# North American Cellular System Based on Code Division Multiple Access

Long-Sheng Li



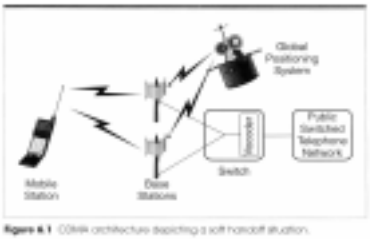


## Architecture

- IS-95 prescribes spread spectrum signals with a bandwidth 1.23 MHz in each direction.
- A soft handoff mechanism
  - A terminal establishes contact with a new BS before giving up its radio link to the original BS.
  - The switch estimates the quality of the two signals and sends one of them to a speech decoder.
- CDMA soft handoff requires BSs to operate in synchronism with one another.
  - All BSs contain global positioning system (GPS) receivers.
  - The GPS signals include precise time information, accurate to within one microsecond, relative to universal coordinated.












## Identification Codes

- Every MS has a 8-bit station class mark (SCM) to indicate capabilities of an MS.
- Each MS stores 40 bits to describe its precise configuration.
  - The 8-bit mobile manufacturer code (MOB_MFG_CODE) identifies the brand of the MS.
  - The 8-bit mobile model number (MOB_MODEL) is the model number assigned by manufacturer.
  - The 16-bit mobile firmware revision (MOB_FIRM_REV) is the terminal firmware version.
  - The 8-bit mobile protocol revision (MOB_P_REV) is the version of IS-95 supported by the MS.





## The BS Identifiers

- The 15-bit system identifier (SID) is assigned by regulators to a geographical service area.
- The network identifier (NID) is denoted a set of BSs defined by an operating company.
- PN_OFFSET is a time delay applied to forward direction transmissions that enables the terminals in a cell to decode the desired signal and reject signals from other BSs.
- The 4-bit BASE_CLASS identifier anticipates terminals that will have access to a variety of wireless services.





## The Identifier About Mobility Management

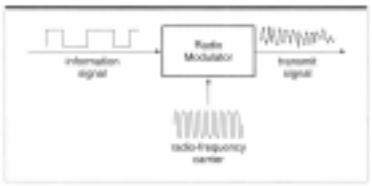
- Mobility management:
  - Location-area registration
  - Timer-based registration
  - Distance-based registration
- A 12-bit REG_ZONE identifier to be assigned to each BS to play role as the LOCAID in NA-TDMA to facilitate location-area registration.
- The identifiers, BASE_LAT (22 bits) and BASE_LONG (23 bits), specify the exact geographic location of the BS, in latitude-longitude coordinates to perform distance-based registration.

## Compare CDMA radio transmission

- CDMA employs different transmission techniques in the forward and reverse directions.
- There are two stages of modulation in a CDMA system.
- To maximize spectrum efficiency, the CDMA employs variable-bit-rate traffic channels.
- The CDMA system has a reuse factor of one. Each radio channel is used in all sectors of all cells.

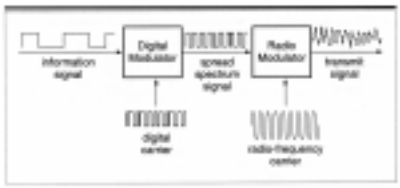






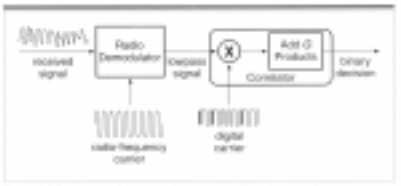










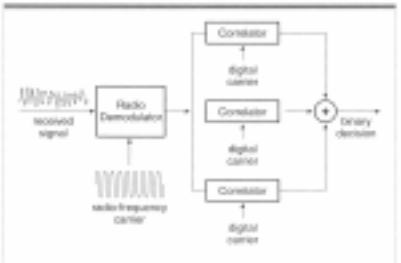



## Synchronization

- Mobility changes the nature of the multiple signal paths between a terminal and a BS.
- Location changes cause some paths to disappear and new signal paths to appear.
- IS-95 prescribes multiple correlators in each receiver. The correlators are referred to as demodulating elements.
- Each correlator operates with a digital carrier synchronized to one propagation path.





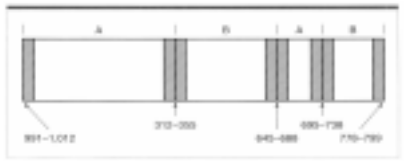


# CDMA Carriers

- The bandwidth of a CDMA signal is 1.23 MHz.
- Each physical channel in AMPS occupies 30 kHz.
- The bandwidth of a CDMA signal corresponds to the aggregate bandwidth 41 AMPS channels.









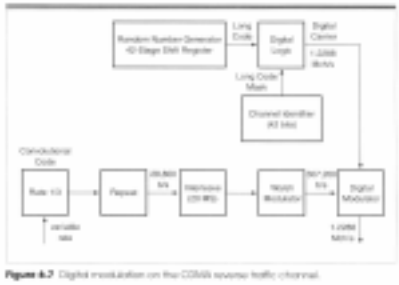


# Reverse-Direction Radio Transmission

- The digital carrier is derived from a channel identifier, 42-bit long code mask, containing the ESN of the terminal and a long code, produced by a binary random number generator.
- The long code repeats itself after 2^42-1 chips. The repetition rate is 41.4 days.









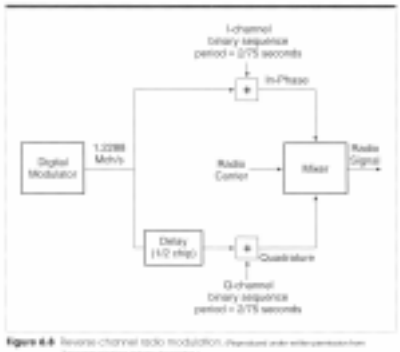


# Contents of 20 ms Frames, Reverse Channel

| Data Rate R b/s | 1200 | 2400 | 4800 | 9600 |
|---|---|---|---|---|
| Information rate R1 b/s | 800 | 2000 | 4000 | 8600 |
| Information bits per frame (IBPF) | 16 | 40 | 80 | 172 |
| Parity bits per frame (PBPF) | 0 | 0 | 8 | 12 |
| Data bits per frame (IBPF+PBPF+8) | 24 | 48 | 96 | 192 |
| Code bits per frame (CBPF) | 72 | 144 | 288 | 576 |
| Repetitions | 8 | 4 | 2 | 1 |
| Total bit per frame (BPF) | 576 | 576 | 576 | 576 |





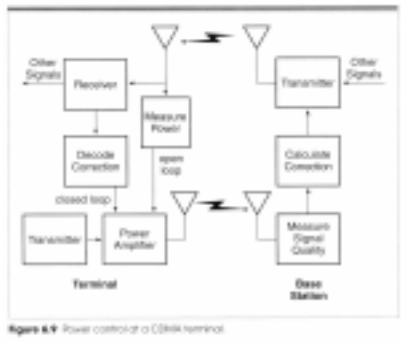


# Radiated Power in the Reverse Transmission

- The aim is to make all reverse-direction signals in a cell arrive at the BS with the same strength.
- The terminal performs power adjustments 800 times per second under the control of the BS. These adjustments are referred to as closed-loop power control.
- IS-95 specifies open-loop power control, which causes the terminal to adjust its transmitter power as a function of the power it measures in the received forward-direction signal.
- To arrive at equal energy per bit in the transmitted signal, a CDMA terminal transmits reduced-bit-rate signals intermittently with a duty cycle inversely proportional to the data rate.









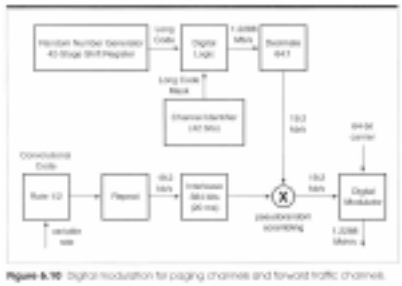



# Forward Link Radio Transmission

- All digital carriers in the forward direction are mutually orthogonal.
- In a system operating with orthogonal carriers, a digital demodulator tuned to one physical channel contains no interference from other physical channels arriving on the same propagation path.
- A convolutional code, with constraint length nine, rate ½, protects each signal. The resulting channel bit rate can range from 2400 b/s to 19200 b/s.
- When the rate is less than 19200 b/s, the transmitter repeats code bits to bring the rate up to 19200 b/s, corresponding to 384 bits per frame.









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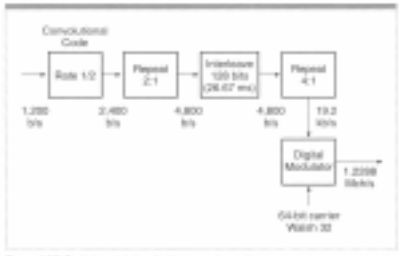
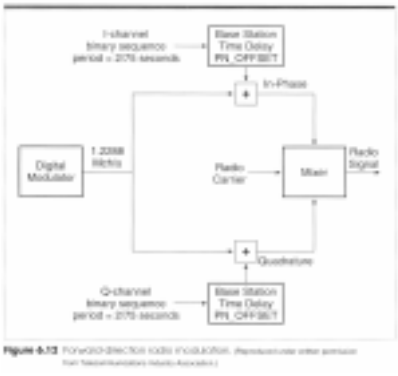
| Code bits per frame (CBPF) | 48 | 96 | 192 | 384 |
| Repetitions | 8 | 4 | 2 | 1 |
| Total bit per frame (BPF) | 384 | 384 | 384 | 384 |













# Spectrum Efficiency

- One of the most striking properties of CDMA is that all cells simultaneously use the same radio bands.
- In CDMA, capacity depends on the amount of interference a system can tolerate within the constraint of a signal quality objective, such as binary error rate.
- $E_b$ is the energy per bit in the desired signal and $N_0$ is proportional to the sum of the interference power and noise power at the receiver.
- A system that can operate with a lower value of $E_b/N_0$ can tolerate more interference and admit more conversations.
- Capacity calculations are complicated and depend critically on properties of the probability distributions of these random quantities.





# Capacity

- Directional BS antennas increase capacity.
- Variable-bit-rate speech transmission also increases capacity.
- Interference from surrounding cells reduces capacity.
- Imperfect power control also reduces capacity.
- An outage margin reduces capacity.



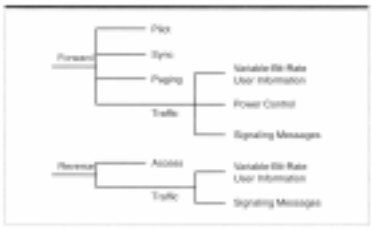


# Logical Channels

- There are 64 physical channels available for CDMA BS transmission.
- One of these channels is always active as a pilot channel and another one serves as a sync channel.
- The remaining physical channels in the forward direction comprise a mixture of paging channels and forward traffic channels.
- IS-95 specifies that the BS transmit at most one sync channel and at most seven paging channels.











# Pilot Channels

- The pilot channel transmits a continuous sequence of 0s at a rate of 1.2288 Mch/s.
- Terminals in other cells tune to the pilot channel to obtain signal strength indications as part of a CDMA mobile-initiated handoff procedure.

# Sync Channel

- The sync channel repeatedly transmits one message, which conveys system information to terminals, including system time and the time delay.
- Also transmits the BS's SID/NID and the minimum IS-95 protocol revision.
- Also transmits the information rate of the BS paging channels.





# Paging Channel

- A CDMA signal carries up to seven paging channels.
- The information rate is either 4800 b/s or 9600 b/s.
- The maximum length of a paging message is 1184 bits.
- A maximum paging channel slot cycle consisting of 2048 paging channel slots.
- The total duration of this slot sequence is 2048*80 ms=163.84 s.
- A terminal determines the specific paging channel and the slots within the channel that it monitors by performing a computation based on the terminal's MIN and ESN.





# Sleep Mode and Paging Channel

- For example
  - The terminal can examine one slot in every 16 slots.
  - The terminal in an idle state can operate with reduced power for 15 out of every 16 slots and then wake up to examine the sixteenth slot for a paging message.





# Access Channel

- A terminal without a call in progress uses an access channel to send messages to a BS for 3 principal purposes:
  - To originate a call
  - To respond to a paging message
  - To register its location
- Each BS operates with up to 32 access channels.
- The digital carrier of an access channel depends on the 42-bit channel identifier.
- The transmission rate of each access channel is 4800 b/s.





# Access Channel (cont.)

- The maximum length of an access message is 880 bits or 10 frames (200 ms).
- The minimum length of an access message is 3 frames.
- A preamble consisting of 1-16 frames, each containing 96 0s, precedes each access message.
- A transmission on an access channel covers a minimum of 4 frames and a maximum of 26 frames.





# Access Protocol

- Each transmission is referred to as probe.
- After transmitting a message, the terminal waits for an ACK to arrive on the paging channel.
- The transmissions collide at the BS and mutual interference prevents the BS from receiving more than one transmission in any slot.
- The random waiting time reduces the probability that the two terminals will transmit again in the same slot.
- The variable power levels increase the probability that one message will be received at higher power than interfering messages.
- The process continues until the terminal receives an ACK or the number of probes reaches a limit specified by the system.
- The number of allowed probes is between 1 and 16.





# CDMA Traffic Channels

- Compared with other systems, IS-95 traffic channels have 2 distinguishing characteristics.
  - They carry speech at variable bit rates ranging from 9600 b/s, to 1200 b/s, depending on an analysis of input speech and on signaling activity.
  - The carry a dynamic mixture of user information and network control information.





# Variable-Bit-Rate Speech Transmission

- The system performs encoding and decoding operations on 20 ms speech frames.
- The coder represents speech at 4 bit rates: 8000 b/s, 4000 b/s, 2000 b/s, 800 b/s, producing 160, 80, 40, or 16 bits per 20 ms frame.
- In each frame, the QCELP speech coder generates 10 linear prediction coding filter coefficients.
  - There are 40, 20 and 10 linear predictor bits per frame.
- The speech coder performs a long-term prediction (pitch) analysis that generates 2 quantities: an estimated pitch period and a pitch gain.
  - There are 40, 20, and 10 bits per frame of pitch information.
- At the highest rate, the speech coder introduces an error-correcting block code to protect the 18 bits in the 20 ms frame.
  - This block code adds 11 bits per frame to the 8000 b/s speech coder output.
- At the two higher rates, the system also adds a cyclic redundancy check error-detecting block code to each speech frame to enable the receiver to monitor transmission quality.





# Contents of Traffic Channel Speech Frames

| Data Rate (b/s) | 1200 | 2400 | 4800 | 9600 |
|---|---|---|---|---|
| Speech raate (b/s) | 800 | 2000 | 4000 | 8000 |
| Speech content (bits per frame) | 16 | 40 | 80 | 160 |
| Filter coefficients (bits per frame) | 10 | 10 | 20 | 40 |
| Pitch parameters (bits per frame) | 0 | 10 | 20 | 40 |
| Excitation parameters (bits per frame) | 6 | 20 | 40 | 80 |
| Error-correction code (bits per frame) | 0 | 0 | 0 | 11 |
| Frame content bit (bits per frame) | 0 | 0 | 0 | 1 |
| Information bits per frame (IBPF) | 16 | 40 | 88 | 172 |
| Error-detecting code (PBPF) | 0 | 0 | 8 | 12 |





# Variable-Bit-Rate Speech Transmission (cont.)

- Variable-bit-rate speech coding serves 2 purposes.
  - It raises system capacity by reducing the average amount of interference that each transmitter causes to other communications.
  - In addition to reducing interference, variable-bit-rate speech coding allows the BS to multiplex signaling information with user information on a traffic channel.
- The encoder examines the contents of each speech frame and determines the necessary coding rate. The most important part of this analysis is voice-activity detection.
  - The effective transmission rate goes from 9600 b/s to 1200 b/s and the transmitter produces 1/8 of the interference energy of a full-rate transmission.





# Signaling on CDMA Traffic Channels

- To exchange network control information while a call is in progress, CDMA terminals and BSs interrupt or reduce the flow of speech information and insert messages into traffic channels.
- There are five modes of operation.
  - In the blank-and-burst mode, control messages completely replace the speech.
  - In the 3 dim-and-burst modes, there is a mixture of speech information and control information in each frame.
  - When control messages are present, the traffic channel always operates at 9600 b/s.
- The first content indicator bit distinguishes speech-only frames from other frames.

# Number of Bits per Frame in Full-Rate CDMA Traffic Channels

| Transmission Mode | Blank-and Burst | Dim-and-Burst | | | Speech Only |
|---|---|---|---|---|---|
| Speech | 0 | 16 | 40 | 80 | 171 |
| Control message | 168 | 152 | 128 | 88 | 0 |
| Content indicator | 4 | 4 | 4 | 4 | 1 |
| Parity check | 12 | 12 | 12 | 12 | 12 |
| Coder tail bits | 8 | 8 | 8 | 8 | 8 |
| Information bits | 192 | 192 | 192 | 192 | 192 |





# Power Control Subchannel

- With a call in progress, a BS monitors the received power from each terminal and transmits power control commands to the terminal at a data rate of 800 b/s.
- Each bit transmitted in the power control subchannel commands a terminal either to increase or decrease its transmitter power by 1 dB.
- The BS inserts 16 power control bits into every frame transmitted on a forward traffic channel.
- Every 1/800 s=1.25 ms, the multiplexer replaces 2 traffic channel code bits with 1 power control bit. The process is known as puncturing the convolutional code.





# Messages

- IS-95 performs network control operations by exchanging messages between terminals and BSs on 4 types of logical control channels.
- The power control signal is a continuous 800 b/s stream with each bit directing a terminal to raise or lower its power by 1dB.
- The pilot channel carries an unmodulated beacon signal that allows terminals in the local cell to synchronize their code generators.
- Terminals in nearby cells measure the strength of the pilot as part of CDMA handoff procedures.
- The sync channel broadcasts one message that conveys system information to all terminals in a cell.






Figure 6.16 CDMA message format





# Layer 2 Acknowledgments

- The CDMA system inserts into each message at least 7 bits of information for data link layer control at layer 2.
- The layer 2 information in every CDMA message consists of a 3-bit message sequence field (MSG_SEQ), a 3-bit acknowledgment sequence field (ACK_SEQ), and 1 acknowledgment required (ACK_REQ) bit.





# Acknowledgment Messages

- A layer 2 ACK confirms the reception of legitimate bit sequence.
- An ACK message confirms the logic of the content of an original message and indicates whether a terminal or BS is prepared to perform a function prescribed in the signaling message.

## Message Content

- The sync channel carries one message with the principal purpose of synchronizing the random-number generator.
- The SYSTEM PARAMETERS message, carried on paging channels, carries information on mobility management procedures to be used in the current cell, and information on the maintenance of channel sets used in soft handoff procedures.





## Radio Resource Management

- A CDMA system has to maintain a narrow range of received power levels among the signals arriving at a BS.
- In order to confine the received signal powers to a narrow range, IS-95 performs a combination of open-loop and closed-loop operations to control the power of the transmitters at terminals.



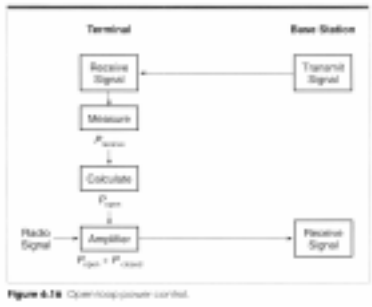


## Open-Loop Power Control

- A terminal measures the strength of the received pilot signal associated with the forward traffic channel.
- $P_{open}=-P_{receive}+P_{target}$
- $P_{receive}$ is the measured power level of the received signal at the terminal.
- $P_{target}$ is the difference between the transmitted power level at the BS and the desired received signal level at the BS.
- $P_{target}$ is calculated on the basis of information received from the BS in an ACCESS PARAMETERS message.









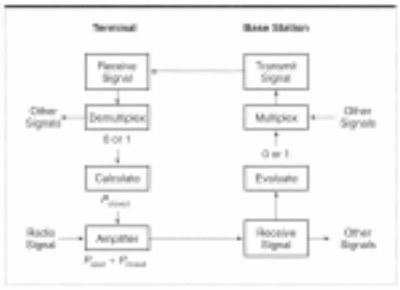



## Closed-Loop Power Control

- To control the closed-loop power adjustment, the BS decides, every 1.25 ms, whether the power received from the terminal is too high or too low.
- It transmits this decision as 1 bit in the power control subchannel.
- On receiving this signal, the terminal modifies $P_{closed}$ by increasing $P_{closed}$ by 1dB or decreasing $P_{closed}$ by 1 dB.
- $P_{transmit}=P_{open}+P_{closed}$







## Power Control at BSs

- Each BS contains its own algorithms for regulating forward link power.
- The BS uses a POWER CONTROL PARAMETERS message to request information from the terminal about the quality of the forward traffic channel signal.
- The terminal responds with a POWER MEASUREMENT REPORT message that contains the strength of the received forward traffic channel signal.
- The BS uses the data in the message to determine the power of the forward traffic channel signal.





## Soft Handoff

- As a terminal moves from one cell to another, it communicates simultaneously with the BSs in both cells.
- CDMA handoff is mobile assisted, with each terminal performing measurements that influence handoff decisions.
- CDMA handoff is exceptional in being mobile initiated.
- CDMA handoff is switch controlled, with the switch making handoff decisions and assigning new physical channels.





## Soft Handoff (cont.)

- Each terminal has its own unique physical channel, determined by the 32-bit electronic serial number (ESN).
- During soft handoff, 2 different BSs assign correlators to receive signals on this physical channel.
- Soft handoff requires 2 sets of signal-processing functions: measurement and diversity reception.
  - A terminal dedicates at least one correlator, referred to as a searcher, to performing the measurement.
  - The other correlators participate in diversity reception.





## 4 lists of BSs

- To perform its measurement and reporting tasks, a terminal maintains 4 lists of BSs, with each BS characterized by a 9-bit PN_OFFSET.
  - Active list: contains BSs currently used for traffic channel transmissions.
  - Candidate list: consists of BSs classified by the terminal, on the basis of measured signal quality, as available for traffic channel transmissions.
  - Neighbor list: is a set of nearby BSs that could soon be available for handoff.
  - Remaining list: contains the BSs that are not in any of the other categories.





## Soft Handoff Procedure

- The searching correlators in the terminal monitor the signal strengths of all pilots in the active, candidate, and neighbor lists.
- When these measurements suggest that a handoff by sending a PILOT STRENGTH MEASUREMENT message.
- On receiving the HANDOFF DIRECTION message, a BS commands a terminal, the terminal then tunes one or more correlators to this forward traffic channel.
- While the call is in a soft handoff state, all BSs perform closed-loop power control.





# Other Types of Handoff

- IS-95 is capable of transferring a call from CDMA traffic channel to an analog voice channel (hard handoff).
- The system is not capable of transferring a call in progress from an analog voice channel to a CDMA digital traffic channel.





# IS-95 Registration Modes

| Registration Type | Event Triggering Registration |
|---|---|
| Power up | Subscriber turns on the terminal |
| Power down | Subscriber turns off the terminal |
| Timer | Elapsed time since previous registration exceeding a limit |
| Distance | Distance between present BS and BS that received previous registration exceeds a limit |
| Zone | Terminal enters a new registration zone |





# Authentication and Privacy

- IS-95 incorporates the authentication and encryption technologies specified for NA-TDMA.
- IS-95 includes a privacy technique, allows each user to operate with a private long code mask, unique to a CDMA system.
- Like the encryption A-key, the private long code mask is stored in the memory of a CDMA telephone and in a secure location managed by the network operator.





# OA&M

- With signals in all cells covering a bandwidth of 1.23 MHz, CDMA systems are especially vulnerable to malfunctions in individual terminals.
- To protect a system against this possibility, IS-95 specifies messages that a system can send on paging channels and forward traffic channels in order to stimulate corrective action at a terminal.
- A LOCK_UNTIL_POWER_CYCLED message disables a terminal's transmitter until the user turns off the terminal power and turns it on again.
- A MAINTENACE REQUIRED message causes the terminal to inform the user that there is a problem that requires attention.