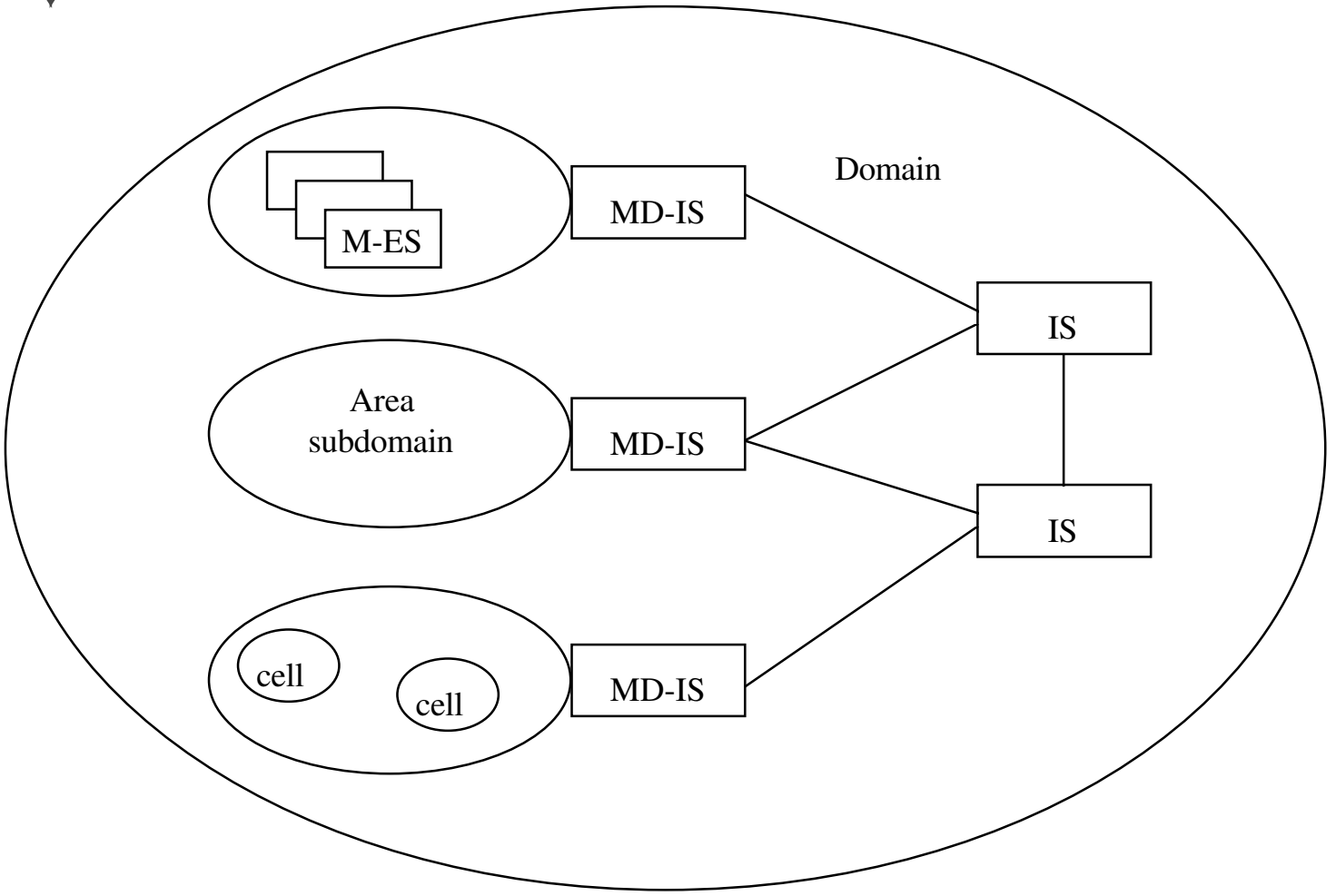
- each cell can have multiple pairs of up- and downlink channels for data transmission (**channel streams**), each stream managed by one logical MDBS
- MDBS monitors voice channels used by “sniffing” low-level radio frequencies
  - narrowband sniffing: scans each 30 kHz channel, one at a time
  - wideband sniffing: analyze all radio frequencies in the complete 12.5 MHz spectrum
- if voice channels become active, MDBS initiates hop
- timing is crucial to avoid interfering with AMPS system
  - MDBS has a ramp-up and ramp-down time of 10 ms
  - M-ES has ramp-up and ramp-down time of 2 ms

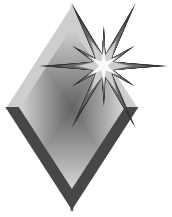


CDPD: Sharing AMPS Channels

- two types of channel hops:
  - forced channel hop is the one described before: get out of the way of voice channel that is about to be used
  - planned channel hop: initiated by MDBS periodically. Timer value typically set to a value less than an AMPS user's perception that the CDPD traffic is interference ("cross-channel interference"?)
- specifications are based on notion that CDPD users are second-class citizens. However, if CDPD becomes more popular, nothing prevents network providers from dedicating channels to CDPD (except that as is, voice is the big cash cow.....)

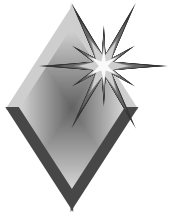
CDPD: Mobility Management





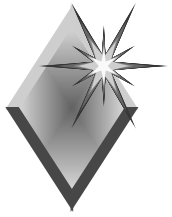
CDPD: Mobility Management Identifiers

- NEI (Network Entity Identifier): identifies mobile
- LCI (Local Cell Identifier): unique cell identifier for all cells controlled by the same MDBS
- CSI (Channel Stream Identifier): unique 6-bit identifier for all channel streams in a cell
- LCI and CSI together uniquely identify all channels on any given cell or its adjacent cells
- LSAI (Local Service Area Identifier): 16-bit unique number for all service areas in a CDPD network
- SPNI (Service Provider Network Identifier): 16-bit unique CDPD network identifier



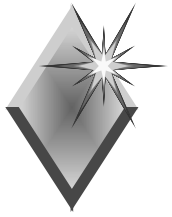
CDPD: Mobility Management

- single MDBS may control multiple cells
- combined coverage of all MDBSs under the control of a single MD-IS defines a routing area subdomain
  - may cover multiple cellular geographic service areas (CGSA) or it may be only one CGSA
- CDPD domain is cohesive set of MD-ISs that are operated and controlled by one CDPD service provider
- cell transfer decision based on LCI, CSI, and channel stream color code (combination of 5-bit cell group color and 3-bit area color)
  - all cells in same routing area are assigned same area color
  - cell group color distinguishes groups of RF channels available for CDPD in adjacent cells



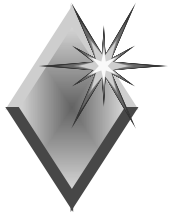
CDPD: Mobility Management

- cell transfer decision: compare relevant parameters on previous RF channel and current RF channel (after channel hop):
  - no change in LCI, CSI, cell group color or area color: channel hop occurred within current cell
  - area color is the same, but LCI and CSI are different: intra-area cell transfer is performed
  - different area colors: inter-area cell transfer procedure is performed



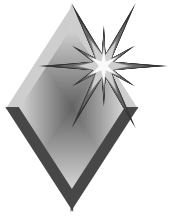
CDPD: Intra-Area Cell Transfer

- intra-area cell transfer: controlled by same MD-IS
- M-ES initiates transfer if channel becomes bad (extended loss of channel synchronization and/or unacceptable error rate)
- to assist M-ES in locating CDPD channel, MDBS periodically broadcasts RF channel number in use or as candidates for use in adjacent cell
- after M-ES synchronized with new RF channel, sends link-layer receive ready to serving MD-IS
- MD-IS acknowledges frame and updates its information for M-ES (physical media association)



CDPD: Inter-Area Cell Transfer

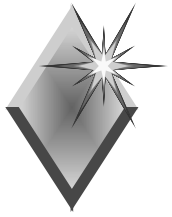
- starts out identical to intra-area cell transfer
- once M-ES synchronized with new channel, mobile sends “end system hello” (ESH) to new serving MD-IS
- ESH informs MD-IS of presence of M-ES, register its address (NEI)
- new serving MD-IS sends message to home MD-IS to tell it where data for M-ES should be redirected
- home MD-IS acknowledges if registration is successful
- new serving MD-IS confirms successful registration to M-ES
- home MD-IS “flushes” previous serving MD-IS, telling it that messages are no longer forwarded for this M-ES



CDPD: Deployment

Service Provider	Cities
Bell Atlantic Mobile	Baltimore, Pittsburgh, Washington, Philadelphia
Airtouch Communications	San Diego, San Francisco
GTE	San Francisco, Houston
McCaw Cellular	Dallas, Las Vegas, Miami, New York, Seattle
NYNEX Mobile	New York
Sprint Cellular	Farmington, New Mexico
Ameritech	selected parts of Chicago

Status: 1996, in United States of America



CDPD: Evaluation

- based on widespread system, AMPS
- provides reasonable data rate at variable cost (12 to 19 cents/US per kilobyte of data)
- What does the future hold?
  - Andrew Tanenbaum: “use is growing rapidly”
  - Ulysses Black: whether CDPD will be the technology of choice for wireless data remains to be seen
  - Bob Egan, DEC: CDPD will become competitor to packet radio systems such as ARDIS or MOBITEX in short term, but will be only interim solution until digital cellular radio is available