IS-95 (cdmaone)

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IS-95 CDMA

- IS-95 (cdmaone) 2G digital cellular standard
- Motivation
  - Intended as a new system (greenfield) or replacement for AMPS (not an upgrade)
  - Increase system capacity
  - Add new features/services
- History:
  - 1990 Qualcomm proposed a code division multiple access (CDMA) digital cellular system claimed to increase capacity by factor 20 or more
  - Started debate about how CDMA should be implemented and the advantages vs. TDMA (religious tones to debate)
  - 1992 TIA started study of spread spectrum cellular
IS-95 CDMA (cont)

- Several alternative CDMA proposals floated – large debate in the CTIA
  - came down to Interdigital vs. Qualcomm
  - Qualcomm proposal won
- 1993 TIA IS-95 code division multiple access (CDMA) standards completed
  - 1995 IS-95A enhanced revision
  - ANSI J-STD-008 (IS-95b) is standard upbanded to 1900 MHz PCS band
  - 1996 Commercial deployment in US (Sprint PCS)
  - Most popular system in U.S. and Korea
  - 1997 IS-95 name changed to cdmaone
- IS-95 evolves to cdma 2000 in 2.5 and 3G

IS-95 System Features

- Digital Voice
  - QCELP fixed rate 14.4Kbps coder
  - variable rate QCELP coder: 9.6, 4.8, 2.4, 1.2 Kbps
    - Use of voice activation to reduce interference
    - As data rate reduces, the transmitter can reduce the power to achieve the same error rates
- Dual Mode (AMPS/CDMA), Dual Band (900, 1900 MHz bands)
- Low power handsets (sleep mode supported)
- Soft Handoff possible
- Digital Data services (text, fax, circuit switched data)
- Advanced Telephony Features (call waiting, voice mail, etc.)
- Security: CDMA signal + CAVE encryption
- *Air Interface Standard Only*
IS-95 System Features

- Code Division Multiple Access/FDMA/FDD
- Traffic Channel
  - Pair of 1.25 MHz radio channels (up/downlink)
  - Several users share a radio channel separated by a code not a timeslot or frequency!
  - Receiver performs a time correlation operation to detect only desired codeword
  - All other codewords appear as noise due to decorrelation
  - Receiver needs to know only codeword and frequency used by transmitter
  - Adjust power often to prevent near-far problem
- Universal frequency reuse (frequency reuse cluster size $K = 1$)
  - Simple planning
  - Large capacity increase

Universal Frequency Reuse

Frequency Reuse Factor = 7 for AMPS

Frequency Reuse Factor = 4 or 3 for GSM systems

CDMA Universal Frequency Reuse
IS-95 CDMA - Radio Aspects

- IS-95 is an air interface standard only
- System use FDD/FDMA/CDMA
- FDD => Uplink and Downlink channels separated according to Cellular band or PCS band regulatory requirements
- FDMA – breaks up licensed spectrum into 1.25 MHz channels
- CDMA – multiple users share a 1.25 MHz channel by using orthogonal spreading codes (Walsh codes)

- IS-95a standard designed for AMPS cellular band
  - Each cellular provider is allocated 25 MHz spectrum
  => ten 1.25-MHz CDMA duplex channels if A AMPS Band provider, 9 if B band provider

Physical channels

- A CDMA system has 1.25 MHz wideband carriers
  - Carrier bandwidth in AMPS is 30 kHz
  - Carrier bandwidth in GSM is 200 kHz
  - Carrier bandwidth in IS-95 is 1.23 MHz – 1.25 MHz with guard band
    - One CDMA carrier can contain 41 AMPS channels of spectrum
- In Cellular Band IS-95 carrier frequencies are denoted in terms of the AMPS channel numbers

253 254 262 263 283 303 304 312 313

41 AMPS channels
Interference between CDMA and AMPS/TDMA systems

- The recommended guard band between the CDMA carrier band edge and an AMPS or TDMA carrier is 270 KHz => 9 AMPS channels of 30 kHz
- To set up one CDMA channel, 59 AMPS channels have to be cleared (1.77 MHz)
- To set up two CDMA channels, only 100 AMPS channels have to be cleared (3 MHz)

% IS-95 Radio Aspects

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Quadrature phase shift keying or variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel/Chip rate</td>
<td>1.2288 Mcps</td>
</tr>
<tr>
<td>Nominal data rate (Rate Set 1)</td>
<td>9.6 kbps</td>
</tr>
<tr>
<td>Filtered bandwidth</td>
<td>1.23 MHz -&gt; 1.25 MHz with guard band</td>
</tr>
<tr>
<td>Coding</td>
<td>Convolutional coding</td>
</tr>
<tr>
<td></td>
<td>Constraint length = 9</td>
</tr>
<tr>
<td></td>
<td>Viterbi decoding</td>
</tr>
<tr>
<td>Interleaving</td>
<td>With 20 ms span</td>
</tr>
</tbody>
</table>
IS-95 Radio Aspects

- IS-95 uses several techniques adapted from military
  - Direct Sequence Spread Spectrum (DSSS)
    - Narrowband signal is multiplied by very large bandwidth signal (spreading signal)
    - Spreading signal is pseudonoise code sequence with chip rate much greater than data rate of message
    - DSSS provides resistance to narrowband interference, inter-symbol interference and low power operation
  - Code Division Multiple Access
    - All users, each with own codeword approximately orthogonal to all other codewords, can transmit simultaneously with same carrier frequency
    - Receiver performs a time correlation operation to detect only desired codeword
  - Rake Receiver
    - Multiple parallel receivers used to combat multi-path interference and inter-symbol interference

IS-95 Multipath Combining

- Multipath: reflection, diffraction, and dispersion of the signal energy caused by natural obstacles such as buildings or hills, or multiple copies of signals sent intentionally (e.g., soft handoff)
- Rake receiver used to combine different path components: each path is despread separately by “fingers” of the Rake receiver and then combined
- Possible due to “low auto-correlation” of spreading code
Rake Receiver

RAKE receiver combines the multipath signals constructively.

Multopath and the RAKE Receiver

The RAKE receiver combines the multipath signals constructively.
Processing of multipaths using the Rake Receiver

Codes used in IS-95 systems

- **Walsh codes**
  - They are the “orthogonal codes” used to create “logical channels” on the up/downlink (at the same time and within the same frequency band)

- **PN (pseudo-noise) codes**
  - They are used to distinguish between transmissions from different cells and are generated using “linear feedback shift registers”
  - Basically a pseudo-random number generator
  - They have excellent autocorrelation properties
  - Two short PN codes and a long PN code are used in IS-95 that have periods of $2^{15} - 1$ and $2^{42} - 1$

- Convolutional codes for error correction
- Block codes with interleaving and error correction
### Sample IS-95 System Identifiers

<table>
<thead>
<tr>
<th>Notation</th>
<th>Name</th>
<th>Size (bits)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>Mobile Identifier</td>
<td>34</td>
<td>Directory number assigned by operating company to a subscriber</td>
</tr>
<tr>
<td>ESN</td>
<td>Electronic serial number</td>
<td>32</td>
<td>Assigned by manufacturer to a mobile station</td>
</tr>
<tr>
<td>SID</td>
<td>System identifier</td>
<td>15</td>
<td>Assigned by regulators to a geographical service area</td>
</tr>
<tr>
<td>NID</td>
<td>Network identifier</td>
<td>16</td>
<td>Service providers ID</td>
</tr>
<tr>
<td>PN_OFFSET</td>
<td>Pseudo-noise code offset</td>
<td>9</td>
<td>Delay applied to random number sequence at a base station</td>
</tr>
<tr>
<td>Reg_Zone</td>
<td>Registration Zone</td>
<td>12</td>
<td>Location Area defined by operating company</td>
</tr>
</tbody>
</table>

### IS-95 Logical Channels

- CDMA systems define multiple channels *per frequency channel*
- Pilot channel
  - Provides a reference to all signals (beacon)
- Sync channel
  - Used for obtaining timing information
- Paging channel
  - Used to “page” the mobile terminal when there is an incoming call
- Traffic channel
  - Carries actual voice or data traffic: fundamental code channel
    - Up to seven supplemental code channels
IS-95 CDMA Channels

- Types of channels

<table>
<thead>
<tr>
<th>Channels</th>
<th>Application</th>
<th>bits/s</th>
<th>Spreading code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward channels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot</td>
<td>System mon.</td>
<td>NA</td>
<td>Walsh code 0</td>
</tr>
<tr>
<td>Synchronization</td>
<td>Sync.</td>
<td>1200</td>
<td>Walsh code 32</td>
</tr>
<tr>
<td>Paging</td>
<td>Signaling</td>
<td>9600</td>
<td>Walsh codes 1-7</td>
</tr>
<tr>
<td>Traffic</td>
<td>Voice/data</td>
<td>9600/14,400</td>
<td>Walsh 8-31,33-63</td>
</tr>
<tr>
<td>Reverse channels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access</td>
<td>Signaling</td>
<td>4800</td>
<td>Access channel long code mask</td>
</tr>
<tr>
<td>Traffic</td>
<td>Voice/data</td>
<td>9600/14,400</td>
<td>Walsh code in modulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+ Access channel long code mask</td>
</tr>
</tbody>
</table>

Basic Spreading Procedure on the Forward Channel in IS-95

- Symbols are generated at different rates
- For the spread signal to be at 1.2288 Mcps, the incoming stream must be at: 1.2288 \times 10^6/64 = 19.2 \text{ kbps}
- What happens if the incoming stream is at a lower rate?
  - Example: Incoming stream is at 4.8 kbps
  - Number of chips per bit = 1.2288 \times 10^6/4.8 \times 10^3 = 256
  - End result is greater spreading
IS-95 Forward (Downlink) Channel

One Forward CDMA Link, 1.25 MHz in the 824 – 849 MHz bands

IS-95 CDMA Forward Channel Modulation

[Rapport Fig 10.14] CDMA forward channel modulation process
Pilot Channel

- It is continuously transmitted by a BS on the forward link
  - Like a “beacon” (Compare BCCH in GSM)
  - Acts as the reference signal for all MSs
  - Used in demodulation and coherent detection
  - Used to measure RSS for handoff and open loop power control

The Pilot Channel (II)

- It carries NO information but it is a very important signal
- It has 4-6 dB higher transmit power than any other channels
- The transmit power of the pilot channel is constant (No power control)
- The I and Q PN sequences
  - Are generated using a pseudorandom number generator of length $m = 15$
  - The period is $2^{15} - 1 = 32767$
  - In time, one period is $32767 \times 0.8138 \mu s = 26.7$ ms
  - Number of repetitions/second = $1/26.7 \times 10^{-3} = 37.5$
  - Number of repetitions in 2 seconds = 75
PN Sequences and Offsets

- All base stations use the same PN sequences but with a different "offset"
- The offsets are by 64 chips
  - Total number of offsets = $32767/64 = 511$ offsets

Short PN code Offsets

Source: CDMA Systems Engineering Handbook, J. S. Lee and L. E. Miller
CDMA System Concepts

- Cell Configuration in IS-95
  - Cells identified by Short Code PN Offset 511 different ones are available, same as random number seed in random number generators
  - Users identified by Walsh Code
  - Rake receiver allows user to receive signal from multiple base stations or multiple sectors simultaneously

Pilot Channels and the Use of PN Sequences in IS-95

- The MS processes the pilot channel to find the strongest signal
  - A search correlator sweeps through all possible frequency offsets to identify BSs in the area
- The MS picks the strongest pilot signal
  - This has a PN-offset
- The MS uses the PN-offset of this pilot to track the synch channel

Search correlator output: 5 strong signals have been detected
The Synch Channel

- The synch channel is locked to the offset of the PN-sequence used in the pilot channel
  - It contains system information pertinent to the associated base station
- Operates at a fixed data rate of 1.2 kbps
  - After rate ½ convolutional encoding, it becomes 2.4 kbps
  - The symbols are repeated to 4.8 kbps and then transmitted

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The Synch Channel

- The base stations in IS-95 are completely synchronized using GPS satellite
  - Transmitted chips on the downlink are all synchronized from all base stations
  - The Base Station “System Time” is synchronized to a “Universal Coordinated Time” or UTC
    - UTC is loosely what used to be GMT
Details of the Synch Channel

- The frame is aligned to the start of the PN sequence
  - One synch channel frame lasts 26.7 ms
  - Three synch channel frames = one synch channel superframe = 80 ms
- SOM = start of message indicator
  - 0 – continuation from previous frame
  - 1 – start of a new synch message
- Data can be 2 – 1146 bits
- CRC is 30 bits

Sample IS95 Message

IS 95 message format

<table>
<thead>
<tr>
<th>Length</th>
<th>Type</th>
<th>ACK</th>
<th>Contents</th>
<th>CRC check</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 bits</td>
<td>8 bits</td>
<td>7 bits</td>
<td>1-2008 bits</td>
<td>16 or 30 bits</td>
</tr>
</tbody>
</table>

**SYNC Channel Message**

used to synchronize the random number generator for traffic channel transmission

<table>
<thead>
<tr>
<th>Bit Position</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>message type 00000001</td>
</tr>
<tr>
<td>9-16</td>
<td>protocol version</td>
</tr>
<tr>
<td>17-24</td>
<td>minimum protocol version</td>
</tr>
<tr>
<td>25-39</td>
<td>SID</td>
</tr>
<tr>
<td>40-55</td>
<td>NID</td>
</tr>
<tr>
<td>56-64</td>
<td>PN_OFFSET</td>
</tr>
<tr>
<td>65-106</td>
<td>long code state</td>
</tr>
<tr>
<td>107-142</td>
<td>system time (from GPS)</td>
</tr>
<tr>
<td>143-147</td>
<td>local time differential to system time</td>
</tr>
<tr>
<td>158-159</td>
<td>paging channel rate (4800 bps or 9600 bps)</td>
</tr>
<tr>
<td>160-168</td>
<td>CDMA Freq</td>
</tr>
</tbody>
</table>
The Paging Channel

- Transmits control information to the MS
  - Page message to indicate incoming call
  - System information and instructions
    - Handoff thresholds
    - Maximum number of unsuccessful access attempts
    - List of surrounding cells PN Offsets
    - Channel assignment messages
  - Acknowledgments to access requests
- It operates at either 4.8 kbps or 9.6 kbps
  - It is passed through a rate ½ convolutional encoder to go up to 9.6 kbps or 19.2 kbps
  - If the output is 9.6 kbps, it is repeated to go up to 19.2 kbps
- MS chooses which slot to monitor within its cycle based on its mobile identification number (MIN)

The Paging Channel (2)

- The 19.2 kbps stream is block interleaved
  - Block size is 20 ms (384 bits) but the information is essentially a stream
- The data is scrambled by multiplying it with a 19.2 kbps stream generated by decimating a long code generator output
Slotted paging

- The paging messages are sent in slots of 80 ms
  - The MS either uses the slotted mode or the unslotted mode
- In slotted mode operation
  - MS monitors the allocated slots (one or two slots per cycle)
    - The MS starts monitoring just in time to receive the first bit of its assigned slot
  - The page message contains a field called MORE_PAGES
    - If the field is zero, there are no more messages for the MS
    - If no such field is set, the MS monitors the next slot as well
- The MS continues to monitor the paging channel till MORE_PAGES = 0 or a valid page message is received
  - How does it know if the message is valid?

IS-95 Paging Messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Network Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYSTEM PARAMETER</td>
<td>Call/Radio Resources Management</td>
</tr>
<tr>
<td>Access Parameters</td>
<td>Access channel assignments</td>
</tr>
<tr>
<td>Neighbor List</td>
<td>PN offsets of neighbor cells</td>
</tr>
<tr>
<td>CDMA channel list</td>
<td>List of CDMA frequency channels</td>
</tr>
<tr>
<td>PAGE</td>
<td>Incoming Call</td>
</tr>
<tr>
<td>Authentication Challenge</td>
<td>Security challenge</td>
</tr>
<tr>
<td>Registration Request</td>
<td>Call Management</td>
</tr>
<tr>
<td>INTERCEPT</td>
<td>Call Management</td>
</tr>
<tr>
<td>Channel Assignment</td>
<td>Walsh code for traffic channel</td>
</tr>
<tr>
<td>Challenge confirmation</td>
<td>Security ACK of authentication</td>
</tr>
<tr>
<td>RELEASE</td>
<td>Call Management</td>
</tr>
<tr>
<td>CONFIRM REGISTRATION</td>
<td>Mobility Management</td>
</tr>
</tbody>
</table>
Traffic Channel

- Traffic channels
  - Carries user traffic and control messages to specific MSs, dedicated exclusively to one MS
  - assigned dynamically, in response to MS accesses, to specific MS
  - always carries data in 20 ms frames
  - carry variable rate traffic frames, either 1, 1/2, 1/4, or 1/8 of 9600 bps or fixed 14.4 Kbps
  - rate variation is accomplished by 1, 2, 4, or 8-way repetition of code symbols, but the energy per bit approximately constant
  - rate is independently variable in each 20 ms frame
  - An 800 bps reverse link power control subchannel is carried on the traffic channel by puncturing 2 from every 24 symbols transmitted

IS-95 Downlink Traffic Channel

- PCM Voice
- QCELP Vocoder
- Convolutional Coding
- Symbol Repetition
- Puncturing
- Block Interleaving

- Reduces bit rate needed to represent speech. Operates in a variable mode of full, 1/2, 1/4 & 1/8 rates. Rate set 1 vocoder full-rate output is at 9.6 kbps and rate set 2 full rate output is at 14.4 kbps.
- Provides error detection/correction. Two symbols are output for each incoming bit. Repetition of input symbols from the encoder. Repetition is done to maintain a constant input to the block interleaver. Full-rate symbols are not repeated and sent at full power, half-rate repeated once & sent at half power and so on. For rate set 1 the output is maintained at 19.2 kbps (independent of vocoding rate) and for rate set 2 the output is 28.8 kbps.
- Used only for vocoder operating in rate set 2 mode. Deletes 2 out of every 6 inputs for an output of 19.2 kbps. This results in an identical input rate to the block interleaver of 19.2 kbps irrespective of the rate set of the vocoder.
- Combat the effects of Rayleigh fading by ensuring that sequential data is not lost.
IS-95 Downlink Traffic Channel

- **Data Scrambling**: Provides security by scrambling the input data with a long code mask permuted with the user's ESN.
- **Power Control Subchannel**: Provides a very fast power control subchannel (800 times a second). The input data is punctured 800 times a second and a power up/down command is sent to the mobile station. Each command can increase or decrease a mobile station's power by 1 dB.
- **Orthogonal Spreading**: Provides identity and orthogonality to the forward channels by spreading them with a unique Walsh code. Each input symbol is exclusive-or'd with a 64-bit Walsh code resulting in a data rate of 1.228 Mcps (megachips per second).
- **Quadrature Spreading**: Provides unique base-station identity. The spreading sequence is 32768 chips and repeats every 26.66 ms. The same sequence is used by all base stations but is offset in each. There are 512 possible offsets. Ensures that the mobile station is locked on to the right base station.
- **Baseband Filtering**: Converts the signals to the cellular frequency range (800 MHz) or the PCS frequency (1900 MHz).

### IS-95 Traffic Channel Example

- **Input data 0**: 0000111100001111111100001111000000001111000011111111000011110000
- **Walsh function 20**: Pattern transmitted by the Base station: 000011110000111111110000000001111000011111111000011110000
- **Pattern received at the Mobile station**: 000011110000111111110000000001111000011111111000011110000
  - Each 64 bit (symbol) block of the received pattern is exclusive-or'd with Walsh Function 20:
    - 000011110000111111110000000001111000011111111000011110000
    - 0000000000000000000000000000000000000000000000000000000000000000

Count number of 1’s and 0’s to determine what bit was sent!
IS-95 Traffic Channel Example

Pattern received at the Mobile station (1)

11110000111100000000111110000111111110000111100000000111100001111

Each 64 bit (symbol) block of the received pattern is exclusive-or'd with Walsh Function 40 which is not the same Walsh Function used for orthogonal spreading at the base station.

Walsh Function 40

0000000011111111111000001111111111100000111111111000000001111111100

Inconclusive output – Equal number of 1s and 0s in the despread pattern.

Orthogonal despreading with incorrect Walsh code

Forward Traffic Channels

- 9.6, 4.8, 2.4, or 1.2 kbps; 20 ms frames
- Rate can be changed every frame

Forward Traffic Channel Information

- 8.6 kbps Bits for User m, 4 kbps
- (172, 80, 40 or 20 kbps
- 16 bits/frame, 0.8 kbps

Add Frame Quality Indicator for 9600 & 4800 bps Rates

- 9.2 kbps
- 4.4 kbps
- 2.0 kbps
- 0.8 kbps

Add 8-bit Encoder Tail

- 9.6 kbps
- 4.8 kbps
- 2.4 kbps
- 1.2 kbps

Convolutional Encoder R=1/2, K=9

- 19.2 kbps
- 9.6 kbps
- 4.8 kbps
- 2.4 kbps

Symbol Repetition

- 19.2 kbps
- 9.6 kbps
- 4.8 kbps
- 2.4 kbps

Tom Tom
Forward Traffic Channel Frame Structure (9.6 Kbps coder)

Both Forward and Reverse Traffic channels use 20 msec frames

<table>
<thead>
<tr>
<th>Frame Rate</th>
<th>Frame Information (20 ms)</th>
<th>F</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>9600 bps</td>
<td>192 bits</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>4800 bps</td>
<td>96 bits</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2400 bps</td>
<td>48 bits</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>1200 bps</td>
<td>24 bits</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

F: Frame Quality Indicator (CRC)
T: Encoder Tail Bits

Traffic Channel Messages & Service Option

- **Signaling on Traffic Channels**
  - Blank and Burst mode (replace speech with control traffic) – operates at 9.6 Kbps
  - Dim and Burst mode
    - Reduce bit rate of vocoder, insert control traffic in rest of frame rather than repeating voice info
- **Four types of control messages on the Traffic Channel**
  - messages controlling the call itself
  - messages controlling handoff
  - messages controlling forward link power
  - messages for security and authentication
- **IS-95 supports different user applications, called service options**
  - primary traffic (e.g., voice)
  - secondary traffic (SMS)
Forward Link Channel Parameters

<table>
<thead>
<tr>
<th>Channel</th>
<th>Sync</th>
<th>Paging</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data rate</td>
<td>1200</td>
<td>4800</td>
<td>9600</td>
</tr>
<tr>
<td>Code repetition</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Modulation</td>
<td>4800</td>
<td>19,200</td>
<td>19,200</td>
</tr>
<tr>
<td>symbol rate</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>PN chips/symbol</td>
<td>256</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>modulation symbol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PN chips/bit</td>
<td>1024</td>
<td>256</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1024</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>512</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>256</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>128</td>
</tr>
</tbody>
</table>

IS-95 Reverse Channel

- From MS to Base Station
- On Reverse Channel the Walsh codes are not used to isolate different users, but in orthogonal signaling
  - Orthogonal signaling is an M-dimensional digital modulation technique
  - The larger M is, the larger is the bandwidth requirement => spread spectrum 😊
- There are no pilot or synch channels
- There is an “access channel” where mobile terminals contend in random access fashion to set up a call/register location/page response
Reverse CDMA Channel

One Reverse CDMA Link, 1.25 MHz in the 824 – 849 MHz

Access Channel 0, PCH1
Access Channel N, PCH1
Access Channel 0, PCH7
Access Channel
Traffic Channel 1
Traffic Channel T

Fundamental Code Channel Data
Supplementary Code Channel Data
Supplementary Code Channel Data
Supplementary Code Channel Data
Supplementary Code Channel Data

Access Channel

• Is used by the MS to initiate communication with the BS & to respond to Paging Channel message

Fixed data rate (4800 bps) & 20 ms frame duration

Access Channel Message may carry
• Origination of a call
• Paging responses
• Orders response
• Data bursts
• Acknowledgements to Paging Channel message
• Registration

Basic frame structure

96 bits (20 ms)
Information Bits = 88 bits
Encoder Tail 8 bits
Sample IS-95 Messages

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</table>

Access Channel is the used by phones without a call in progress to perform signaling.

Access Channel

- There are up to 32 access channels per downlink paging channel
  - MSs are pseudorandomly distributed between the access channels
- The access channel data has 96 bits every 20 ms for a data rate of 4.8 kbps
  - 88 bits carry the access channel data
  - 8 bits are encoder tail bits

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  - 8 bits are encoder tail bits
Access channel

- The 4.8 kbps data is encoded using a rate 1/3 convolutional encoder
  - The constraint length is 9
  - Minimum Hamming distance is 18
  - Output of the convolutional encoder is 14.4 kbps
- The output symbols are repeated to get a rate of 28.8 kbps
  - Every six bits is mapped into one Walsh code of 64 bits (chips) in the 64-ary orthogonal modulator
  - Walsh code index $X$ is calculated as follows:
    - $X = c_0 + 2c_1 + 4c_2 + 8c_3 + 16c_4 + 32c_5$
    - $c_0$ is the earliest bit and $c_5$ is the latest bit
  - Example: 110001 ($c_5…c_0$) would translate into $W_{49}$

Reverse Channel Access Protocol

<table>
<thead>
<tr>
<th>Ack. received before timeout?</th>
<th>Max probe?</th>
<th>New attempt</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

Access succeeds

Access fails

Access protocol
IS-95 Reverse Traffic Channel

PCM Voice

Vocoder
- Reduces bit rate needed to represent speech. Operates in a variable mode of full, ½, ¼ & 1/8 rates. Rate set 1 vocoder full-rate output is at 9.6 kbps and rate set 2 full rate output is at 14.4 kbps.
- Provides error detection/correction. Two symbols are output for each incoming bit for rate set 1 and two symbols are output for each incoming bit for rate set 2 resulting in an output of 28.8 kbps in both cases.
- Repetition of input symbols from the encoder. Repetition is done to maintain a constant input to the block interleaver. Full-rate symbols are not repeated and sent at full power, half-rate repeated once & sent at half power and so on. For rate set 1 the output is maintained at 19.2 kbps (independent of vocoding rate) and for rate set 2 the output is 28.8 kbps.
- Combat the effects of Rayleigh fading by ensuring that sequential data is not lost.
- Blocks of 6 input symbols are replaced by a corresponding 64-chip Walsh code.

Convolutional Coding

Symbol Repetition

Block Interleaving

Orthogonal Modulation

IS-95 Reverse Traffic Channel

Data Burst Randomizer
- Provides variable-rate transmission. Symbols which are repeated are deleted, i.e., not transmitted. The transmitted duty cycle varies with the vocoder data rate and the transmission are randomized.

Direct Sequence Spreading
- Provides spreading of the code. In the reverse link the data is spread using the user’s long code mask based on the ESN.

Quadrature Spreading
- The channel is spread with the pilot PN sequence with a zero offset. Ensures that the mobile station is locked on to the right base station.

Baseband Filtering
- Converts the signals to the cellular frequency range (800 MHz) or the PCS frequency (1900 MHz).

To RF section
Sample IS-95 Messages

### Traffic Channel Signaling Messages

<table>
<thead>
<tr>
<th>Uplink</th>
<th>Downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Measurement Report</td>
<td>Neighbor List</td>
</tr>
<tr>
<td>Pilot Strength Measurement</td>
<td>Pilot Measurement Request</td>
</tr>
<tr>
<td>Handoff Completion</td>
<td>Handoff Direction</td>
</tr>
<tr>
<td>Long Code Transition Request</td>
<td>Long Code Transition Request</td>
</tr>
<tr>
<td>Data Burst</td>
<td>Data Burst</td>
</tr>
<tr>
<td>Request Analog Service</td>
<td>Analog Handoff Direction</td>
</tr>
<tr>
<td>Long Code Transition Response</td>
<td>Long Code Transition Response</td>
</tr>
</tbody>
</table>

Reverse Traffic Channel – Supplementary Code Channel

- The supplementary code channel is primarily used for data traffic (full rate is assumed)
  - There is no need for a data randomizer
- A single user can have many codes simultaneously to transmit data
### Reverse CDMA Channel Parameters, Rate Set 1

<table>
<thead>
<tr>
<th>Channel</th>
<th>Access</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data rate</td>
<td>4,800</td>
<td>2,400</td>
</tr>
<tr>
<td>Code Rate</td>
<td>1/3</td>
<td>1/3</td>
</tr>
<tr>
<td>Symbol Rate before Repetition</td>
<td>14,400</td>
<td>7,200</td>
</tr>
<tr>
<td>Symbol Repetition</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Symbol Rate after Repetition</td>
<td>28,800</td>
<td>28,800</td>
</tr>
<tr>
<td>Transmit Duty Cycle</td>
<td>1</td>
<td>1/8</td>
</tr>
<tr>
<td>Code Symbols/Modulation Symbol</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>PN Chips/Modulation Symbol</td>
<td>256</td>
<td>256</td>
</tr>
<tr>
<td>PN chips transmitted/bit</td>
<td>256</td>
<td>128</td>
</tr>
</tbody>
</table>

### Call processing states

- **Power up**
  - Tune to primary or Secondary CDMA carrier

- **Initialization**
  - MS acquires pilot channel and sync channel

- **Idle State**
  - MS acquires paging channel
  - Monitors PCH for messages

- **Traffic Channel State**
  - Speech comm. on forward & reverse links
  - Associated control messages using blank-and burst, dim-and burst and PC

- **Access State**
  - MS sends messages on ACH
  - BS sends messages on PCH

- **End of call**
- **System response**
  - Other than page origination
- **Call origination**
  - Page response
  - Registration
- **Traffic channel acquisition**
- **End of call**
- **System response**
  - Other than page origination
Idle Handoff and Overhead Messages

• An idle handoff occurs when
  – MS moves to another cell in the idle state
  – It determines that a new pilot signal is stronger
  – The MS operates in unslotted mode to acquire a paging message

• Overhead messages on the paging channel
  – System parameters
  – Neighbor list (PN offsets of the neighbors)
  – CDMA channel list (list of CDMA channels)
  – Access parameters
    • Access message sequence number
    • Nominal transmit power of the access channel and power increments

CDMA Properties: Near-Far Problem

• A CDMA receiver cannot successfully despread the desired signal in a high multiple-access-interference environment

• Unless a transmitter close to the receiver transmits at power lower than a transmitter farther away, the far transmitter cannot be heard
• Mobile transmit so that power levels are about equal at the base station
• Power control must be used to mitigate the near-far problem
Power control

- In CDMA, the "near-far" problem is very significant
  - As users transmit at the same time and frequency, a user close to the base station may drown the signal of a user far away from the base station
- To overcome this problem, power control is used
  - Open-loop power control
    - Use a transmit power that is inversely proportional to the received signal strength from a base station
  - Closed-loop power control
    - A power control bit is transmitted 800 times a second on the forward link
    - The bit instructs the mobile station to either increase or decrease the power by 1 dB
- Power control also reduces the battery power consumption making the CDMA phones somewhat smaller than their TDMA counterparts

Power Control: Open Loop vs. Closed Loop

- Open loop:
  - Base station transmits at a known power level (a beacon) which mobile measures to estimate the path loss
  - Assumes path loss in both directions is the same
  - Not very accurate as uplink and downlink are separated in frequency
  - Useful for coarse initial estimates at mobile used in Access channel for signalling
- Closed loop:
  - Signal-to-Interference Ratio (SIR) measured at the receiver and compared to a target value for SIR
  - Receiver sends a power control command to transmitter to reduce or increase the power level - requires a bi-directional link
  - Used in TCH – power control subchannel operates at 800 bps by puncturing downlink data with periodic bits – each power command adjusted MS power in 1 dB increments
Closed Loop Power Control: Inner Loop vs. Outer Loop

- **Inner Loop (or fast power control)**
  - Measures received SIR, controls transmit power
  - Commands sent several times per frame (hence fast power control)

- **Outer Loop (or slow power control)**
  - Measures packet error rate
  - Changes target SIR for inner loop
  - Directly modify transmit power based on FER
  - Commands sent once per frame (hence slow power control)

---

CDMA Capacity

- **CDMA Main Advantages**
  - Resistant to narrow band interference
  - Resistant to multipath fading and ISI
  - No hard limit on number of users (soft capacity)
  - As number of users on a frequency increase the interference level increases and BER increases for all users
  - With proper limits all frequencies can be used in every cell

---

Error probability

BER of CDMA system with 128 cps.
CDMA Capacity

- CDMA is a interference limited system
  - Must limit number of users on a frequency to limit interference within a cell and between cells using same frequency (All CDMA carriers can be assigned to each sector in each cell!)
  - Total Interference $I_t = I_{oc} + I_o + N_o$
    - $I_{oc} =$ other cell interference, $I_o =$ own cell interference, $N_o =$ Noise
    - uplink not downlink in CDMA systems considered the constraining factor
  - Remember in direct sequence spread spectrum Processing Gain = bandwidth of the spread signal to the bandwidth of the data signal = W/R
    - In IS-95 $W/R = 10 \log (1.23 \text{ MHz}/9.6 \text{ KHz}) = 21.1 \text{ dB}$ for rate set 1, for rate set two (14.4 kbps) => 19.3 db
- Number of traffic channels per carrier and cell function of processing gain, interference, speech coder tolerance for errors, error control coding, etc.

CDMA Capacity

- The effect of more users in a cell on frequency is to degrade the channel for everyone – can be thought off as decreasing the usable cell size
Cell Breathing

- Cell breaths in & out with changing load
  - Cells shrink during peak hours, expand during off-peak hours

Drive-test data on the right shows
Eco/lo differences between day and night, around the SMU campus.
Eco/lo values are better at night (and thus the cells are larger)

Soft Handoff

- If a mobile terminal moves away from a base station
  and continues to increase its transmit power to maintain contact with base station – at edge of cell will need to handoff to adjacent cell

- In soft handoff a mobile terminal is required to track the pilot signals from all neighboring base stations
  - It will communicate with *multiple* base stations simultaneously for a short while before deciding on the final candidate
  - This is possible because of the RAKE receiver and direct-sequence spread-spectrum
  - Not all handoffs will be soft!
  - Hard handoff when CDMA to AMPS and inter-CDMA frequency channel handoffs
  - Note soft handoff reduces system capacity as mobile tying up 2 traffic channels
CDMA System Concepts: Soft Handovers

- Mobile located in the area of overlap of multiple base stations
- Transmission:
  - Uplink: No difference
  - Downlink: BSC/MSC sends out a copy of the same packet to each base station
- Reception:
  - Uplink: Each base station demodulates packet, BSC/MSC picks the “better packet” (macro-diversity combining)
  - Downlink: The mobile combines the signals using a Rake receiver (micro-diversity combining)
- Two power control loops

Soft Handoff Procedure

- The mobile terminal maintains a list of pilot channels that it can hear and classifies them into four categories
  - Active set – pilots currently used by the mobile terminal (up to three pilots can be used)
  - Candidate set – pilots that are not in the active set, but have sufficient signal strength for demodulation
  - Neighbour set – pilots of base stations of neighbouring cells that are indicated by the network through the paging channel
  - Remaining set – all other possible pilots in the system
- Several thresholds are used by the mobile terminal to move pilots from one set to another
Soft Handoff Procedure

- Neighboring pilot > threshold: 
  Add neighbor to candidate set

- Select channel at new base

- New active set

- Handoff direction

- Handoff complete

- Traffic channel info

- Program correlators

Soft handoff procedure
Soft Handoff

- IS-95 specifies three basic types of soft handoff
  - (a) Softer: handoff between two sectors of same cell
  - (b) Soft: handoff between sectors of adjacent cells
  - (c) Soft-softer: candidates for handoff include two sectors from the same cell and a sector from adjacent cell

Figure 8.16: (a) Softer (b) soft and (c) soft-softer handoff

Soft Handoff

- Combinations of the three types can occur for example
  - Soft-Soft: 3 adjacent cells
- Downside of soft handoff
  - call uses multiple traffic channels over air (increases interference and decreases capacity)
  - Call uses multiple trunk in portion of wired network
  - figure shows typical soft handoff percentages in a live IS-95 network in Dallas, Texas
  - Note in handoff state 85% of the time!
Encryption

- CAVE (cellular authentication and voice encryption) algorithm used
- Uses a 64 bit A-key along with ESN and Random number to generate 128 bit shared secret data (SSD)
- SSD divided into two 64 bit blocks
  - (A for authentication, B for encryption)
- Challenge/Response technique for Authentication
- Random number used to create key for encryption of voice and data

Example of C-R: IS-41C

Generate RAND

Compute \( \text{AUTHU}^* = \text{CAVE}_{\text{key}}(\text{RAND}) \)

Compare \( \text{AUTHU}^* \) and \( \text{AUTHU} \)

Send \( \text{AUTHU} \)
CAVE

- Challenge/Response based on random number and SSD

IS-95 Summary

- Direct Sequence Spread Spectrum
- Code Division Multiple Access/FDMA/FDD
- Reuse frequencies in every cell K = 1!
- Soft Handoff supported
- Dim and Burst signalling
- Digital Voice
  - QCELP fixed rate 14.4Kbps coder
  - variable rate QCELP coder: 9.6, 4.8, 2.4, 1.2 Kbps
- Dual Mode (AMPS/CDMA) Dual Band (900, 1900 MHz bands)
- Low power handsets (sleep mode)
- Power Control important (800bps)
- Security: CDMA signal + CAVE encryption
- Air Interface Standard Only
- Large increase in capacity over AMPS