IS-95 (cdmaone)

David Tipper
Associate Professor
Graduate Telecommunications and Networking Program
University of Pittsburgh
Slides 9
http://www.sis.pitt.edu/~dtipper/2700.html

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)

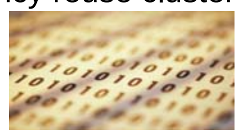
- Several alternative CDMA proposals floated – large debate in the CTIA
  - came down to Interdigital vs. Qualcomm
  - Qualcomm proposal won
- 1993 TIA IS-95 code division multiple access (CDMA) standards completed
  - 1995 IS-95A enhanced revision
  - ANSI J-STD-008 (IS-95b) is standard upbanded to 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

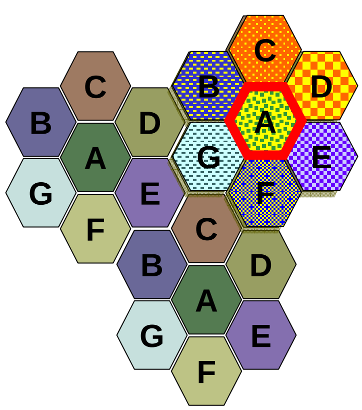
IS-95 System Features

- 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

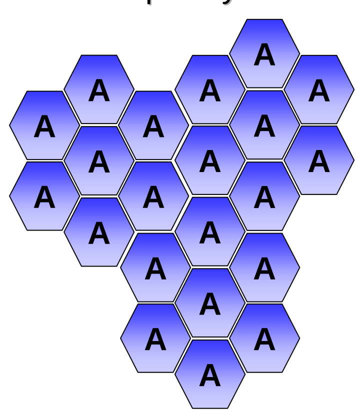


Universal Frequency Reuse

Frequency
Reuse Factor = 7 for AMPS



CDMA Universal
Frequency Reuse



Frequency Reuse Factor = 4 or 3 for GSM systems

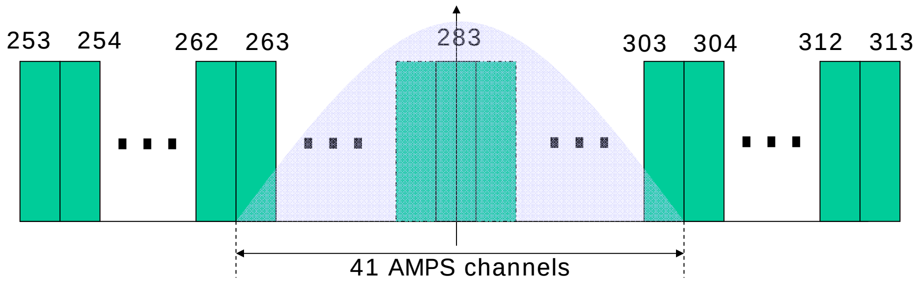
IS-95 CDMA - Radio Aspects

- 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

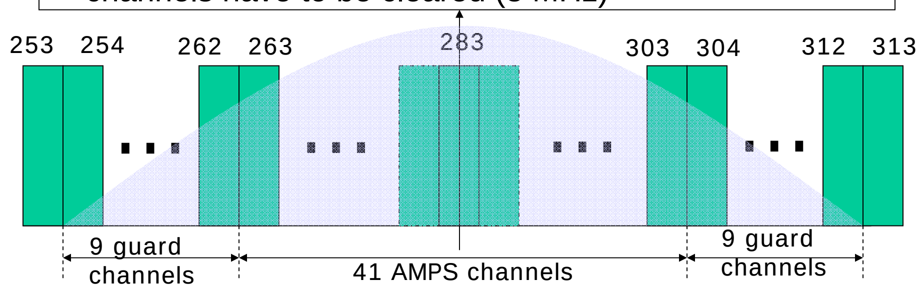
Physical channels

- 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 →1.25MHz 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



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 Ascpects

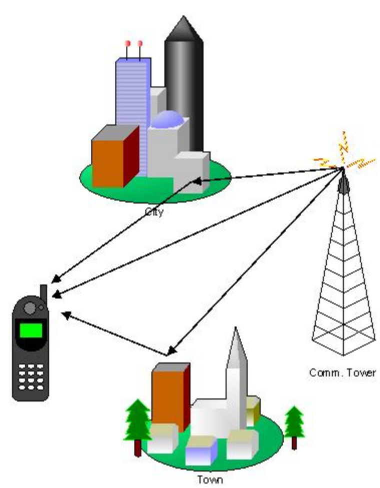
Modulation	Quadrature phase shift keying or variations
Channel/Chip rate	1.2288 Mcps
Nominal data rate (Rate Set 1)	9.6 kbps
Filtered bandwidth	1.23 MHz -> 1.25 MHz with guard band
Coding	Convolutional coding Constraint length = 9 Viterbi decoding
Interleaving	With 20 ms span

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

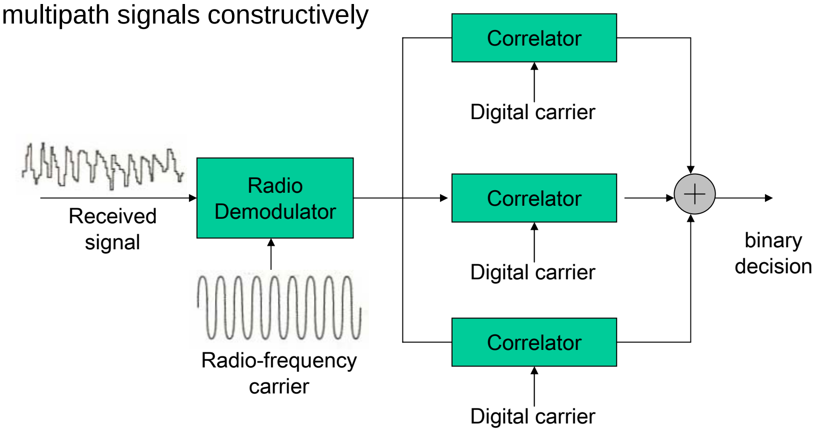
IS-95 Multipath Combining

- 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



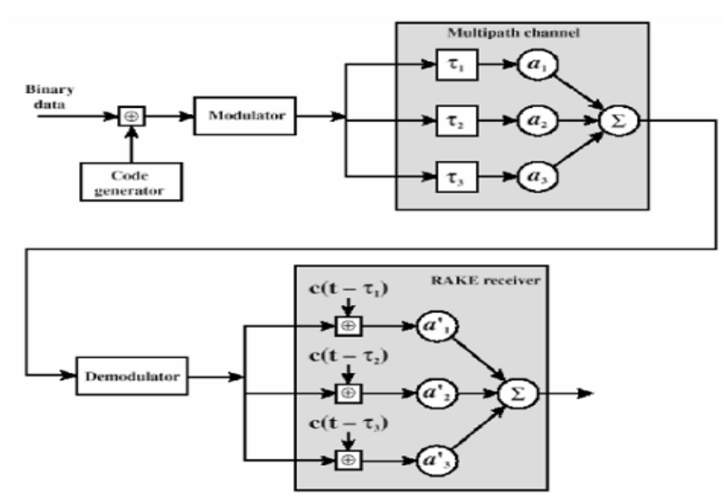
Rake Receiver

RAKE receiver combines the multipath signals constructively

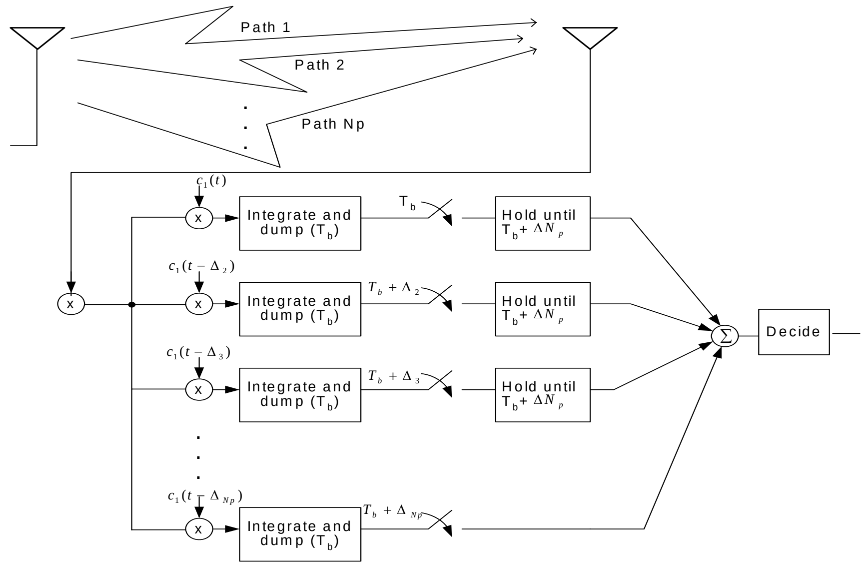


RAKE receiver

Multipath and the RAKE Receiver



Processing of multipaths using the Rake Receiver



Codes used in IS-95 systems

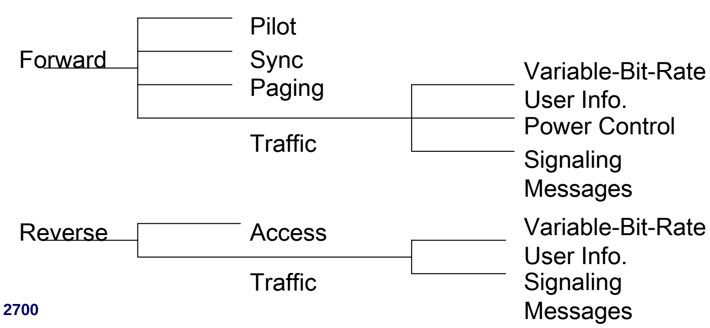
- Walsh codes
  - They are the “orthogonal codes” used to create “logical channels” on the up/downlink (at the same time and within the same frequency band)
- PN (pseudo-noise) codes
  - They are used to distinguish between transmissions from different cells and are generated using “linear feedback shift 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

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

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



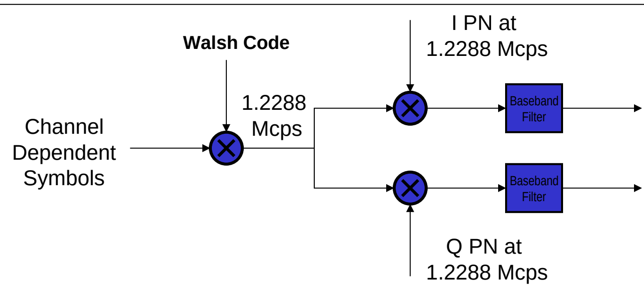
IS-95 CDMA Channels

- Types of channels

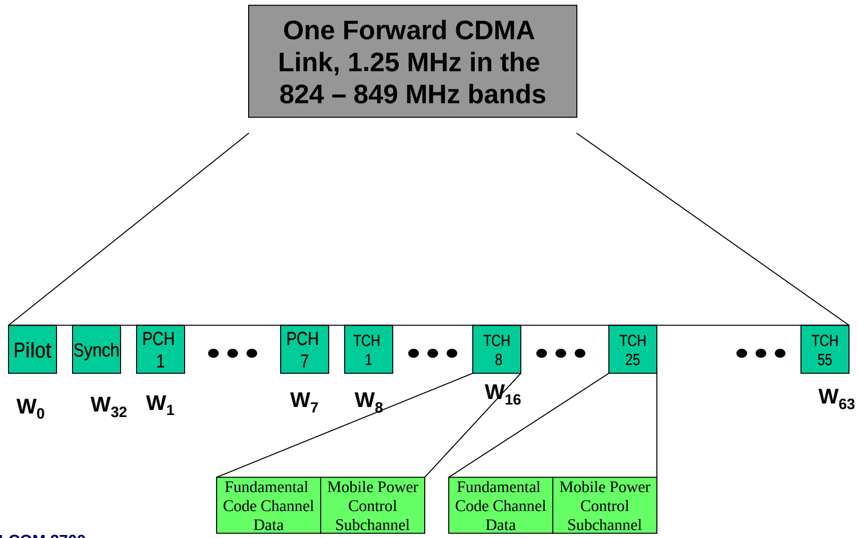
Channels	Application	bits/s	Spreading code
Forward channels			
Pilot	System mon.	NA	Walsh code 0
Synchronization	Sync.	1200	Walsh code 32
Paging	Signaling	9600	Walsh codes 1-7
Traffic	Voice/data	9600/14,400	Walsh 8-31,33-63
Reverse channels			
Access	Signaling	4800	Access channel long code mask
Traffic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

Basic Spreading Procedure on the Forward Channel in IS-95

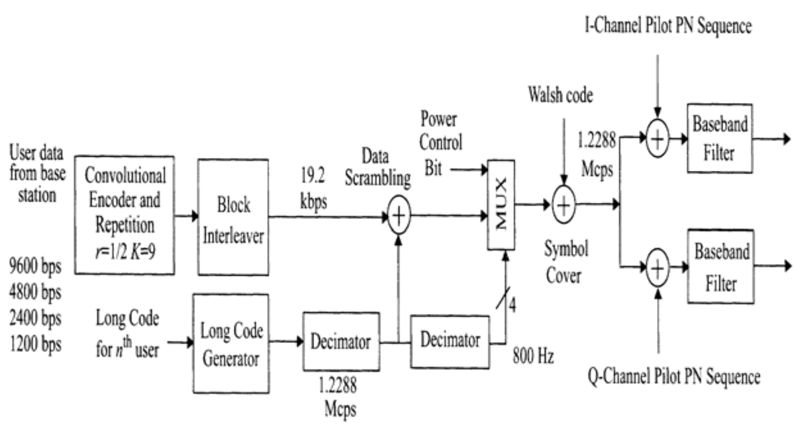
- Symbols are generated at different rates
- For the spread signal to be at 1.2288 Mcps, the incoming stream must be at: 1.2288 x $10^6/64$ = 19.2 kbps
- What happens if the incoming stream is at a lower rate?
  - Example: Incoming stream is at 4.8 kbps
  - Number of chips per bit = 1.2288 x $10^6/4.8$ x 10^3 = 256
  - End result is greater spreading



IS-95 Forward (Downlink) Channel



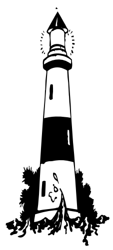
IS-95 CDMA Forward Channel Modulation

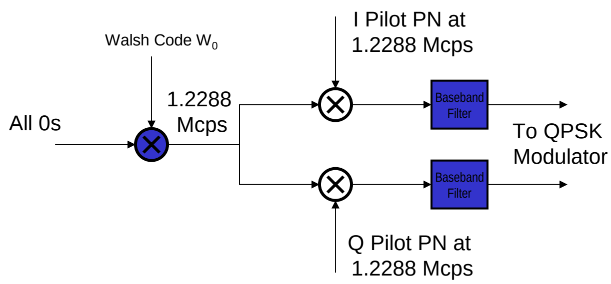


[Rapport Fig 10.14] CDMA forward channel modulation process

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



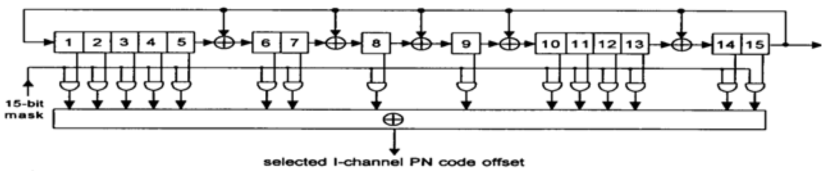


The Pilot Channel (II)

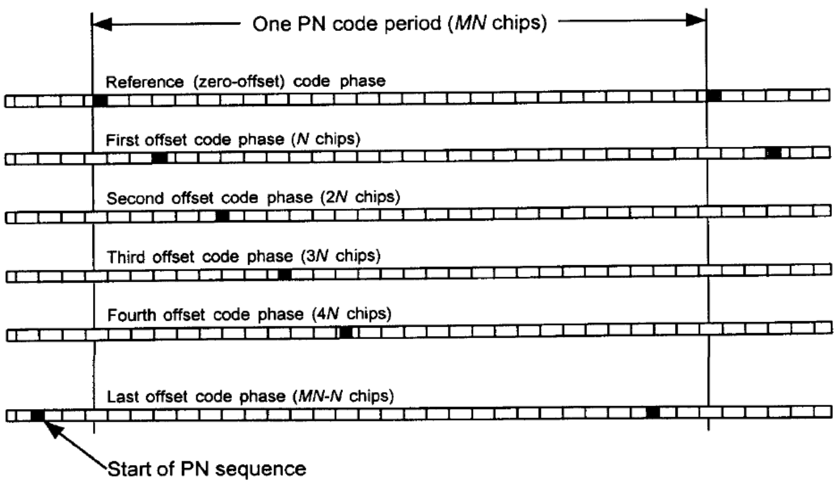
- It carries NO information but it is a very important signal
- It has 4-6 dB higher transmit power than any other channels
- The transmit power of the pilot channel is constant (No power control)
- The I and Q PN sequences
  - Are generated using a pseudorandom number generator of length $m = 15$
 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



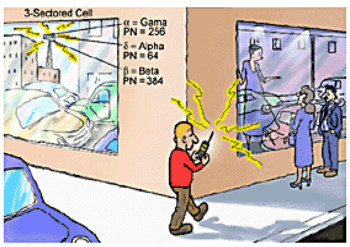
Short PN code Offsets

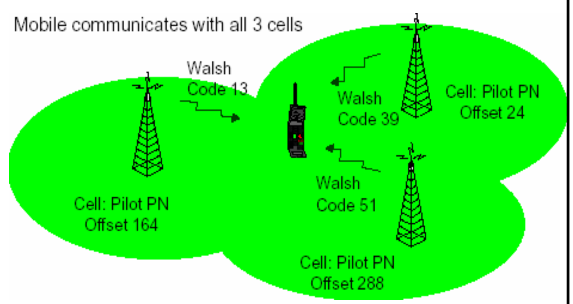


Source: CDMA Systems Engineering Handbook, J. S. Lee and L. E. Miller

CDMA System Concepts

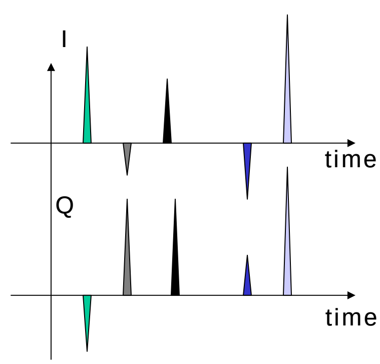
- Cell Configuration in IS-95
  - Cells identified by Short Code PN Offset 511 different ones are available, same as random number seed in random number generators
  - Users identified by Walsh Code
  - Rake receiver allows user to receive signal from multiple base stations or multiple sectors simultaneously





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

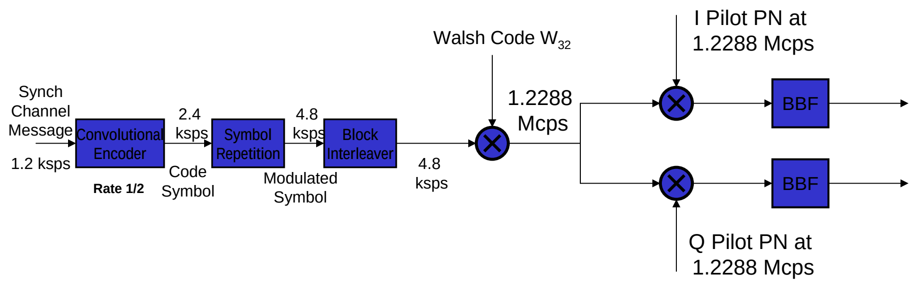
- The MS processes the pilot channel to find the strongest signal
  - A search correlator sweeps through all possible frequency offsets to identify BSs in the area
- The MS picks the strongest pilot signal
  - This has a PN-offset
- The MS uses the PN-offset of this pilot to track the synch channel



Search correlator output: 5 strong signals have been detected

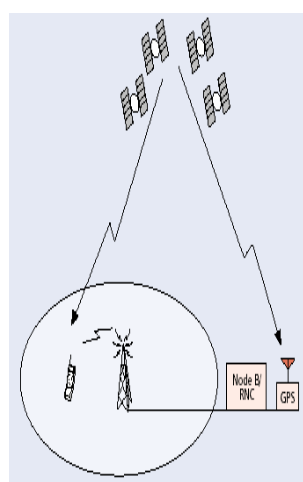
The Synch Channel

- 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



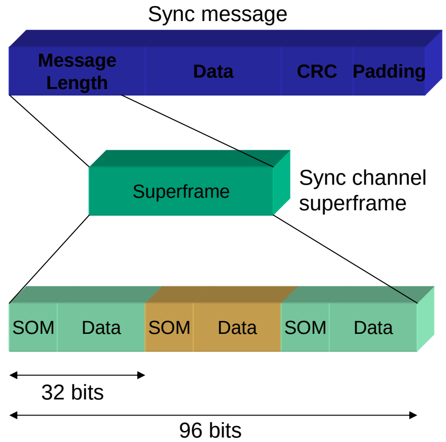
The Synch Channel

- 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

Length	Type	ACK	Contents	CRC check
8 bits	8 bits	7 bits	1-2008 bits	16 0r 30 bits

SYNC Channel Message

used to synchronize the random number generator for traffic channel transmission

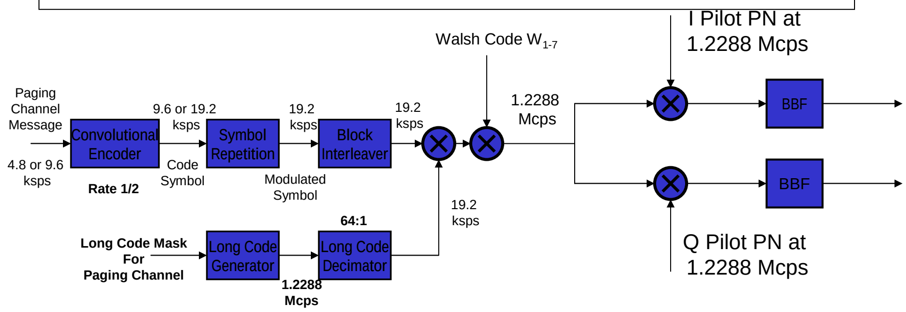
Bit Position	Information
1-8	message type 00000001
9-16	protocol version
17-24	minimum protocol version
25-39	SID
40-55	NID
56-64	PN_OFFSET
65-106	long code state
107-142	system time (from GPS)
143-147	local time differential to system time
158-159	paging channel rate (4800 bps or 9600 bps)
160-168	CDMA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

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

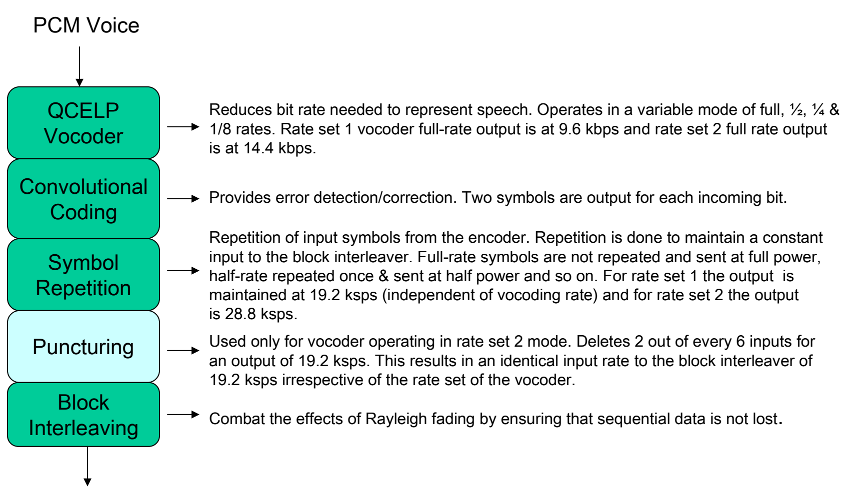
Paging channel: used for broadcast and point to point signaling Walsh codes 1 to 7 used

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

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



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).

To RF section

IS-95 Traffic Channel Example

Input data 0

0000111100001111111100001111000000001111000011111111000011110000

Walsh function 20

Pattern transmitted by the Base station

0000111100001111111100001111000000001111000011111111000011110000

Pattern received at the Mobile station

0000111100001111111100001111000000001111000011111111000011110000

Each 64 bit (symbol) block of the received pattern is exclusive-or'd with Walsh Function 20

0000111100001111111100001111000000001111000011111111000011110000

0000000000000000000000000000000000000000000000000000000000000000

Count number of 1's and 0' to determine what bit was sent!

IS-95 Traffic Channel Example

Pattern received at the Mobile station (1)

1111000011110000000011110000111111110000111100000000111100001111

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

0000000011111111000000001111111111111111000000001111111100000000

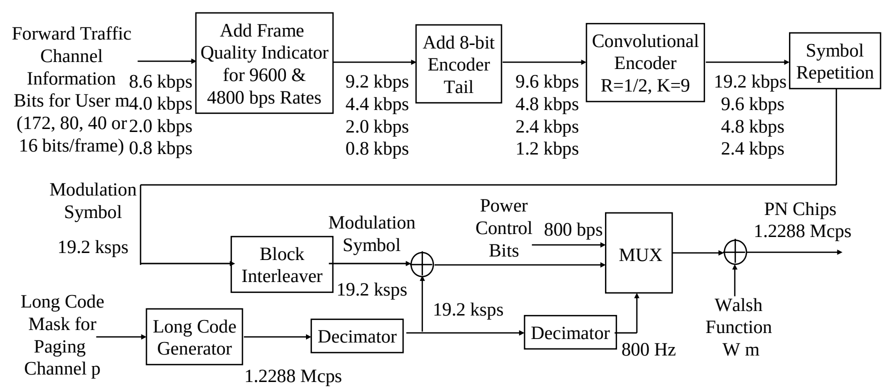
1111000000001111000011111111000000001111111100001111000000001111

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

Orthogonal despreading with incorrect Walsh code

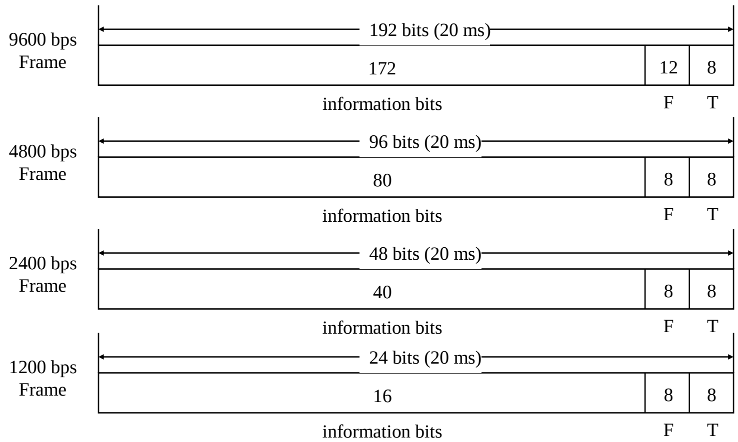
Forward Traffic Channels

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



Forward Traffic Channel Frame Structure (9.6 Kbps coder)

Both Forward and Reverse Traffic channels use 20 msec frames



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)

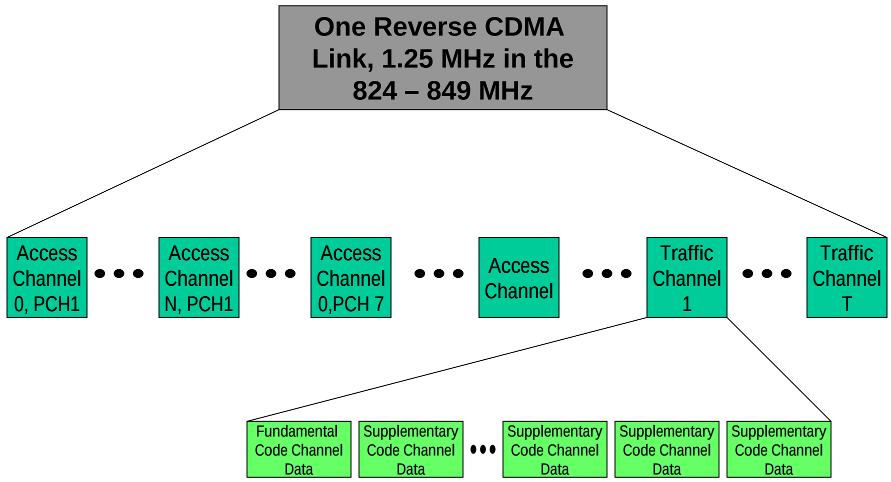
Forward Link Channel Parameters

Channel	Sync	Paging		Traffic			
Data rate	1200	4800	9600	1200	2400	4800	9600 bps
Code repetition	2	2	1	8	4	2	1
Modulation symbol rate	4800	19,200	19,200	19,200	19,200	19,200	19,200 sps
PN chips/ modulation symbol	256	64	64	64	64	64	64
PN chips/bit	1024	256	128	1024	512	256	128

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



Access Channel

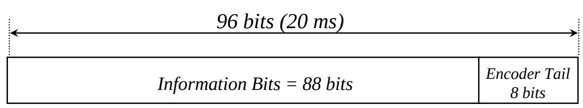
Access Channel

- 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*



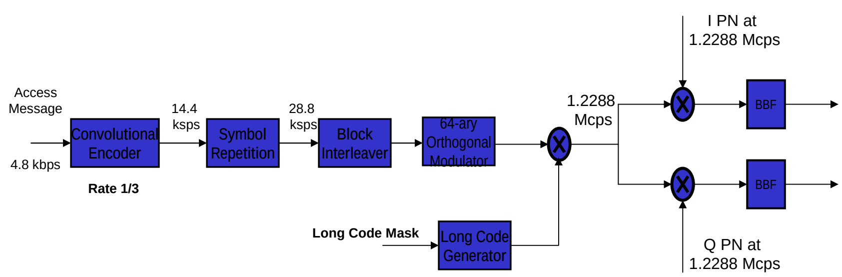
Sample IS-95 Messages

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

Message	Network Operations
Access Channel Messages	
Authentication Challenge Response	Security
Base Station Challenge	Security
PAGE RESPONSE	Call Management
REGISTRATION	Mobility Management
ORIGINATION	Call Management

Access Channel

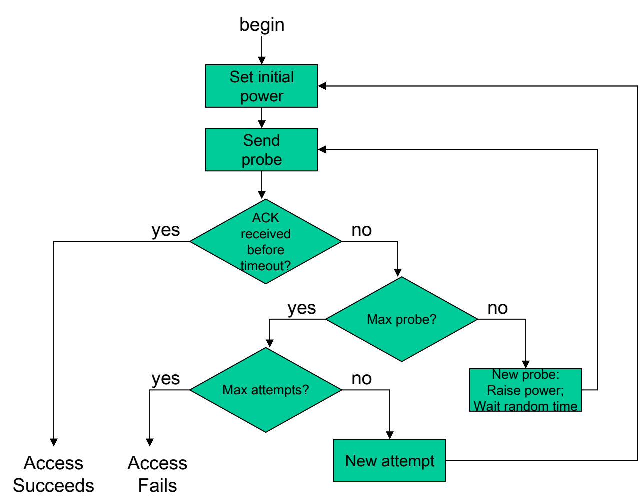
- There are up to 32 access channels per downlink paging channel
  - MSs are pseudorandomly distributed between the access channels
- The access channel data has 96 bits every 20 ms for a data rate of 4.8 kbps
  - 88 bits carry the access channel data
  - 8 bits are encoder tail bits



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 ($c_5 \ldots c_0$) would translate into W_{49}

Reverse Channel Access Protocol



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.
- **Convolutional Coding** → 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 ksps in both cases.
- **Symbol Repetition** → 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 ksps (independent of vocoding rate) and for rate set 2 the output is 28.8 ksps.
- **Block Interleaving** → Combat the effects of Rayleigh fading by ensuring that sequential data is not lost.
- **Orthogonal Modulation** → Blocks of 6 input symbols are replaced by a corresponding 64-chip Walsh code.

IS-95 Reverse Traffic Channel

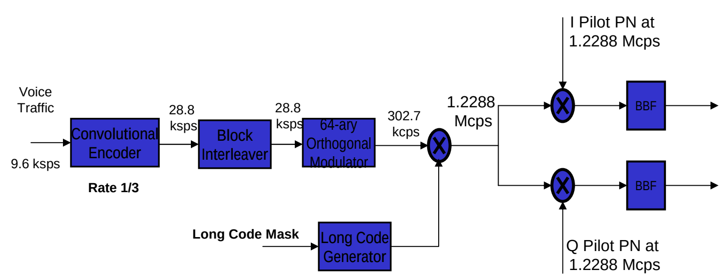
- **Data Burst Randomizer** → Provides variable-rate transmission. Symbols which are repeated are deleted, .i.e., not transmitted. The transmitted duty cycle varies with the vocoder data rate and the transmission are randomized.
- **Direct Sequence Spreading** → Provides spreading of the code. In the 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	
Uplink	**Downlink**
Power Measurement Report	Neighbor List
Pilot Strength Measurement	Pilot Measurement Request
Handoff Completion	Handoff Direction
Long Code Transition Request	Long Code Transition Request
Data Burst	Data Burst
Request Analog Service	Analog Handoff Direction
Long Code Transition Response	Long Code Transition Response

Reverse Traffic Channel – Supplementary Code Channel

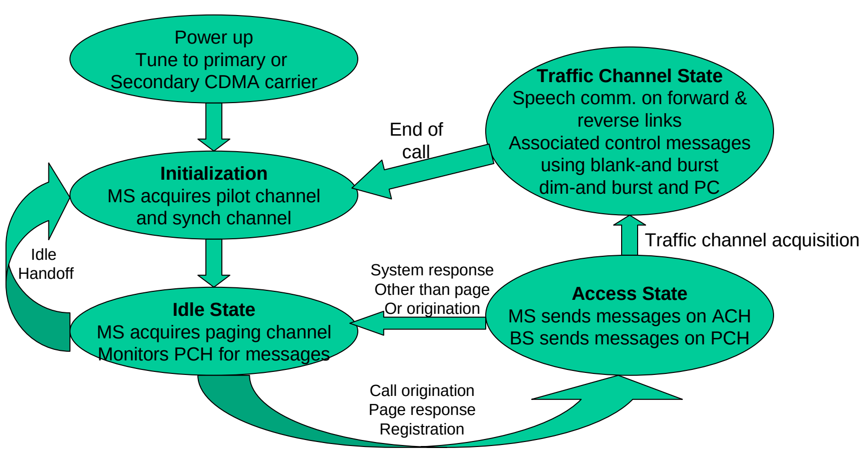


- The supplementary code channel is primarily used for data traffic (full rate is assumed)
  - There is no need for a data randomizer
- A single user can have many codes simultaneously to transmit data

Reverse CDMA Channel Parameters, Rate Set 1

Channel	Access	Traffic			
Data rate	4,800	1,200	2,400	4,800	9,600 bps
Code Rate	1/3	1/3	1/3	1/3	1/3
Symbol Rate before Repetition	14,400	3,600	7,200	14,400	28,800 sps
Symbol Repetition	2	8	4	2	1
Symbol Rate after Repetition	28,800	28,800	28,800	28,800	28,800 sps
Transmit Duty Cycle	1	1/8	1/4	½	1
Code Symbols/Modulation Symbol	6	6	6	6	6
PN Chips/Modulation Symbol	256	256	256	256	256
PN chips transmitted/bit	256	128	128	128	128

Call processing states



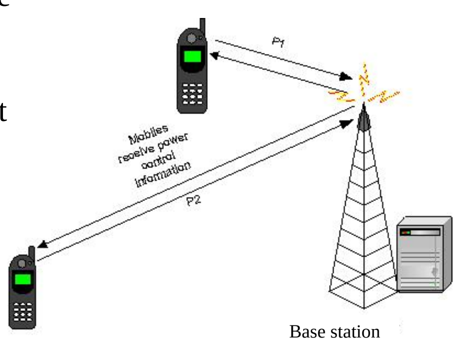
Idle Handoff and Overhead Messages

- 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

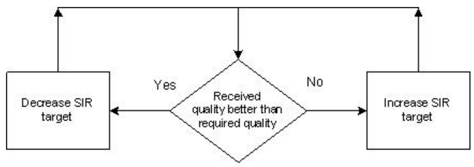
- In CDMA, the “near-far” problem is very significant
  - As users transmit at the same time and frequency, a user close to the base station may drown the signal of a user far away from the base station
- To overcome this problem, power control is used
  - Open-loop power control
    - Use a transmit 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

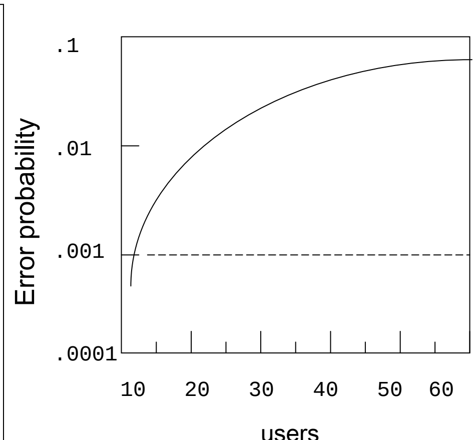
- Inner Loop (or *fast* power control)
  - Measures received SIR, controls transmit power
  - Commands sent several times per frame (hence *fast* power control)
- Outer Loop (or *slow* power control)
  - Measures packet error rate
  - Changes target SIR for inner loop
  - Directly modify transmit power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



General outer loop power control algorithm [1]

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



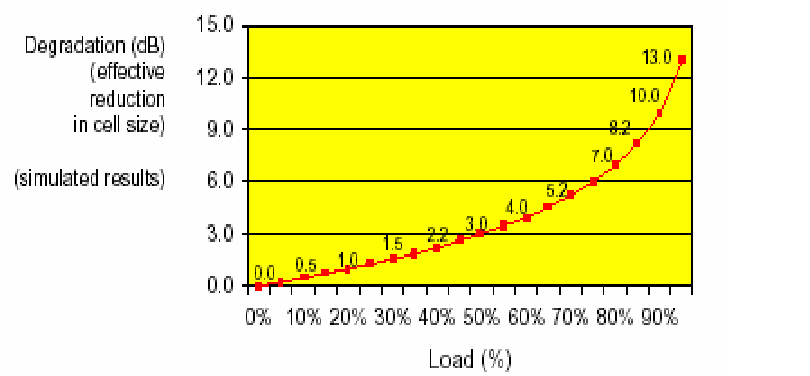
BER of CDMA system with 128 cps.

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.MHz/9.6 KHz) = 21.1 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

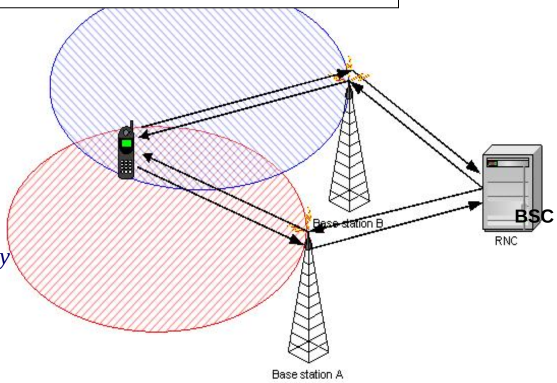
Drive-test data on the right shows Ec/Io differences between day and night, around the SMU campus. Ec/Io values are better at night (and thus the cells are larger)

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

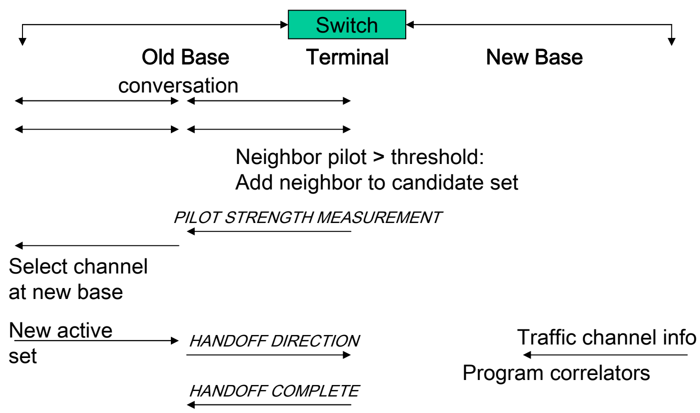
- Mobile located in the area of overlap of multiple base stations
- Transmission:
  - Uplink: No difference
  - Downlink: BSC/MSC sends out a copy of the same packet to each base station
- Reception:
  - Uplink: Each base station demodulates packet, BSC/MSC picks the "better packet" (*macro-diversity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



Soft Handoff Procedure

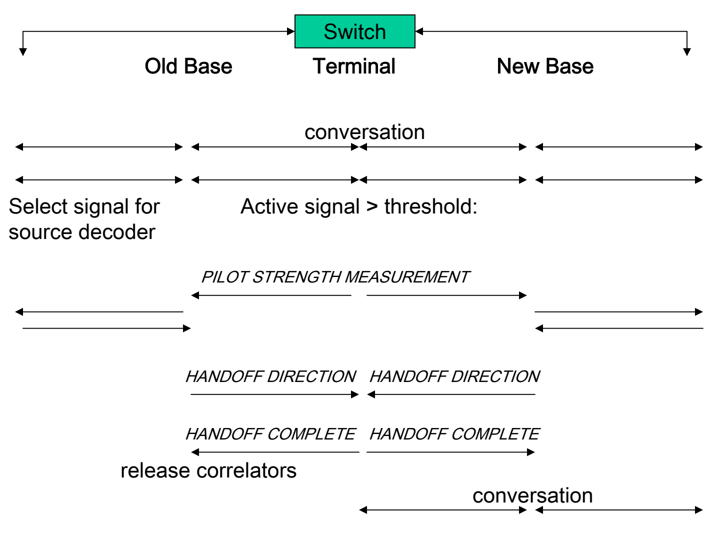
- The mobile terminal maintains a list of pilot channels that it can hear and classifies them into four categories
  - Active set – pilots currently used by the mobile terminal (up to three pilots can be used)
  - Candidate set – pilots that are not in the active set, but have sufficient signal strength 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



Soft handoff procedure

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

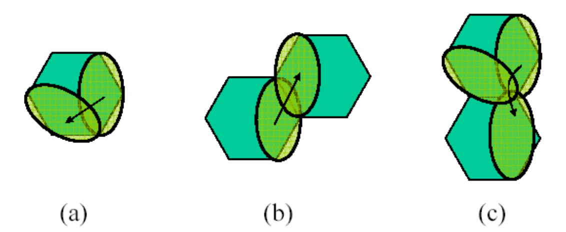
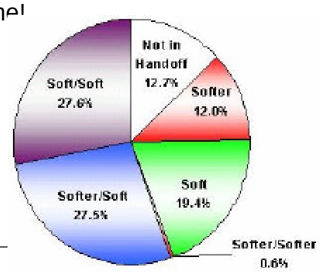


Figure 8.16: (a) Softer (b) soft and (c) soft-softer handoff

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 encyrption) 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

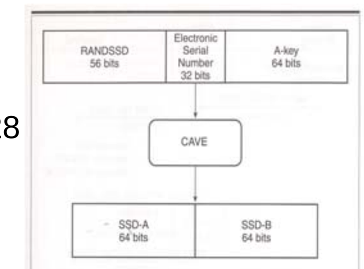
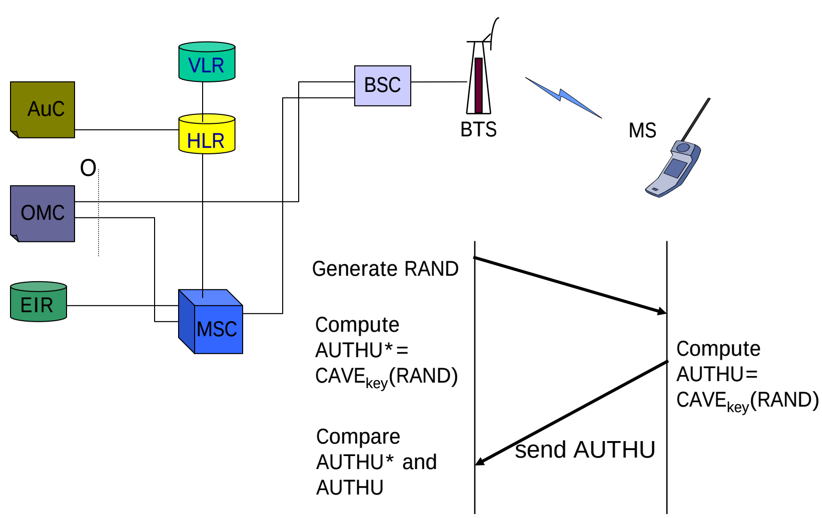


Figure 5.18 Procedure for generating shared secret data at the home system and in a terminal. (Reproduced under written permission from Telecommunications Industry Association.)

Example of C-R: IS-41C



CAVE

- Challenge/Response based on random number and SSD

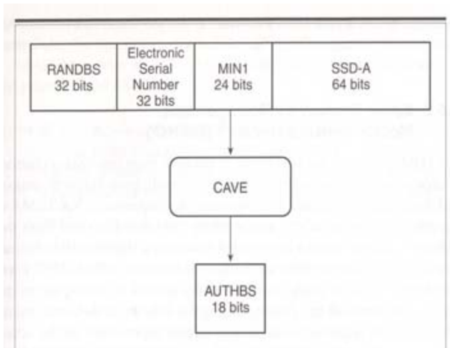


Figure 5.20 Computation of AUTHBS used in the authentication procedure.
(Reproduced under written permission from Telecommunications Industry Association.)

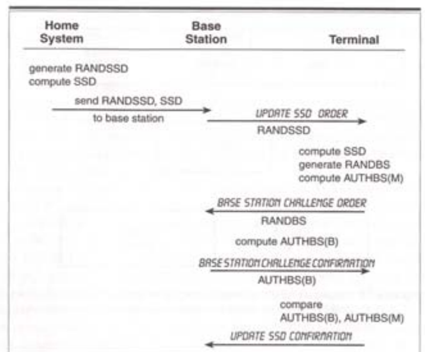


Figure 5.19 Procedure for confirming that the system and the terminal have the same SSD.

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