Course 333

cdma2000 Phase Two: 1xEV DO, 1xEV DV, or 3xRTT?

Contents of Course 333

- Phase II migration: Qualcomm's HDR, 1xEV DO, 1x EV DV vs. 3xRTT
- Spreading Rates and Radio Configurations review
- Qualcomm's HDR - 1xEV High Data Rates
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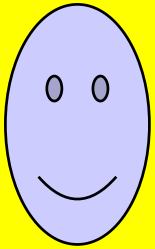
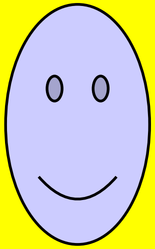
  - Air Interface: Protocol Stack and Channel Structure
  - Forward and Reverse Channels
  - Signaling Layer
- CDMA2000 Phase Three -- 3xRTT
  - Radio Configurations and Channels
  - Access Procedure, Power Control Enhancements
  - HPSK Modulation on the SR3 Reverse Channels
  - Turbo vs. Convolutional Coding and Quasi-Orthogonal Functions
  - New 3xRTT Long PN Codes and Short PN Codes!
  - Inherent Forward Orthogonal Transmit Diversity (OTD)

The CDMA Technology Path to 3G

		CDMAone		CDMA2000/IS-2000		
Generation	1G	2G	2G	2.5G or 3?	**3G**	**3G**
Technology	**AMPS**	IS-95A/J-Std008	**IS-95B**	**IS-2000: 1xRTT**	**IS-2000: 3xRTT**	**1xEV: HDR or 1Xtreme**
Signal Bandwidth, #Users	30 kHz. 1	1250 kHz. 20-35	1250 kHz. 25-40	1250 kHz. 50-80 voice and data	F: 3x 1250k R: 3687k 120-210 per 3 carriers	1250 kHz. Many packet users
Data Capabilities	None, 2.4K by modem	14.4K	64K	**153K 307K 230K**	**1.0 Mb/s**	**2.4 Mb/s** (HDR) **5 Mb/s** (1Xtreme)
Features: Incremental Progress	First System, Capacity & Handoffs	First CDMA, Capacity, Quality	•Improved Access •Smarter Handoffs	•Enhanced Access •Channel Structure	Faster data rates on shared 3-carrier bundle	Faster data rates on dedicated 1x RF data carrier



1xEV

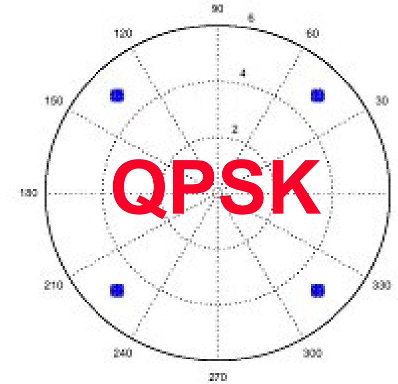


1xEV DO “HDR” 2.4576 Mb/s
1xEV DV “1Xtreme” 4.9152 Mb/s

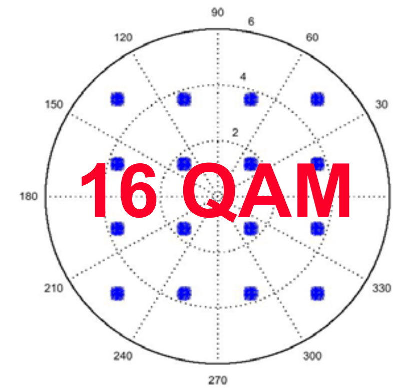
WARNING!

Not available in all areas. Use only as directed. Certain restrictions apply. You probably won’t achieve rates this fast except right across the street from a BTS at 2-3 AM. May cause discomfort, envy, or nausea among TDMA/GSM/GPRS/1xRTT users. May also drain your battery quickly. *If you experience disorientation, dizziness or internet addiction, revert to 1xRTT and seek professional counseling at once.*

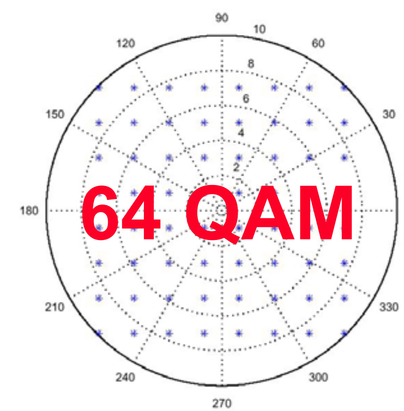
What is 1xEV?



- 1xEV, "1x Evolution", is a family of alternative fast-data schemes that can be implemented on a 1x CDMA carrier.
- 1xEV DO means "1x Evolution, Data Only", originally proposed by Qualcomm as "High Data Rates" (HDR).
  - Up to 2.4576 Mbps forward, 153.6 kbps reverse
  - A 1xEV DO carrier holds only packet data, and does not support circuit-switched voice



- 1xEV DV means "1x Evolution, Data and Voice". Example: 1Xtreme, Motorola/Nokia proprietary
  - Max throughput of 5 Mbps forward, 307k reverse
  - Backward compatible with IS-95/1xRTT voice calls on the same carrier as the data
- All versions of 1xEV use advanced but more fragile modulation techniques to achieve high throughputs.
  - To achieve the highest data rates, users must be in very clean strong-signal environments and the sector must have most of its capacity unused and available

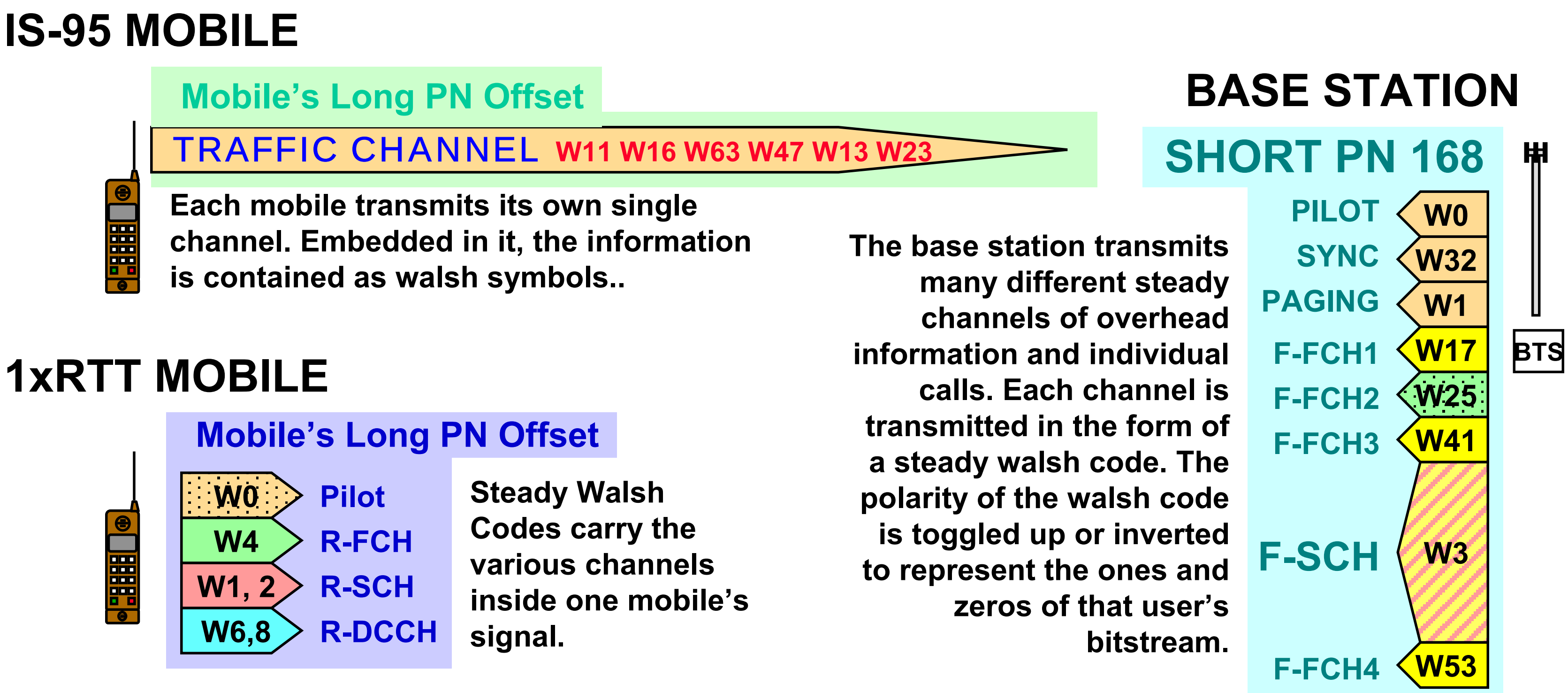


1xEV DO:

1x Evolved, Data Only

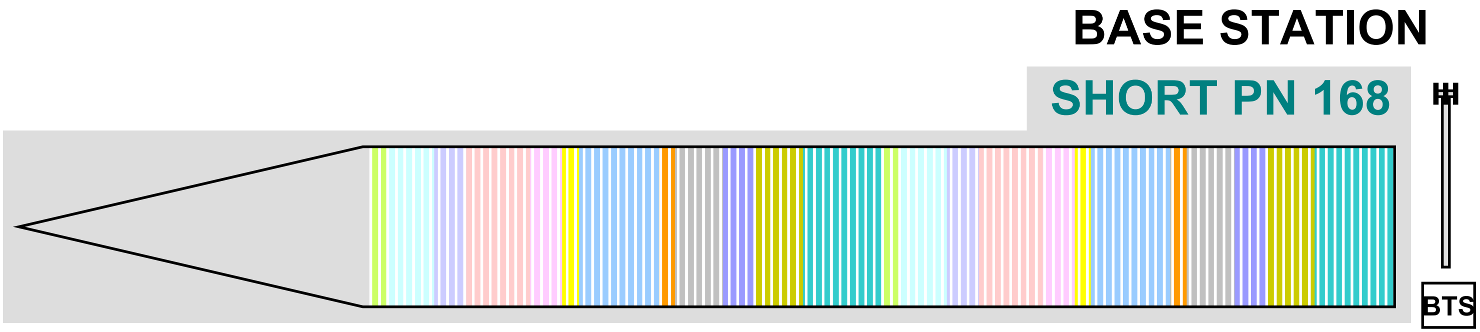
Qualcomm's HDR

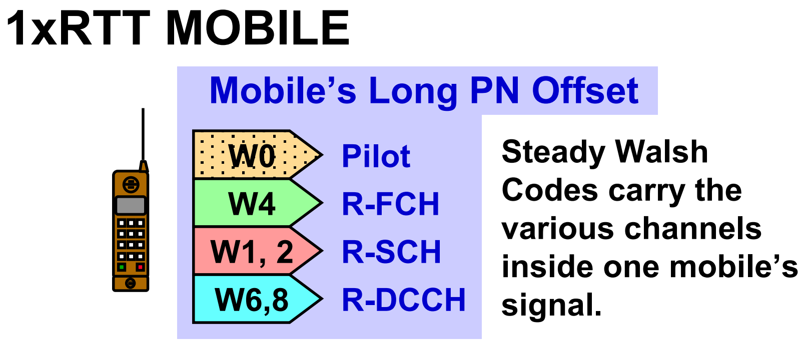
1xRTT Channel Structure



- IS-95 and 1xRTT circuit-switched voice calls are carried by steady, continuous reserved channels.
- The power of each user's channel is individually adjusted in real-time, seeking to maintain the desired target FER.
- Call control commands are sent in the form of layer-3 messages, multiplexed along with the information on the channels

What's Different about 1xEV DO?





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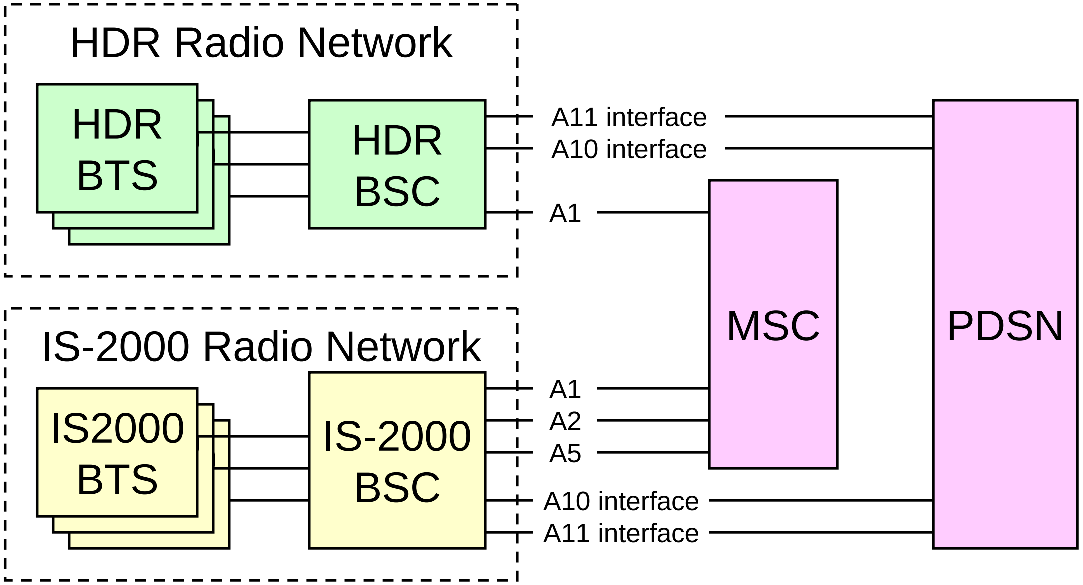
Basic HDR Features

- Qualcomm's HDR uses special modulation techniques to provide fast data transmission on a single 1.25 CDMA carrier
- Instead of the IS-95-standard QPSK modulation, HDR can use
  - 16-QAM for very fast data under favorable conditions
    - 2.4 Mb/s downlink, 307.2 kbps uplink
  - 8-PSK for moderately fast data under fair conditions
  - QPSK if conditions are extremely poor
- HDR uses 32 walsh codes on the uplink
  - Three are used for signalling
  - This leaves 29 codes available for a max of 29 users/sector
- HDR provides data transmission only, not circuit-switched voice

Basic HDR Network Architecture

The HDR Access Network



HDR Glossary

HDR - High Data Rate, Qualcomm's proprietary rapid data service

MSC - Mobile Switching Center

PDSN - Packet Data Serving Node

BTS - Base Transceiver Station

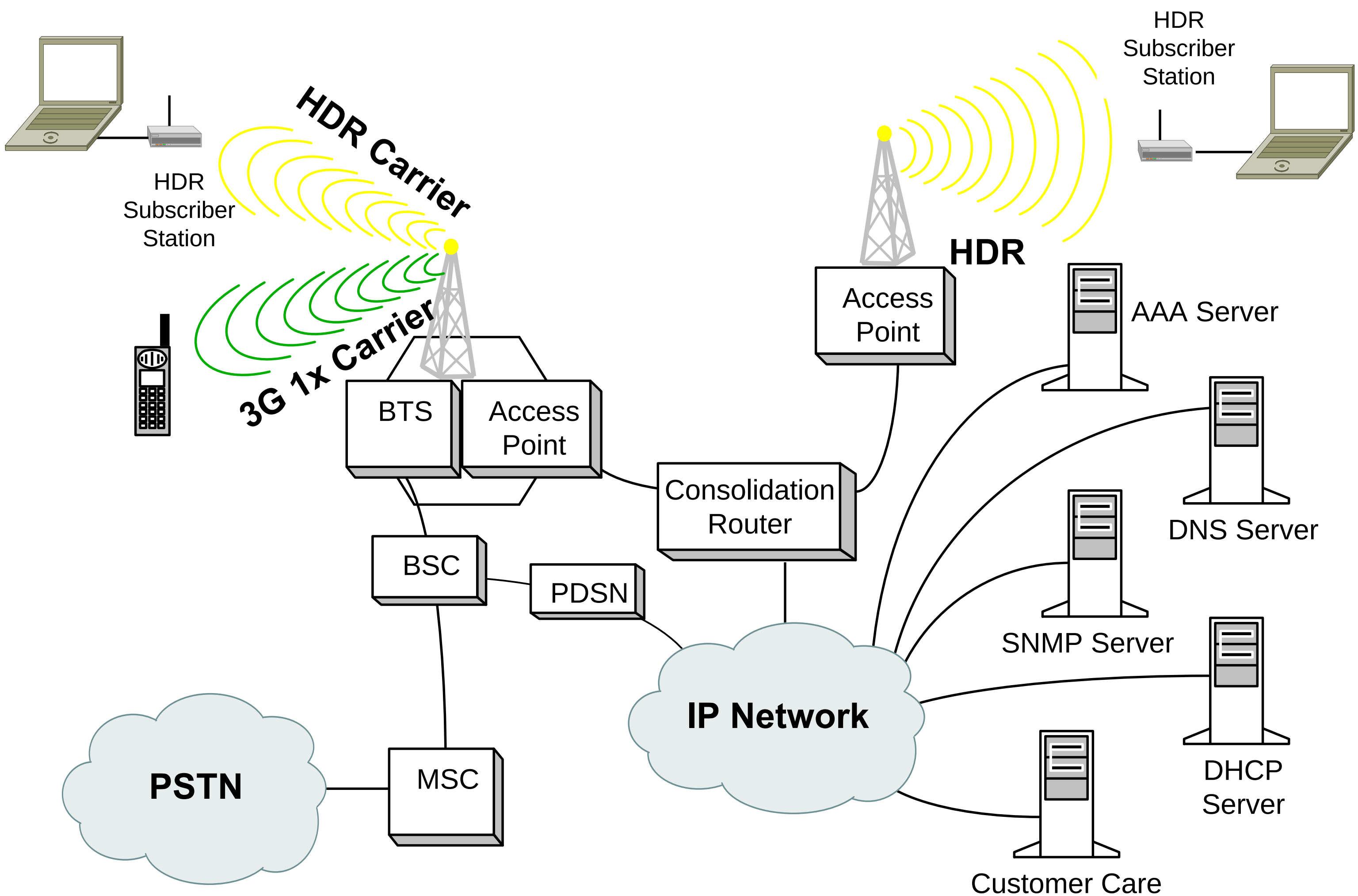
BSC - Base Station Controller

AN - Access Network

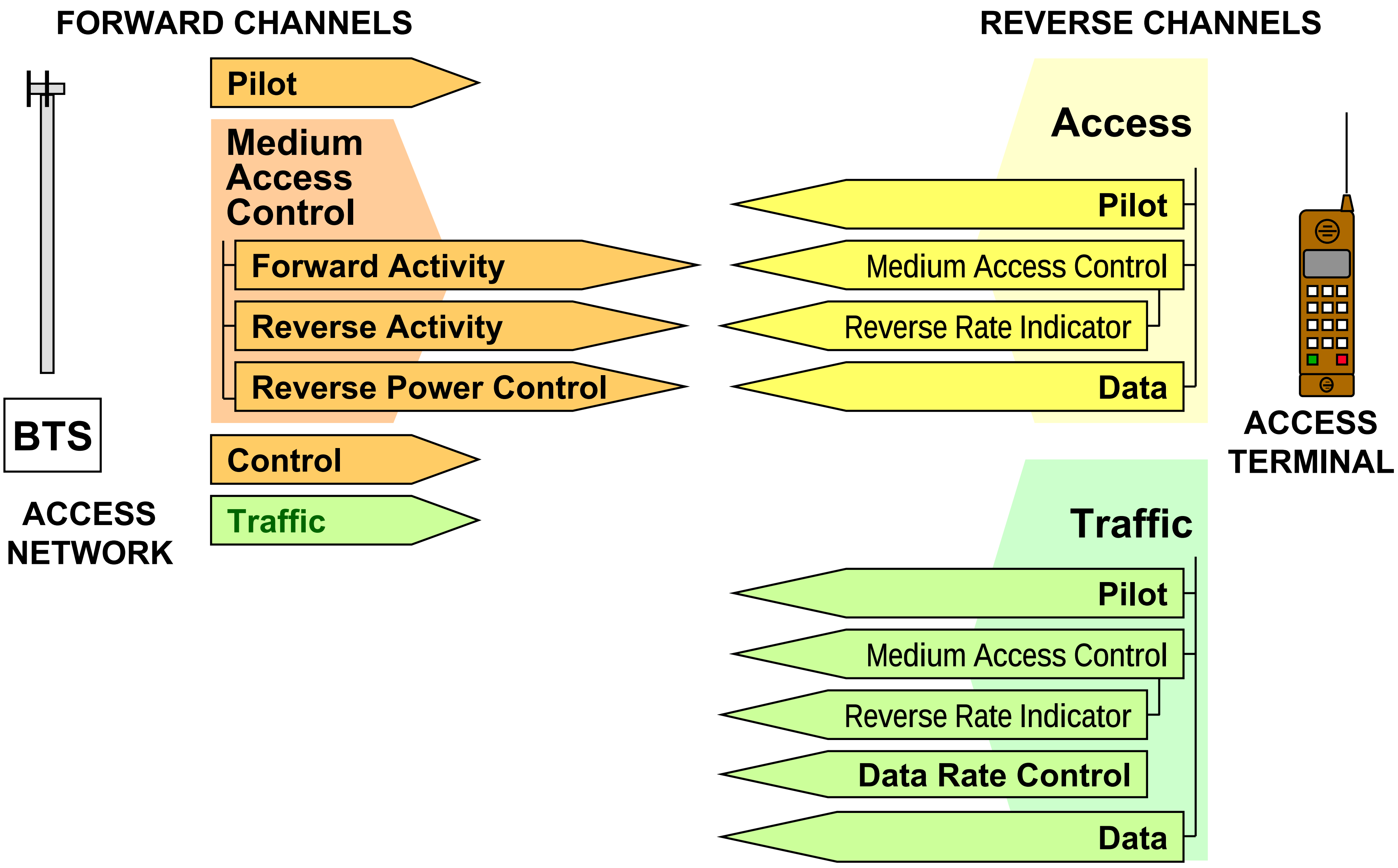
AT - Access Terminal

- HDR Network Architecture: Same as CDMA2000 but logically separate
- Interfaces
  - HDR to MSC: A1
  - HDR to PDSN: A10, A11
- Interoperability:
  - Dual-mode IS-2000/HDR terminals
  - IS-2000/HDR handoff supported using A1, A10, and A11 interfaces

Collocated 3G 1x/HDR System

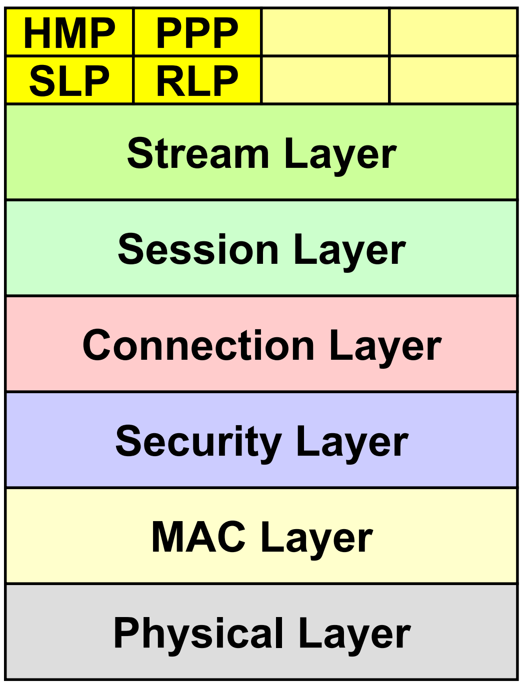


HDR Air Interface Channel Structure



The HDR Air Interface Protocol Stack

HDM Air Interface Protocol Stack

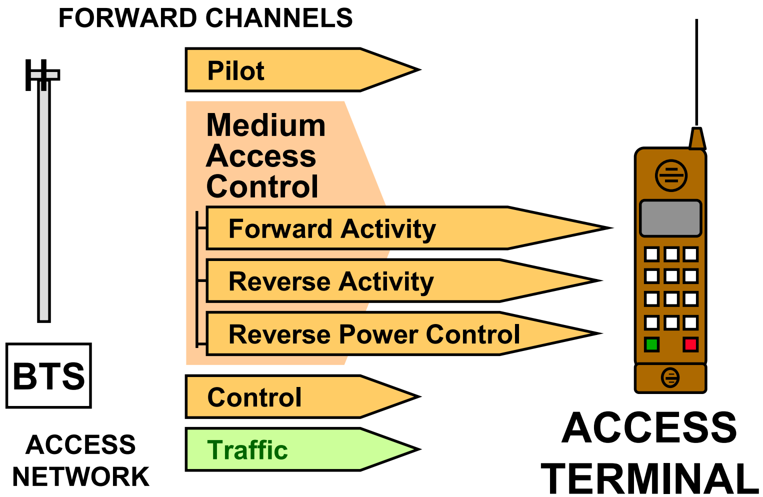


- HMP: HDR Messaging Protocol
  - Governs message exchange
- SLP: Signaling Link Protocol
- RLP carries PPP bytes in Default Packet Application
- Stream Layer adds 2-bit header providing 4 data streams
- Session Layer negotiates and maintains sessions, including “keep-alive”
- Manages Connections, both open & closed
- The security layer is not currently used
- MAC layer manages operation of the main HDR data channels
  - There’s a MAC protocol for each channel

Resource Management Philosophy of HDR

- Capacity is maximized by fully using all available resources
  - Great flexibility for time, bandwidth, and code configuration
  - Each HDR user is dynamically allocated all available bandwidth, code-space, and time for maximum throughput
- HDR's operating strategy is continuous transmission at full power and dynamic adjustment of the bit rate of each user according to C/I for optimal system capacity
- The HDR forward link uses rate control instead of power control

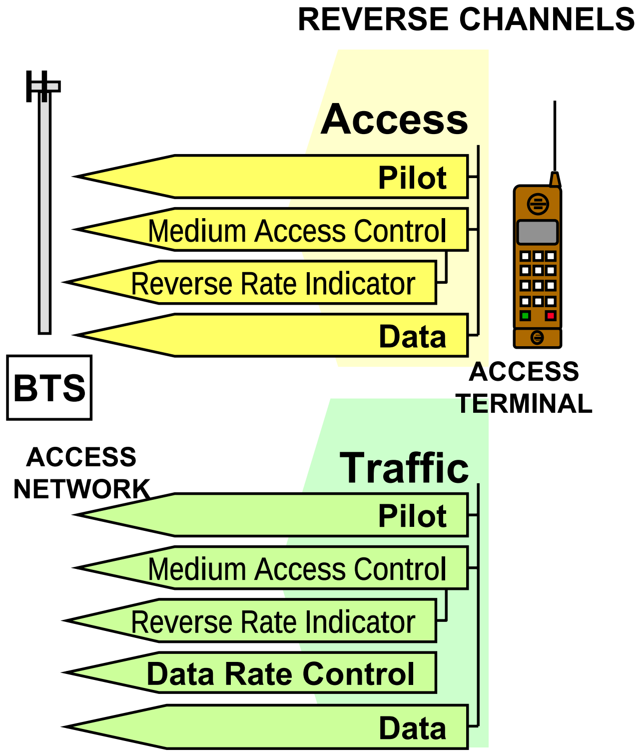
Basic Operation of the HDR Forward Link



- All sectors transmit forward pilot bursts simultaneously
- Each AT estimates C/I of active pilots, predicts C/I and best rate to request for forward link service
- Each slot, the AT reports the requested rate and sector for transmission via the DRC channel
- The AN schedules transmission of preamble and data sequentially to each AT, based on DRC contents
- AT monitors preamble and decodes data after preamble is detected
- Reverse power control and other MAC information are constantly sent over the forward channel

Basic Operation of the HDR Reverse Link

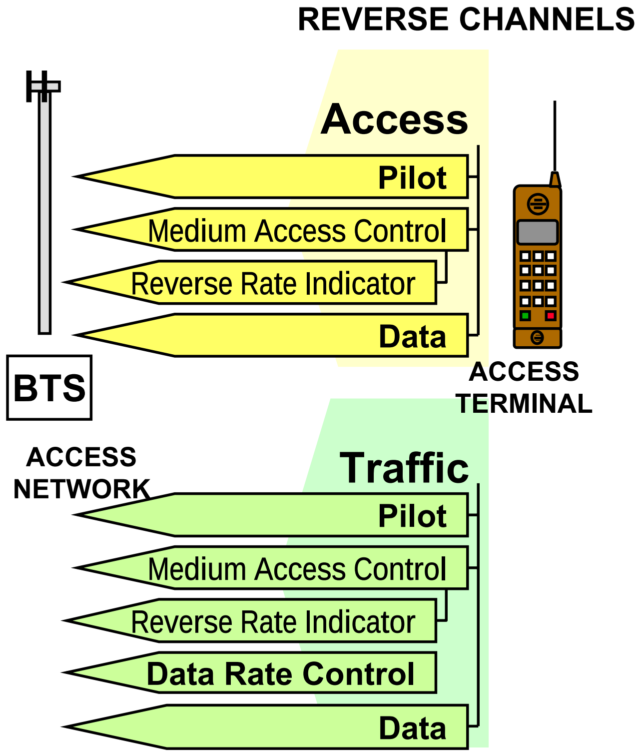
- When an AT has an air link, the reverse pilot and MAC channels are transmitted constantly
- Reverse link is power controlled to achieve reliable BER
- Reverse data is transmitted when available at rate specified in Reverse MAC protocol
- RRI Reverse Rate Indicator is sent over the MAC channel to help AN decode the reverse data channel
- All the channels are BPSK modulated on the I or Q carrier to keep the peak-to-average ratio small



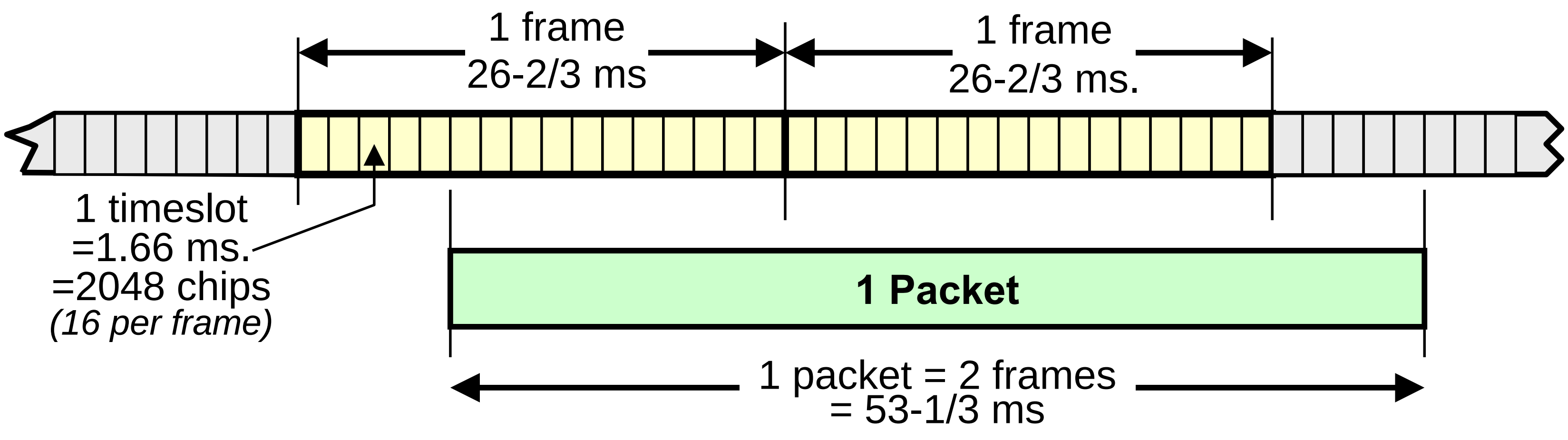
The HDR Reverse Channels

Distinguishing the Reverse Channels

- Each access channel has a distinct Access Channel PN for each sector
- Walsh-4 functions are used to orthogonally spread:
  - Data channels, Pilot/MAC channels
- Each Traffic channel is direct-sequence spread by a distinct user PN code sequence
- Data channels are BPSK-modulated on the Q carrier phase
- Pilot/MAC channels are BPSK modulated on the I carrier phase
- The MAC channel is time-multiplexed with the Pilot Channel
  - Inside the MAC channel the DRC and RRI channels are time-multiplexed
- End result: low peak-to-average power ratios for AT Tx

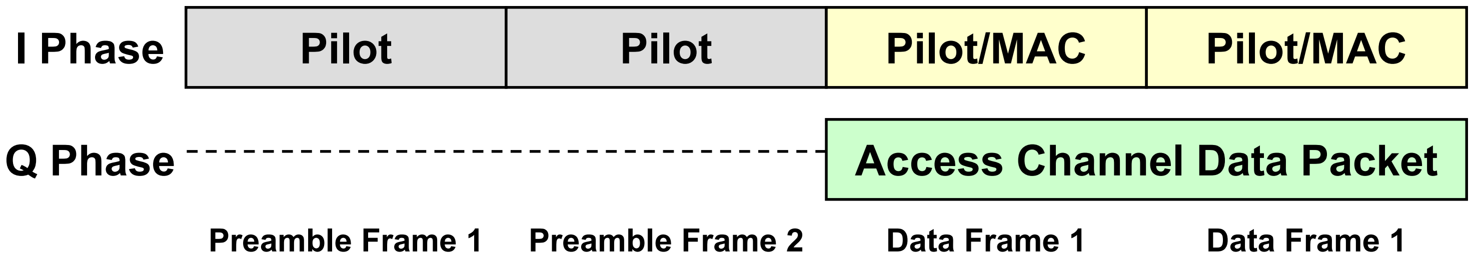


Reverse Link HDR Packets, Slots, Frames

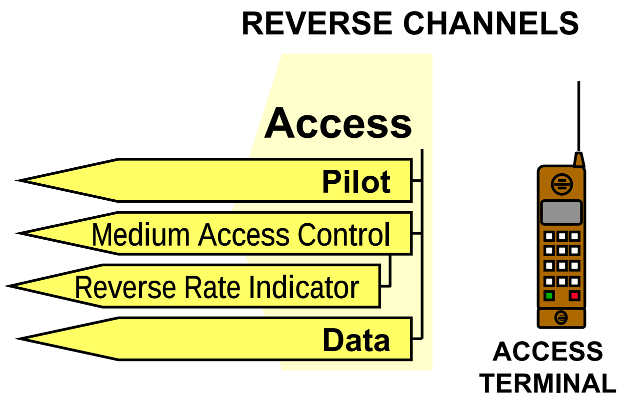


- Each reverse link data packet is 53-1/3 ms. long
  - Packets are exactly two frames long
- Each frame contains 16 timeslots, each 1-2/3 ms. long
- Packets do not have to begin exactly on frame boundaries
  - Packet start can be staggered to begin on the boundary of any of the timeslots to keep reverse transmission loading random
- Since the frame and slot lengths do not have to fit with the customary 20-ms. CDMA Voice frame length, frame and slot lengths have been selected to conform naturally to the length of the PN sequence and the number of chips per slot and per packet

The HDR Access Channel

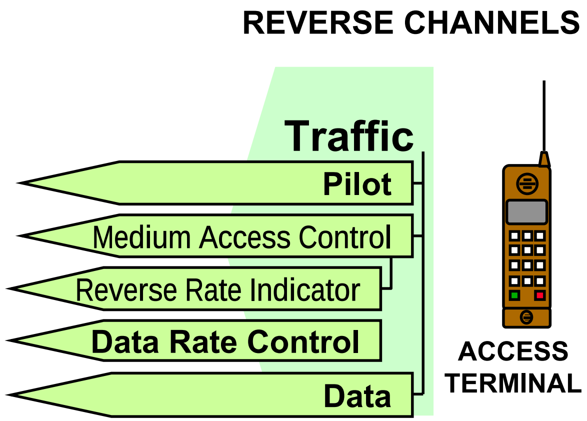


- To access the AN, an AT transmits a random access probe sequence
- An access probe includes
  - a preamble containing just pilot
  - A two-frame-long Access Channel data packet at 9600 bps
- The MAC Channel of an Access data packet includes only an RRI channel punctured into the Pilot Channel as shown

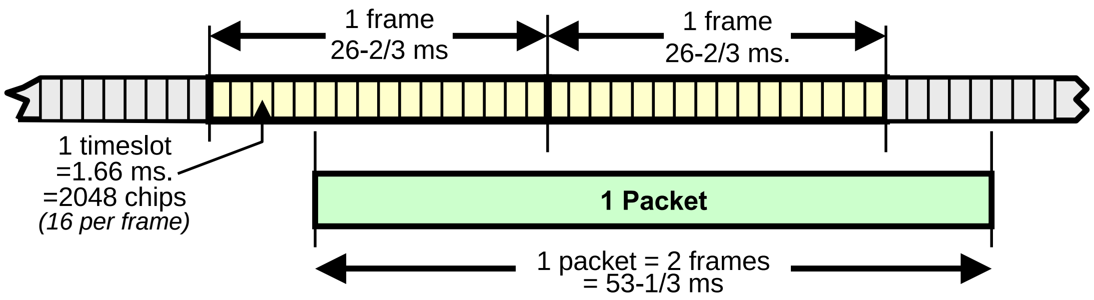


The HDR Reverse Traffic Channel

- Reverse Traffic Channels include:
  - Data Channel
  - Pilot Channel
  - MAC Channel
    - DRC Data Rate Control channel
    - RRI Reverse Rate Indicator channel
- The reverse pilot permits coherent demodulation of the reverse link signal at the base station
  - Turbo decoding can be performed in the synchronous environment



HDR Reverse Traffic Channel Structure



- The Reverse Traffic Channel structure is similar to the Access Channel structure
  - Frames 26-2/3 ms long, Packets 53-1/3 ms (2 frames) long
- Data transmission rate is variable as requested by the terminal and allocated by the network in response to changing C/I conditions
  - Rate may run from 4.8 kbps to 153.6 kbps
- Transmission parameters:
  - Coding is Serial-Concatenated, rate 1/2 or 1/4
  - Channel interleaving is by bit reversal with repetition of interleaved sequence
  - Data packets begin at a specific slot boundary in the frame so that users' signal powers can be randomized

HDR Coding - Forward and Reverse Links

- Much of the "magic" of HDR comes from its advanced nested coding methods
- An inner and an outer encoder are applied
  - Overall code rate is 1/4, 3/8, and 1/2
  - Pseudo-random code interleaver is used
  - Iterative (Turbo) decoding of the serial-concatenated coding yields highly effective capacity performance and a very low background error level

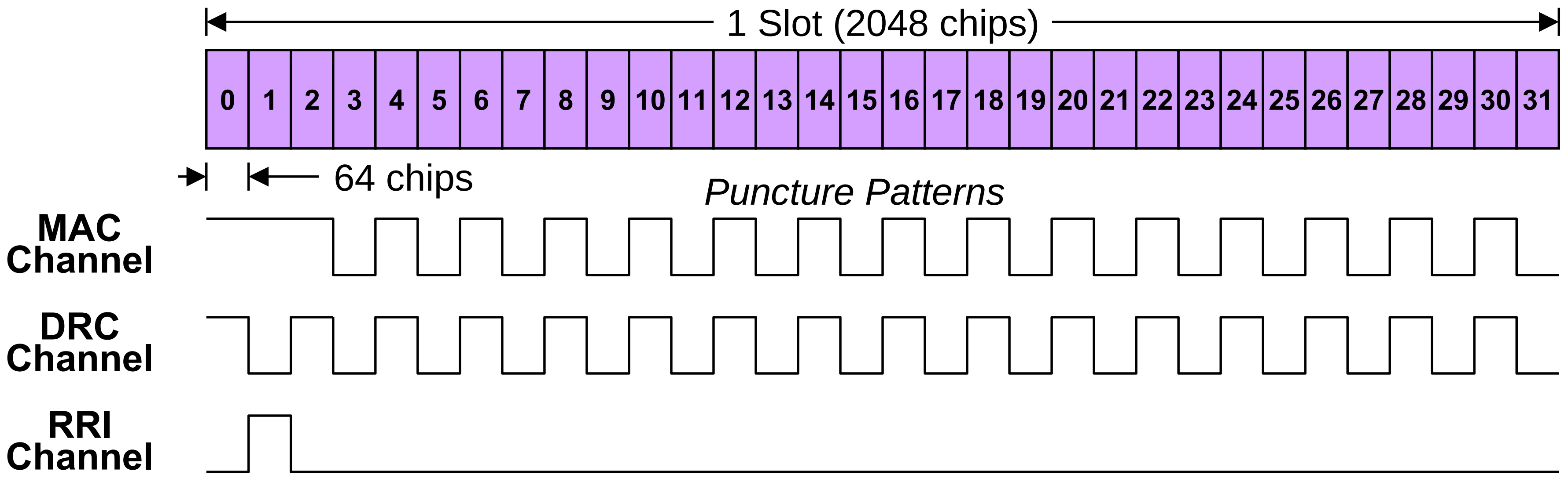
Outer Encoder
16-state, rate 1/2 or 2/3
3/4 puncturing
convolutional

Inner Encoder
4-state, rate 1/2 or 3./4
4/6 puncturing
convolutional

Reverse Traffic Channel
Coding and Modulation Parameters

Data Rate	**4.8**	**9.6**	**19.2**	**38.4**	**76.8**	**153.6**	Kbps
Reverse Rate Index	1	2	3	4	5	6	
Encoder Packet Size	256	512	1024	2048	4096	8192	bits
Packet Duration	53.33…	53.33…	53.33…	53.33…	53.33…	53.33…	ms
Overall Code Rate	0.25	0.25	0.25	0.25	0.25	0.5	Bits/sym
Code Symbols/ Packet	1024	2048	4096	8192	16384	16384	Code Symbols
Code Symbol Rate	19.2	38.4	76.8	153.6	307.2	307.2	Ksps
Interleaved Packet Repeats	16	8	4	2	1	1	
Mod. Symbol Rate	307.2	307.2	307.2	307.2	307.2	307.2	Ksps
Data Modulation	BPSK	BPSK	BPSK	BPSK	BPSK	BPSK	
PN Chips per Encoder Bit	256	128	64	32	16	8	PN Chips

The HDR Reverse Pilot Channel



- The I-carrier phase contains unmodulated binary 0 symbols
- MAC Channel symbols are punctured into this pattern
- MAC and Pilot Channel symbols are gain-equalized to have same amplitude so peak-to-average ratio is very low
- Nearly half of the Pilot/MAC channels content are pilot channel energy to support synchronous demodulation and multipath searching

Reverse MAC Channel Contents

- The Reverse MAC channel contains two streams of information
- DRC Data Rate Control channel is used by the AT to request the data rate and desired sector
  - Data rate is requested using 8-ary bi-orthogonal coding
  - Desired sector is requested using 8-ary Walsh cover
  - Each DRC channel slot contains 1024 chips to facilitate reliable detection
  - DRC messages start at the center of a slot to minimize the delay between C/I estimation and the start of AN transmission
- RRI Reverse Rate Indicator channel identifies up to 8 different desired reverse data transmission rates
  - 8-ary orthogonal code is used to indicate rates
  - The RRI symbol is transmitted 32 times in each frame
  - RRI symbols are inverted in the last half of the frame to make synchronization easier

How the DRC Channel Operates

- The AT estimates the forward channel C/I and identifies the feasible data rate and the requested sector to be used
- The AT sends this information to the AN on the DRC channel
- Only the requested sector will transmit packets to this AT
- The requested sector sends a data packet including preamble to the AT at the rate requested by the DRC in the immediately preceding slot
- After the packet transmission is initiated, it must be continued until the payload has been fully transmitted

The PN Sequences Used by HDR

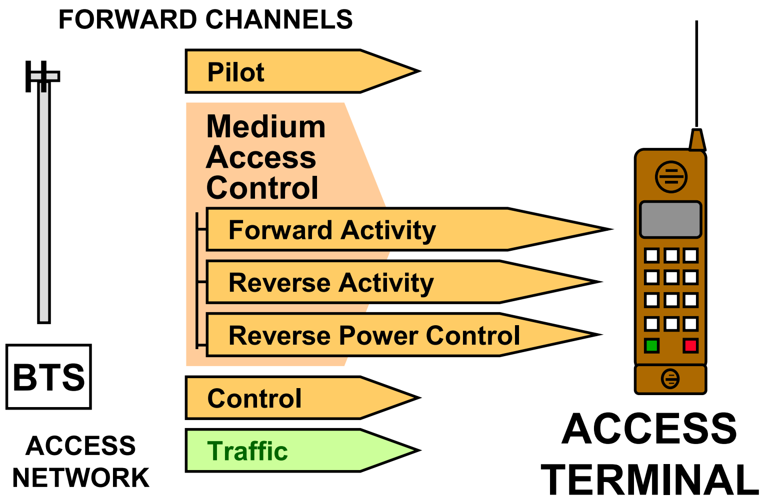
- Each user has a unique PN sequence which is used for quadrature spreading of its traffic channel
  - These sequences have periods of 26-2/3 ms, same as IS-95
  - The sequences are generated by exclusive-ORing the I and Q user long code sequences with the I and Q common short PN sequences
  - The long code generation is restarted at the beginning of each frame
- Every AT's Traffic and Access channels use the common short sequence, which is the same as the short PN sequence of IS-95
- Each sector has its own Access Channel which is spread by a unique PN sequence used only by that sector

HDR AT Reverse Link Power Control

- The same open-loop/closed-loop schemes used in IS-95 are used for reverse-link power control of HDR
- Each AT adjusts its transmit power based on received forward link RF levels in real-time
- Each AT obeys the 800/second power control bit stream from its sector
- Each AT also adjusts the nominal power of its Data Channel to maintain a constant Eb/No at the AN despite the dynamic variations in rate

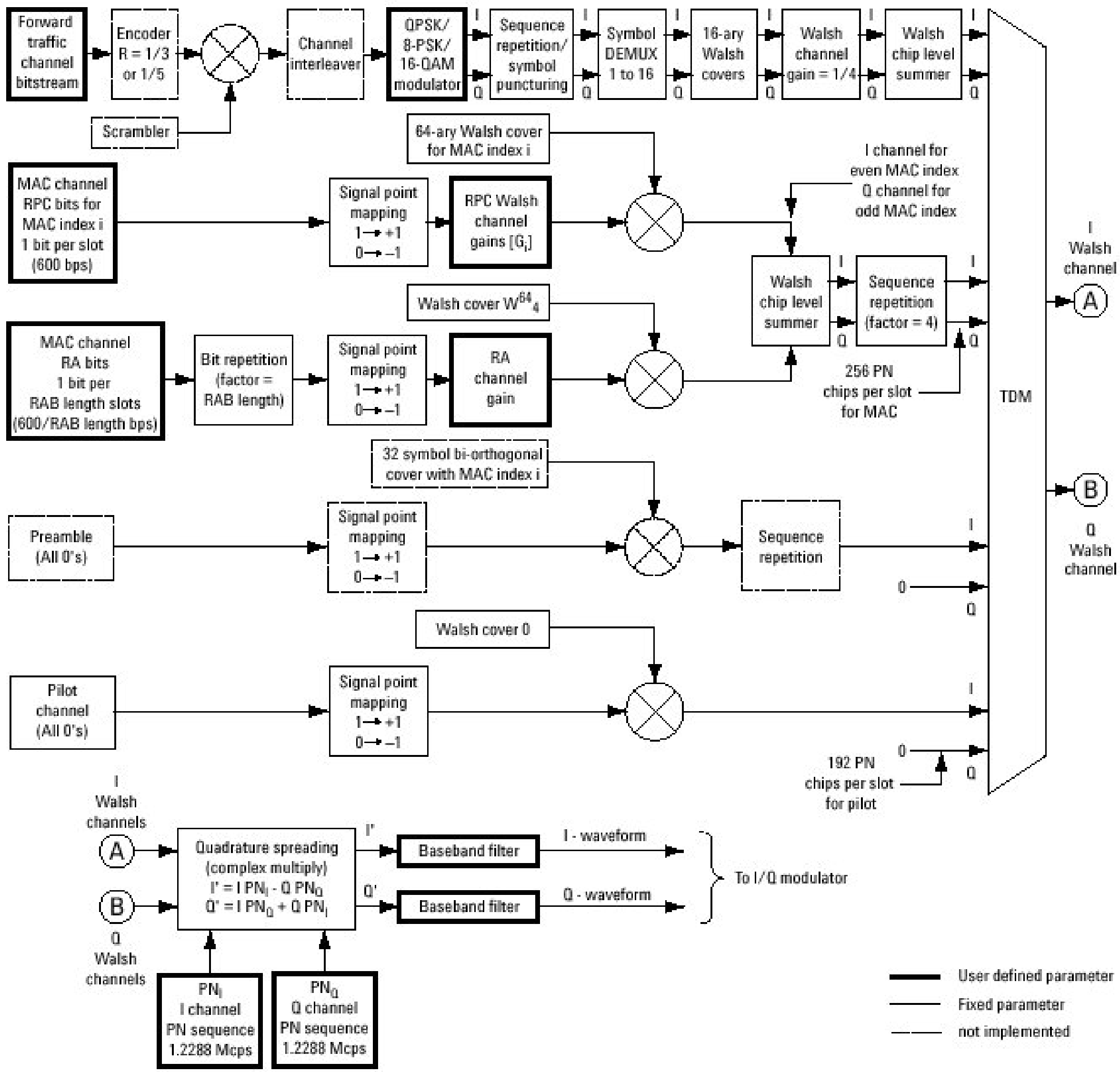
The HDR Forward Channels

The Forward Link Channels

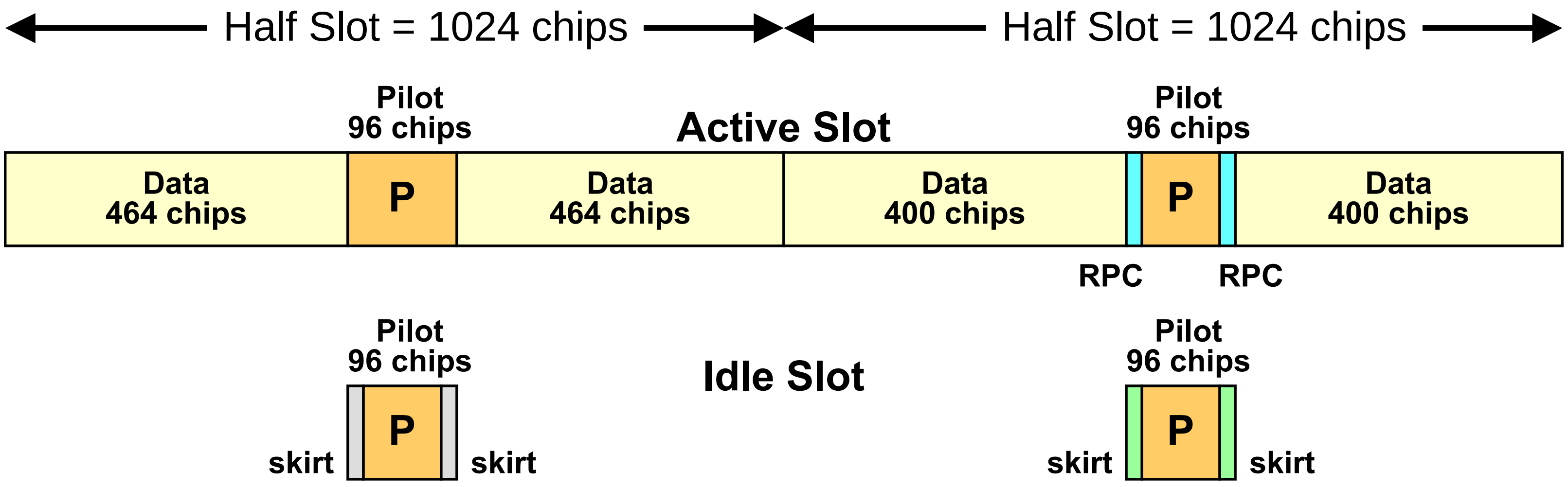


- The HDR forward link time-multiplexes several channels
  - Forward Pilot Channel
  - Forward MAC Channel, with:
    - RPC Reverse Power Control Channel
    - FA Forward Activity Channel
    - RA Reverse Activity Channel
  - Forward Traffic Channel
  - Forward Control Channel

1xEV DO Forward Link Time-Multiplexing

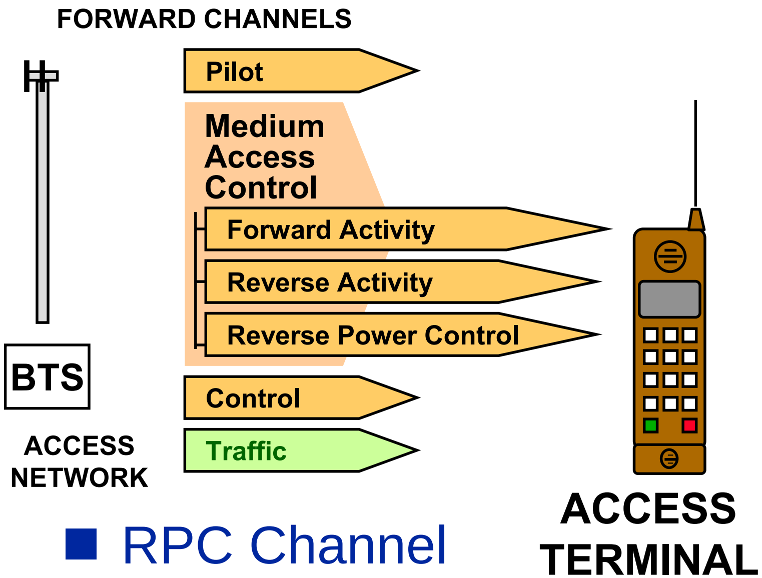


The HDR Forward Link Slot Structure



- Sectors always transmit a pilot on each active Forward HDR channel
  - Pilot is unmodulated BPSK transmitted as bursts 96 chips long every half slot at full sector power
  - 64-chip idle skirts surround the first pilot burst per idle slot to improve accuracy
- The pilot is used for acquisition, synchronization, demodulation, decoding, and C/I estimation by all ATs in the serving area
  - All sectors transmit simultaneously to allow C/I estimation
  - Burst pilot gives more accurate C/I estimation essential for DRC generation and Turbo decoding

The Forward MAC Channel



- The MAC channel includes RPC, FA, and RA channels
  - RA Reverse Activity Channel
  - FA Forward Activity Channel
  - RPC Reverse Power Control Channels
- RPC Channel
  - 600 bps, each access terminal with an assigned air link has an RPC
- FA Channel
  - Transmits one forward activity bit per slot, indicates to an AT whether or not the traffic or control channel will be transmitting later to exploit inactive channels
- RA Channel
  - Transmits one reverse activity bit per slot, telling ATs if reverse link loading is too high, requiring rate reduction

HDR Forward Traffic Channel Features

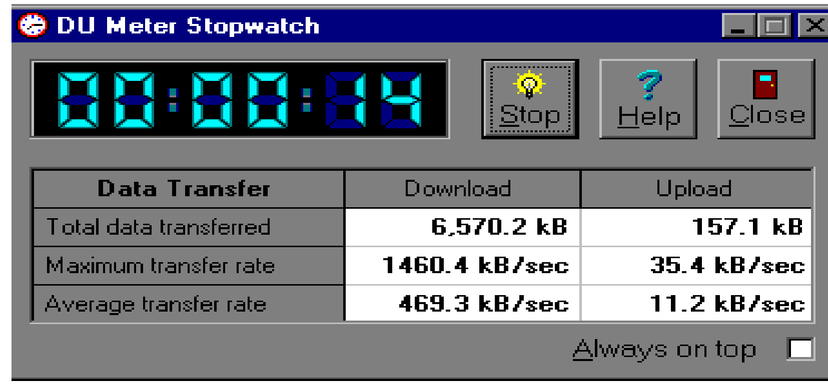
- The Forward Traffic Channel data rate varies from 38.4 kbps to 2.4576 Mbps
- The data packets have variable length:
  - 1024, 2048, 3072 or 4096 bits; from 1-2/3 to 26-2/3 ms.
- Different multiplexing and modulation methods are used depending on the data rate
  - QPSK, 8-PSK, 16-QPSK and bit reversal interleaving
  - Bit-reversal-interleaved symbols are demultiplexed into 16 parallel symbol streams covered by 16-ary Walsh Codes
  - The 16 walsh code channels are analog-summed for transmission
  - The Traffic Channel is serial-concatenated-coded with a pseudo-random code interleaver, same as Reverse Channel
  - This coding with iterative Turbo decoding gives a low Eb/No requirement and low background error rate

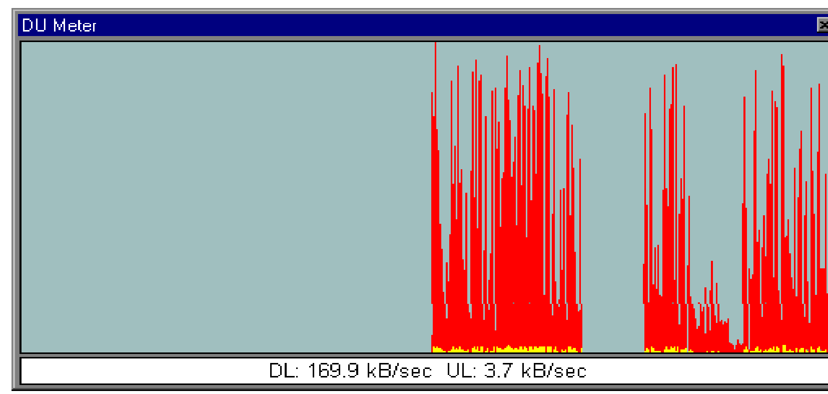
Forward Traffic Channel Coding and Modulation Parameters

Data Rate (kbps)	**38.4, 76.8, 102.4, 153.6 Short, 204.8, 307.2 Short, 614.4**	**153.6 Long, 307.2 Long**	**921.6**	**1,228.8**	**1,843.2**	**2,457.6**
Concatenated Code rate	1/4	1/4	3/8	1/2	1/2	1/2
Information Bits per Encoder Packet	1019	4091	3067	2043	3067	4091
Effective no. of Tail Bits	0.25	0.25	0.25	0.25	0.25	0.5
Code Interleaver length (binary symbols)	2046	8190	6142	3070	4606	6142
PN Generator for Code Interleaver	P11[x]	P13[x]	P13[x]	P12[x]	P13[x]	P13[x]
Encoder Output Block Length (code symbols)	4096	16384	8192	4096	6144	8192

Assymetric Data - Uplink/Downlink

- Web-surfing and many other internet applications are assymetric
  - Different data volumes on uplink and downlink
- Downlink (Forward link) is usually much heavier due to pattern of “download”, “response”, “download”, “response”
- The data usage metering display at right shows an example of typical web-surfing or file downloading





HDR Summary

- HDR is a highly-specialized wireless data environment carefully optimized for packet data throughput
- HDR provides extreme spectral efficiency - 2.45 Mbps in just 1.25 MHz of spectrum - approx. 2 bits data per hertz of bandwidth!!
- The forward link runs the sector at maximum power and dynamically adjusts its data channel rates to the highest possible
- The radio links are optimized for highest possible channel rates under dynamic channel conditions, in real-time
- Physical-layer-based signaling for data rate control keeps the whole system supremely responsive to channel quality fluctuations
- Each data rate exploits high-performance Turbo coding for the highest throughput
- The base stations are compatible with standard IS-95 networks
- The frame structure and alignment processes are streamlined for packet data efficiency with the lowest possible use of power for overhead channels and other non-productive functions

1xEV DV
Motorola's 1Xtreme

Motorola's 1x EV DV Proposal, 1Xtreme

- Motorola's 1X EV-DV Proposal
- Peak data rate on a single 1.25 MHz carrier up to 5 Mbps
  - average data throughput of 1.2 Mbps
- backward-compatible with IS-95A/B and CDMA2000 1X
  - same channel structures, frame sizes, and coding schemes
  - one 1.25 MHz channel can carry IS-95A/B, 1xRTT and 1xEV-DV
  - installed base of IS-95A/B and 1X mobiles is fully compatible
- Motorola demonstrated 1xEV at the CTIA show in March 2001
  - high-speed data throughput of 3.2 Mbps using 16-QAM
  - potential rate of almost 5 Mbps with enhancements

Technical Basics of 1Xtreme

- Multiple Walsh Codes can be combined into one wide channel
  - On an idle cell, up to 14 walsh codes are available and can be combined into a single large "pipe" for fast data
  - Maximum data transfer rate up to 4.8 Mbps on the forward link
  - This multicode combined channel can be time-multiplexed and shared among multiple users
- 1Xtreme uses a combination of FEC and ARQ
  - Forward Error Correction (turbo or convolutional coding)
    - Makes the signal more resistant to corruption
  - Automatic Repeat Request Protocols
    - Corrupted packets are requested to be retransmitted
    - Corrupted packets are not discarded; they are saved for combining with the retransmitted packet to improve the probability of successful decoding by improving SNR

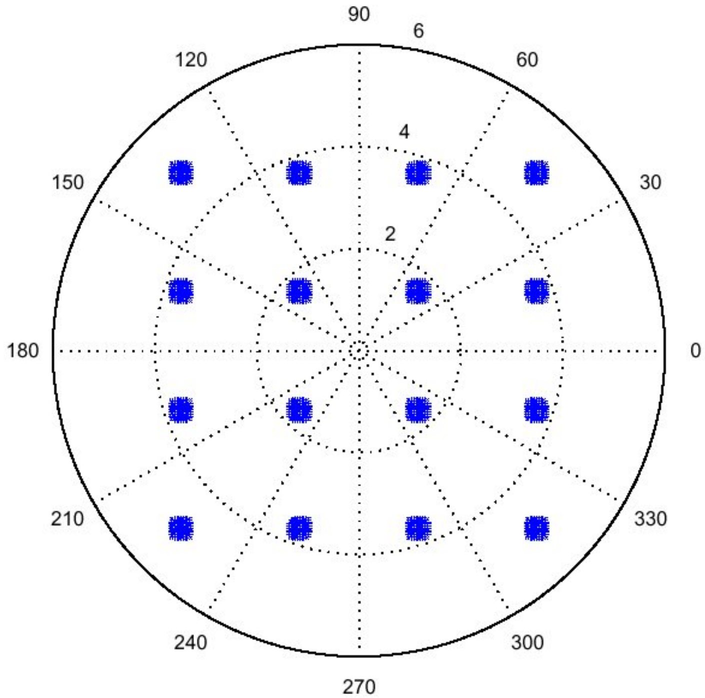
Modulation and Coding Schemes of 1Xtreme

- 1Xtreme offers eight different coding schemes
- The best scheme for current channel conditions is dynamically selected
  - The mobile measures the conditions and relays its requested rate to the BTS

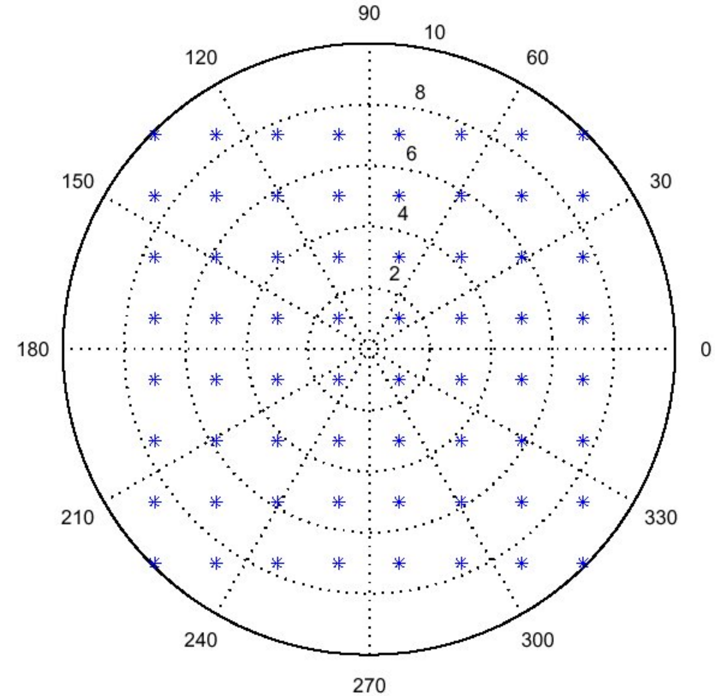
Scheme	Modulation Type	Channel Coding Rate
8	64-QAM	3/4
7	64-QAM	1/2
6	16-QAM	3/4
5	16-QAM	1/2
4	8-PSK	3/4
3	8-PSK	1/2
2	QPSK	3/4
1	QPSK	1/2

1Xtreme Phase Constellations

16-QAM



64-QAM

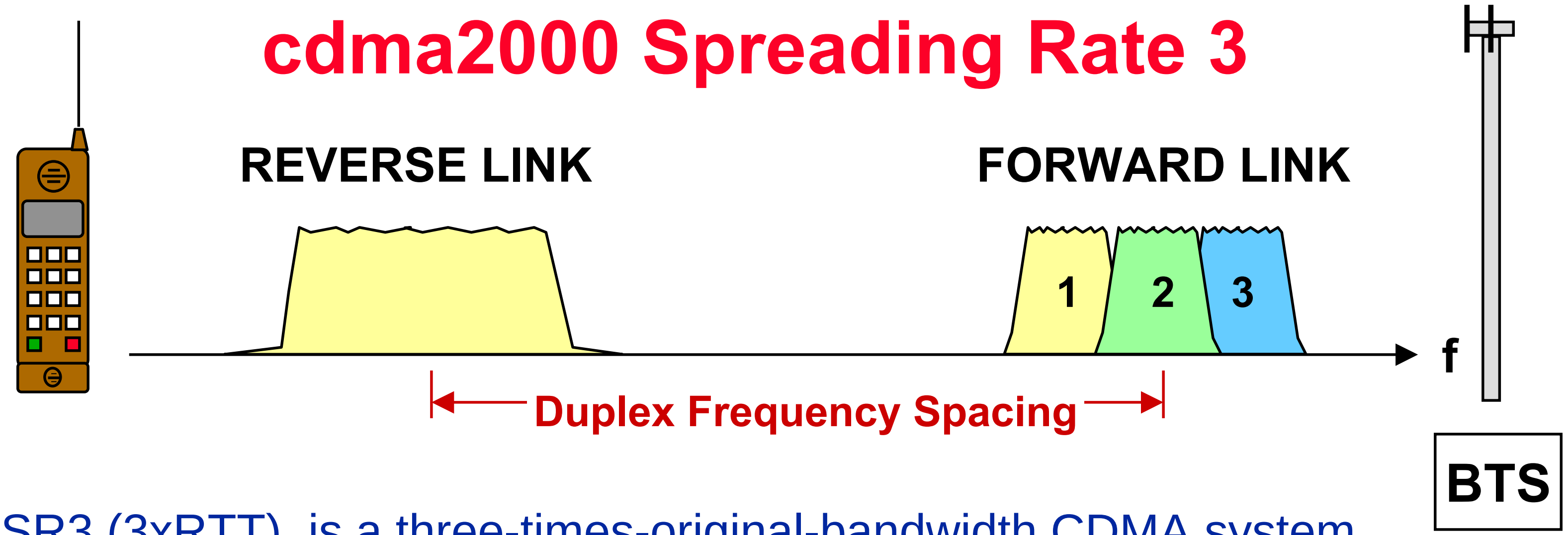


- Dynamic selection of modulation type, coding scheme, and data rate squeeze the best performance out of each moment

3xRTT:

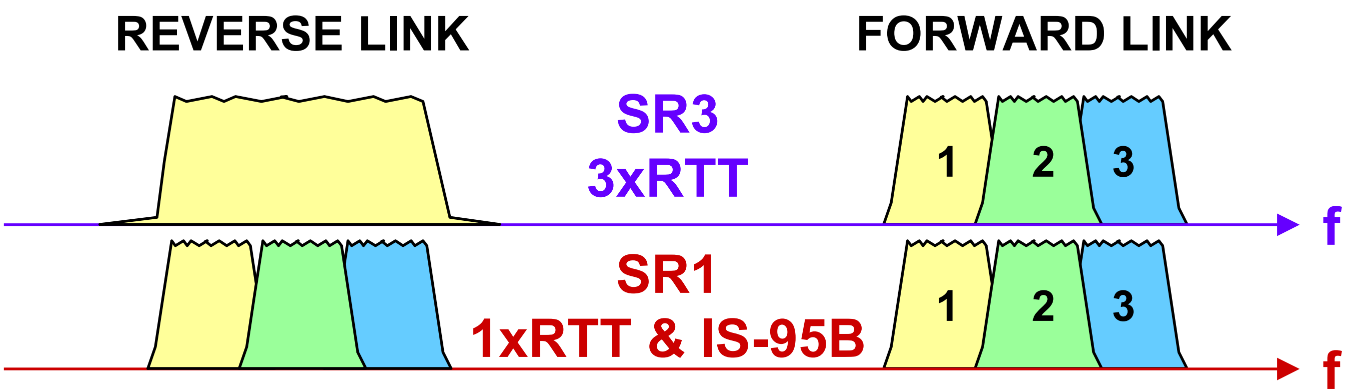
Dark Horse or *Dead Horse*?

cdma2000 Spreading Rate 3



- SR3 (3xRTT) is a three-times-original-bandwidth CDMA system
- 3xRTT uses all the new coding implemented in SR1 1xRTT
- 3xRTT can support higher data rates than 1xRTT
- Prior to harmonization, there were two SR3 modes of operation:
  - Direct Spread
    - A single signal forward & reverse, 3x bandwidth of 1xRTT
    - This mode has been dropped from IS-2000 and is now considered part of the 3GPP WCDMA family of modes
  - Multi-Carrier
    - Designed to fit nicely in overlay mode with IS-95 systems
    - Forward Link uses three adjacent 1xRTT carriers
    - Reverse Link uses single 3xRTT carrier

Relationships between SR3 and IS-95 SR1

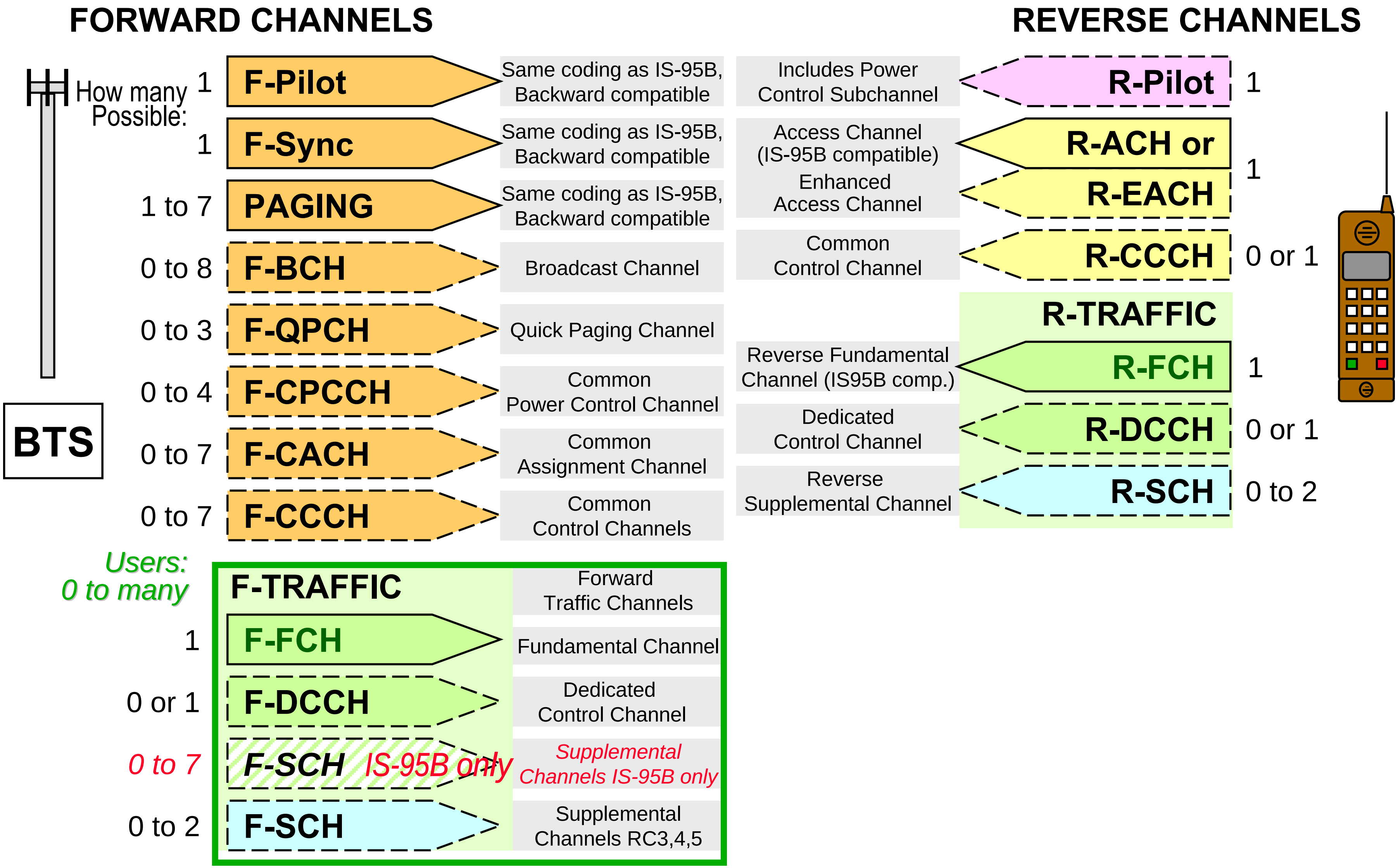


- SR3 signals can be overlaid on top of existing IS-95B systems.
- If the Walsh codes used by the SR3 forward link carriers are not used by the corresponding SR1 carriers below, interference does not occur. The two carriers divide the available capacity
- SR3 reverse link carriers above SR1 carriers do not interfere since different long PN offsets are used. They divide capacity.
- Operators can smoothly upgrade from IS-95B>1xRTT>3xRTT without requiring additional spectrum!
  - Older network equipment remains usable
  - Even existing 800 MHz. operators and PCS D, E, F, and C1/C2/C3 operators can benefit from 3xRTT without requiring additional licensed spectrum

Spreading Rates & Radio Configurations

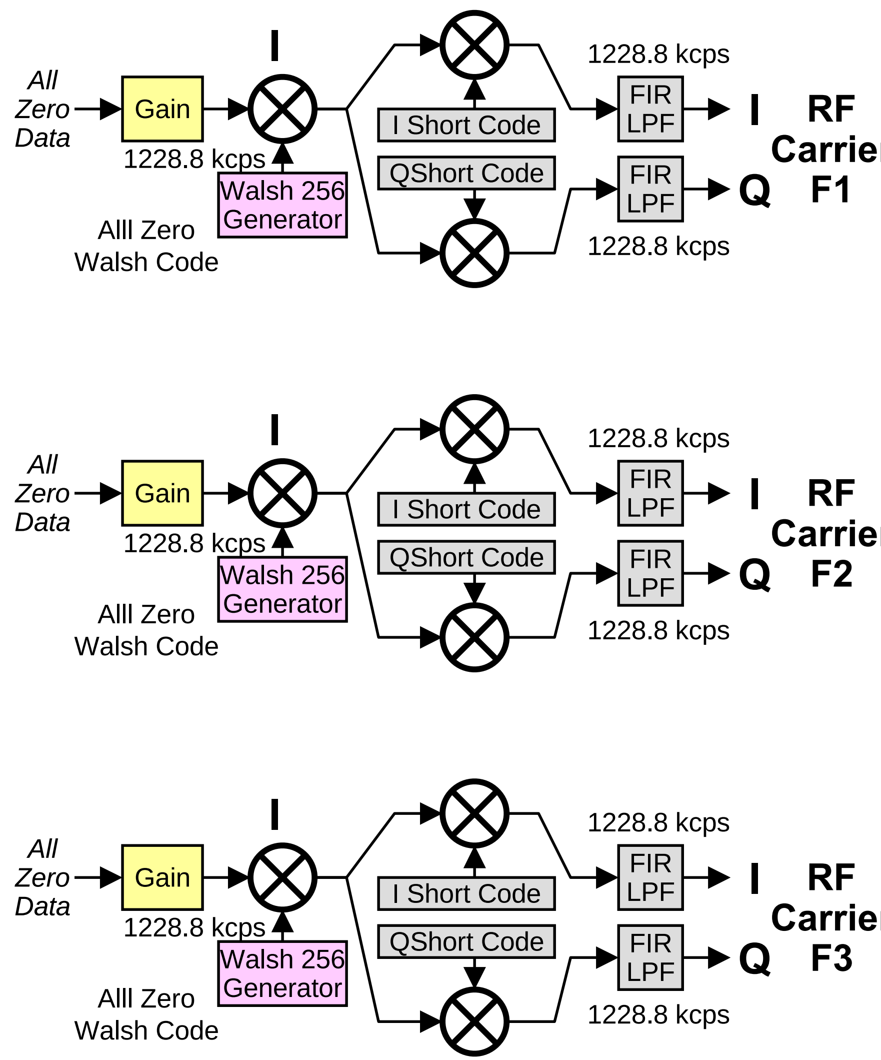
Spreading Rate	Forward Link Radio Configuration	Forward Link	Forward Link Data Rates	Reverse Link Radio Configuration	Reverse Link	Reverse Link Data Rates
SR1 1xRTT 1 carrier 1.2288 MCPS	RC1	Required. IS-95B Compatible No CDMA2000 coding features	9600	RC1	Required. IS-95B Compatible No CDMA2000 coding features	9600
	RC2	Compatible with IS-95B RS2 No CDMA2000 coding features	14400	RC2	Compatible with IS-95B RS2 No CDMA2000 coding features	14400
	RC3	Quarter-rate convolutional or Turbo Coding, base rate 9600	9600 153600	RC3	¼ rate conv or Turbo coding ½ rate conv or Turbo coding base rate 9600	9600 153600 307200
	RC4	Half-rate convolutional or Turbo Coding, base rate 9600	9600 307200			
	RC5	Quarter-rate convolutional or Turbo Coding, base rate 14400	14400 230400	RC4	¼ rate convolutional or Turbo Coding, base rate 14400	14400 230400
SR3 3xRTT Fwd: 3 carriers 1.2288 MCPS Rev: 3.6864 MCPS	RC6	1/6 rate convolutional or Turbo coding, base rate 9600	9600 307200	RC5	Required. ¼ or 1/3 convolutional or Turbo coding, base rate 9600	9600 307200 614400
	RC7	Required. 1/3 rate convolutional or Turbo coding, base rate 9600	9600 614400			
	RC8	¼ or 1/3 rate convolutional or Turbo coding, base rate 14400	14400 460800	RC6	¼ or ½ convolutional or Turbo encoding, base rate 14400	14400 460800 1036800
	RC9	½ or 1/3 rate convolutional or Turbo encoder, base rate 14400	14400 1036800			

CDMA2000 SR3 CDMA Channels

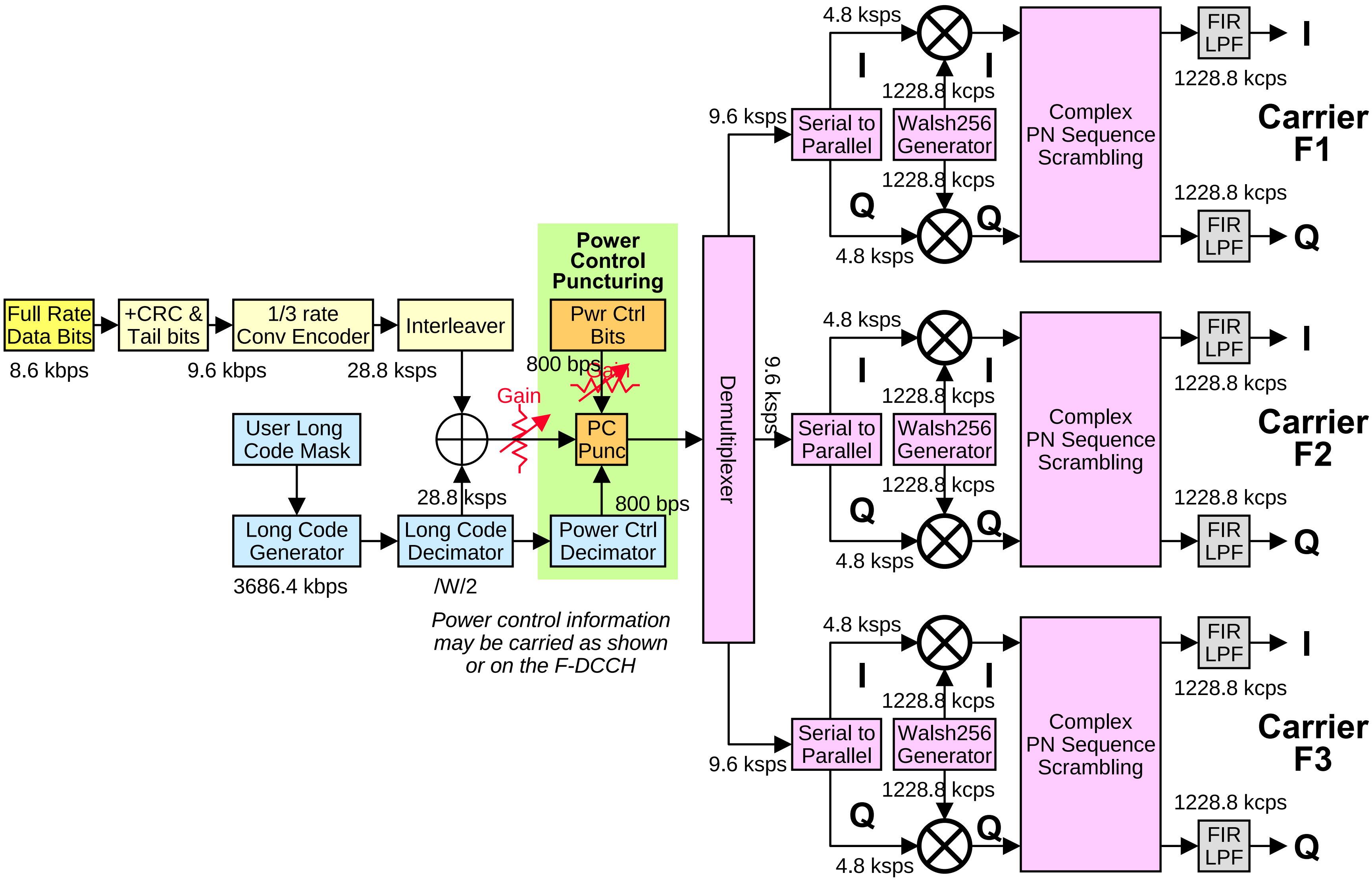


SR3 Multi-Carrier Pilot F-PICH Coding

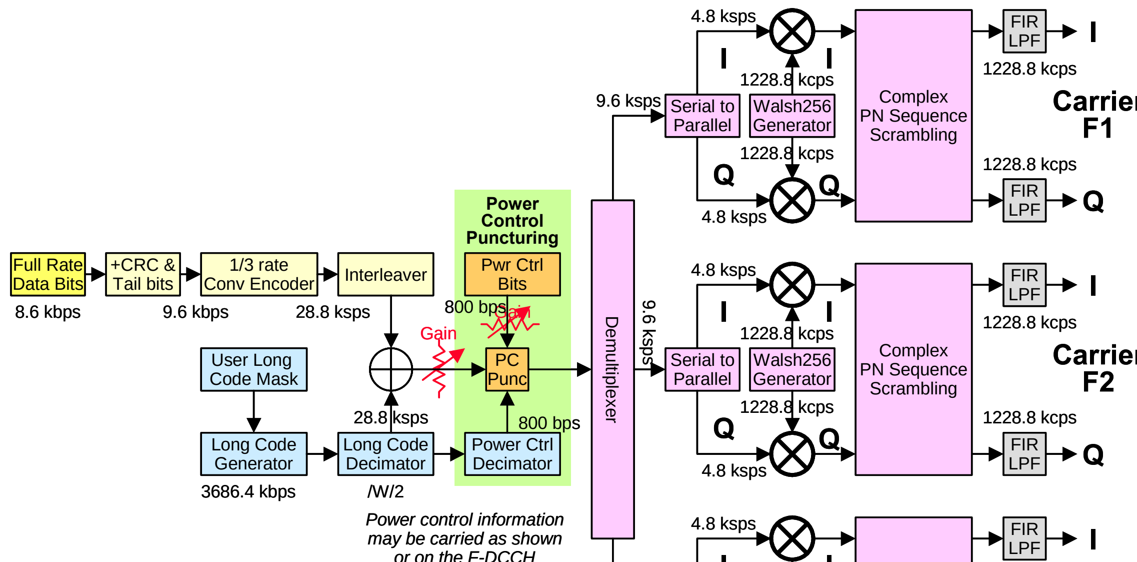
- Each RF carrier has its own pilot
- The pilot is all zeros and the spreading Walsh code is all zeros
- The resulting string of all zeros is applied to only the I data channel, resulting in non-complex short code scrambling just like IS-95
- IS-95B mobiles on F1, F2, or F3 will be able to use the carrier as if it were an IS-95 carrier
- The I and Q components are sent along for summing with any other forward channels on each carrier



SR3 MC, RC7 (9600 bps) F-FCH

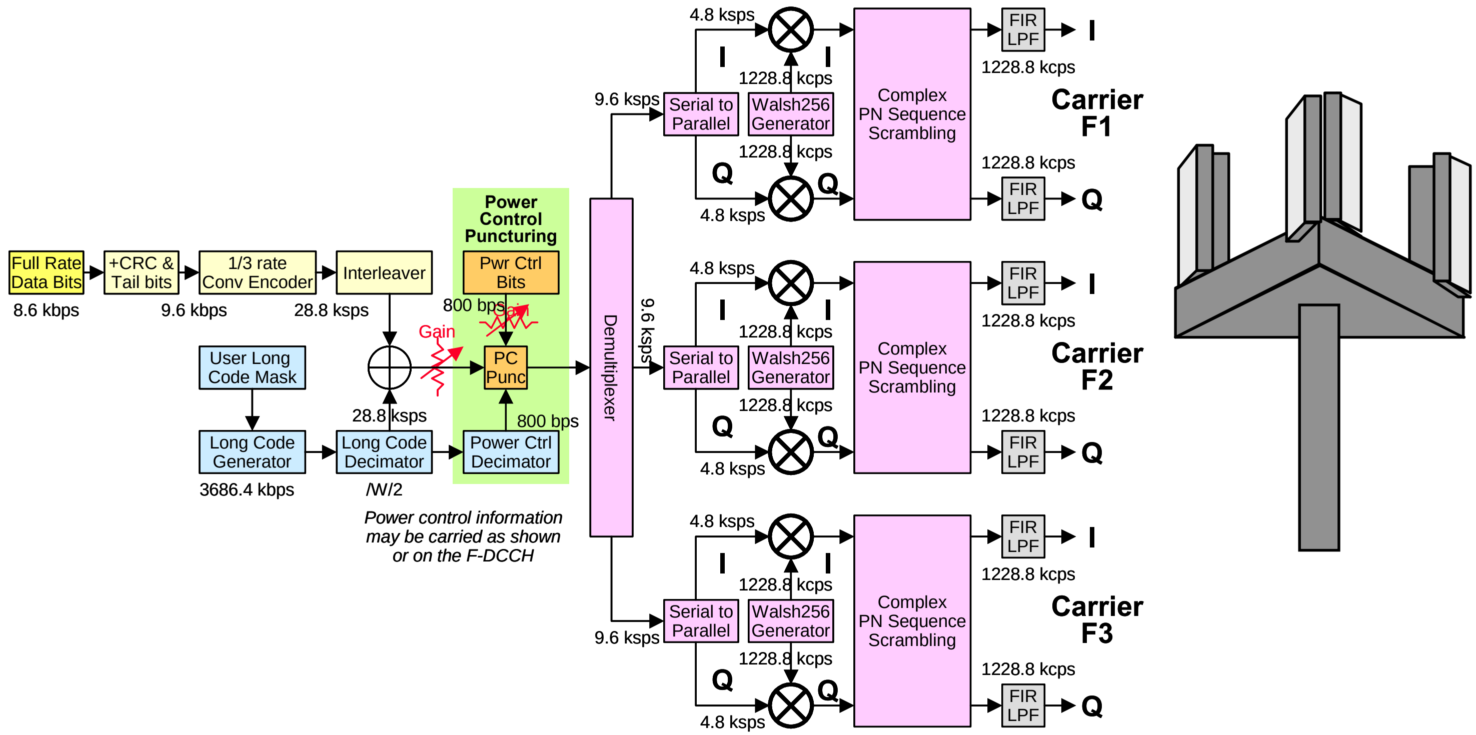


SR3 MC, RC7 (9600 bps) F-FCH Coding Details



- After coding, symbol repetition, block interleaving, long code scrambling, and power control puncturing, the symbols are split into three streams
- One stream is transmitted over each carrier
- This provides processing gain per carrier far larger than provided in IS-95B

SR3 Forward Transmit Diversity



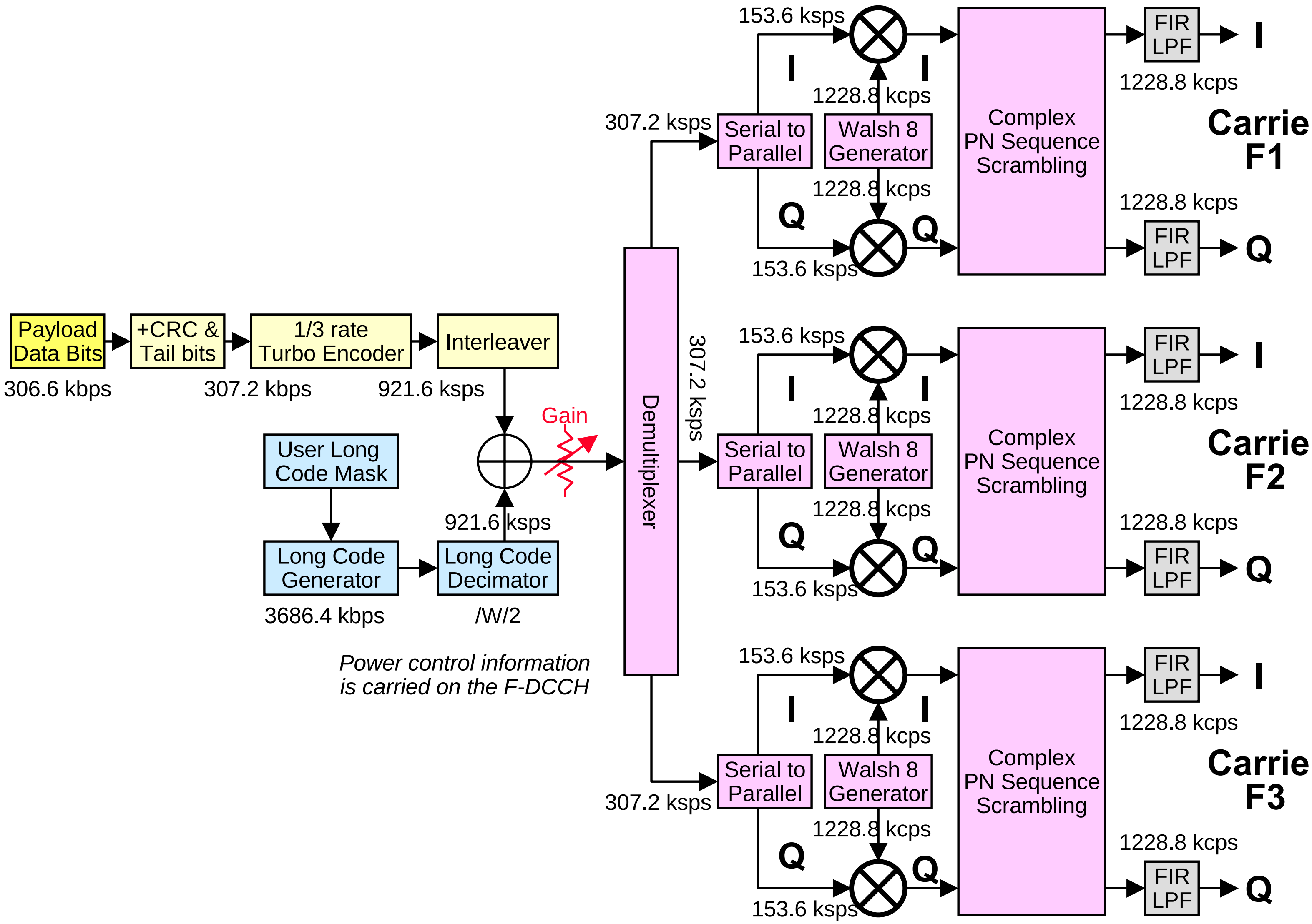
- Each SR3 forward channel is already split into three parts, carried on three different RF carriers
- Although the three transmitters could be duplexed into the same antenna if desired, space diversity is obtained if separate antennas are used
- This improves forward link capacity by combating Raleigh fading

SR3 Power Control Puncturing

- The different SR3 radio configurations (RCs) have different symbol rates.
- The number of symbols punctured varies for each RC as shown in the table at right
- The long code decimator adjusts its decimation length proportionally to the length of the Walsh code being used for the channel
  - Decimation length = Walsh code length/2

Radio Configuration	Symbol Rate, ksps	Number of Symbols Punctured
RC6	**57.6**	**6**
RC7	**28.8**	**3**
RC8	**57.6**	**6**
RC9	**28.8**	**3**

SR3 MC, RC6 (306.6 kbps) F-SCH



Power control information is carried on the F-DCCH

3xRTT Codes and Coding Details

What if we run out of Walsh Codes? Quasi-Orthogonal Functions

- 3xRTT has 256 Walsh codes available
  - but so many new types of channels, and variable length codes, can cause Walsh code shortages on some sectors!
- When no more Walsh codes are available, Quasi-Orthogonal Functions can be used
  - QOFs are generated by multiplying Walsh Codes with a quasi-orthogonal mask
  - Following Walsh Spreading, the I and Q channels are rotated 90 degrees gated by another Walsh Code
- Each set of QOFs is self-orthogonal among its members
  - there is slight non-orthogonality between different QOF sets including the original walsh codes, but not at troublesome levels
  - Short PN imperfections are just as bad, and they aren't troublesome
- Manufacturers didn't implement QOFs in their initial CDMA2000 products, but all are expected eventually to support QOFs

The Original Walsh Codes
"Set 0"

Quasi-Orthogonal Functions
"QOF Set 1"

Quasi-Orthogonal Functions
"QOF Set 2"

Quasi-Orthogonal Functions
"QOF Set 3"

Masks for Quasi-Orthogonal Functions

- There are four mask conditions used to create Walsh and QOF functions
  - 0: Walsh Codes (perfectly orthogonal)
  - 1-3: QOF functions (approximately orthogonal)

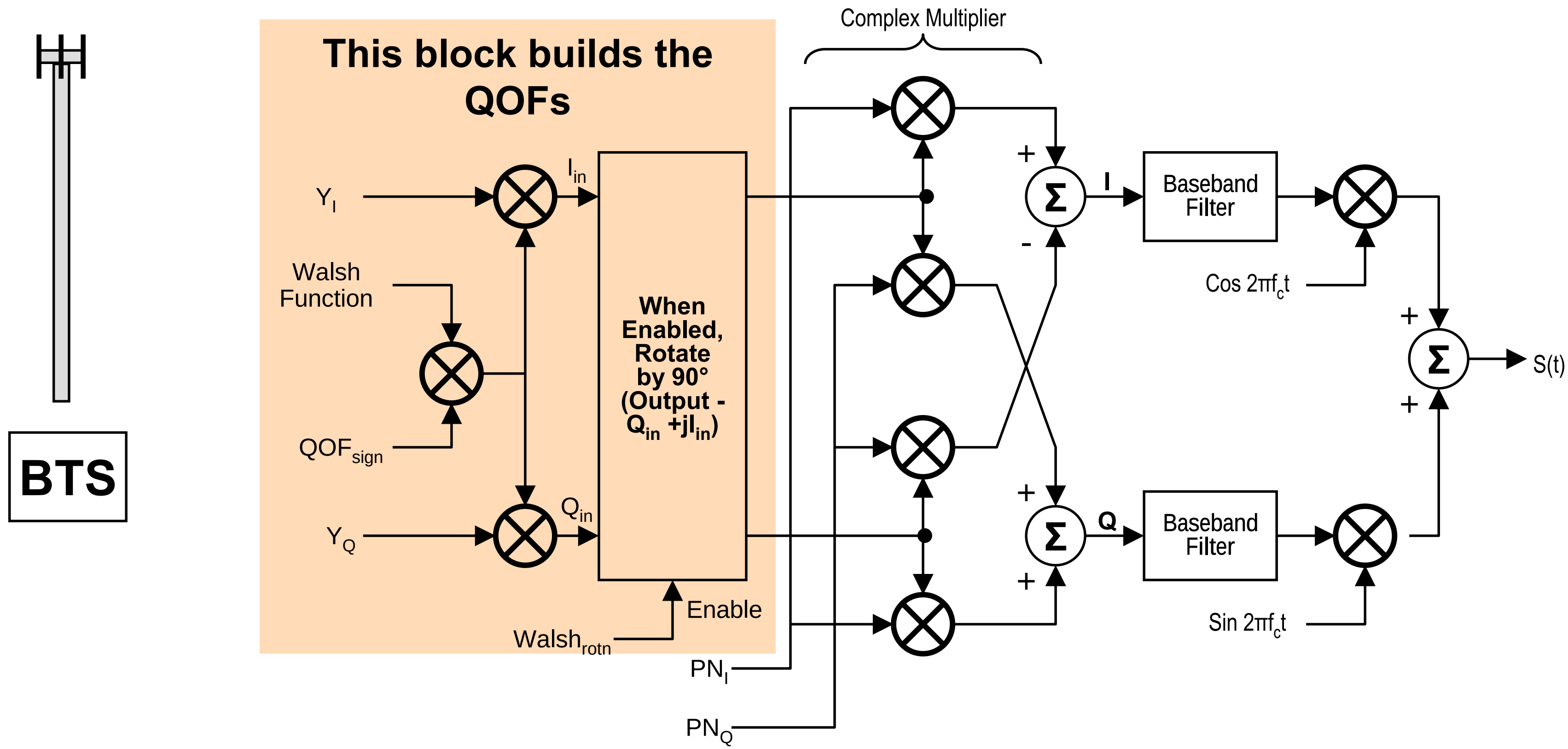
Table 3.1.3.1.12-1. Maximum Walsh Function Length for Code Channels on the Forward CDMA Channel Except the Auxiliary Pilot Channel and Auxiliary Transmit Diversity Pilot Channel

Spreading Rate	Maximum Walsh Length
1	128
3	256

Table 3.1.3.1.12-2. Masking Functions for Quasi-Orthogonal Functions with Length 256

Function	Masking Function	
	Hexadecimal Representation of QOF_{sign}	$Walsh_{rot}$
0	00000000000000000000000000000000 00000000000000000000000000000000	W_0^{256}
1	7228d7724eebebb1eb4eb1ebd78d8d28 278282d81b41be1b411b1bbe7dd8277d	W_{130}^{256}
2	114b1e4444e14beeee4be144bbe1b4ee dd872d77882d78dd2287d277772d87dd	W_{173}^{256}
3	1724bd71b28118d48ebddb172b187eb2 e7d4b27ebd8ee82481b22be7dbe871bd	W_{47}^{256}

Walsh Code/Quasi Orthogonal Implementation

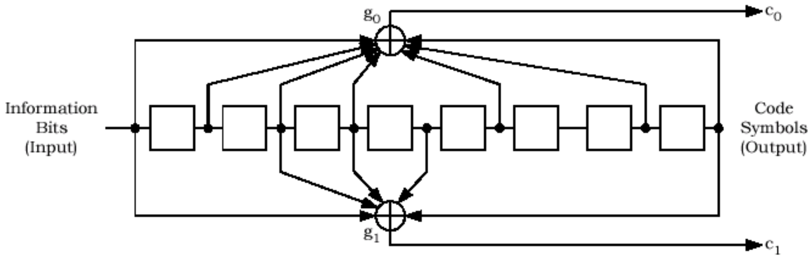


Walsh function = ±1 (mapping: '0'⇒+1, '1' ⇒-1)
QOF_{sign}= ±1 sign multiplier QOF mask (mapping: '0'⇒+1, '1' ⇒-1)
$Walsh_{rot}$ = '0' or '1' 90°-rotation-enable Walsh function
$Walsh_{rot}$ = '0' means no rotation
$Walsh_{rot}$ = '1' means rotate by 90°
The null QOF has QOF_{sign} = +1 and $Walsh_{rot}$ = '0'
PN_I and PN_Q = ±1 I-channel and Q-channel PN sequences
The null QOF is used for Radio Configurations 1 and 2

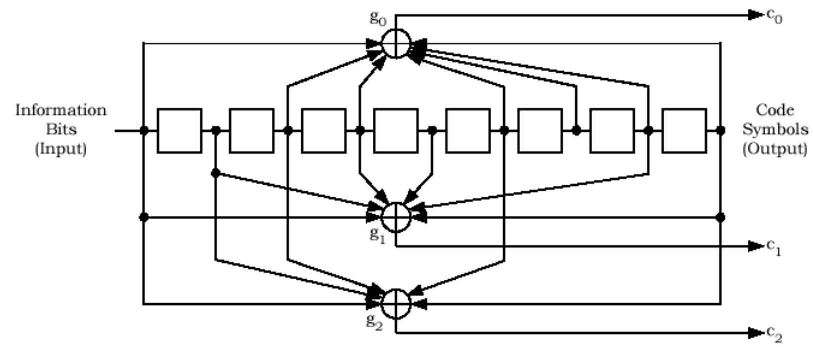
Data Protection: Convolutional vs. Turbo Coding

- In CDMA, bits are protected against transmission errors by first coding them into symbols before transmission. After reception, the decoding process is highly tolerant of bad symbols and the correct bits can be recovered despite symbol errors
- Many different coding methods are available to convert bits into symbols. CDMA voice applications have always used convolutional encoders; CDMA2000 also introduces Turbo coding
- Voice is a real-time streaming application and lost frames can't be retransmitted, they're too late. An FER of about 1% or 2% is the typical target in CDMA systems for voice applications.
- Data applications are more forgiving of lost frames since the main objective is throughput and retransmission of a few frames doesn't hurt throughput significantly
- Turbo coders are a class of coders with higher throughput and efficiency but slightly less error immunity than convolutional encoders.
  - Their design is experimental; optimal algorithms are not yet known
- Experiments have achieved higher overall sector capacities
  - Run data channels at approx. 5% FER with Turbo coding, using packet retransmission to correct lost frames
  - Run voice channels at traditional 1-2% FER with Convolutional coders

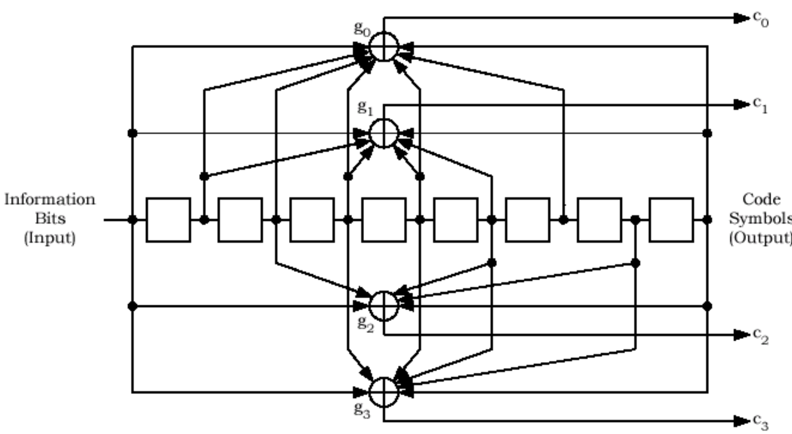
CDMA Convolutional Coders



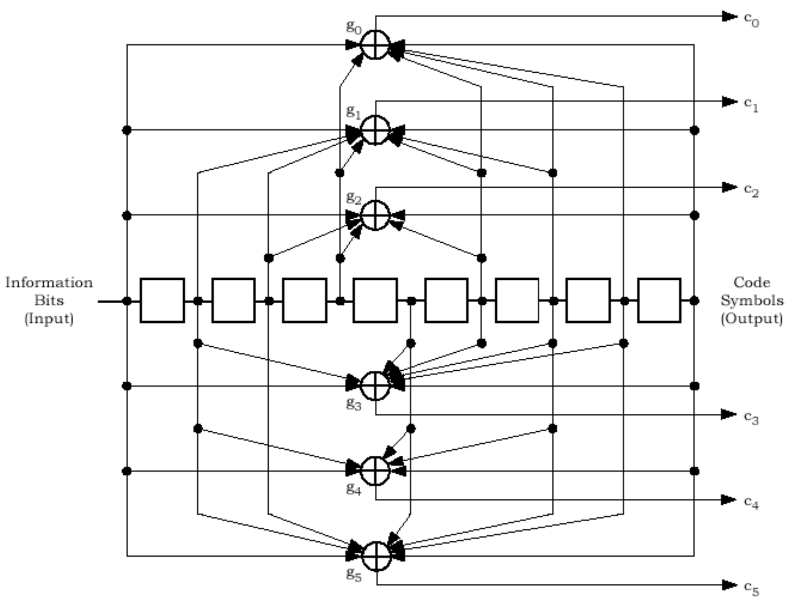
K = 9, Rate 1/2 Convolutional Encoder



K = 9, Rate 1/3 Convolutional Encoder



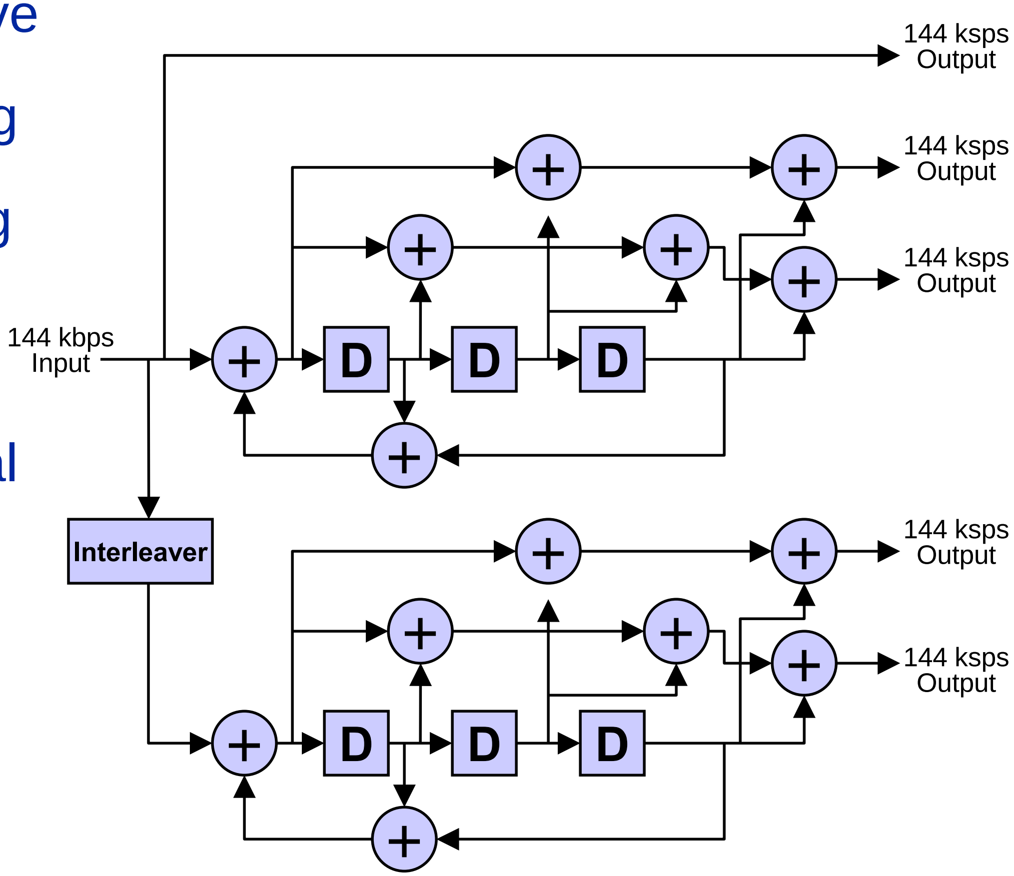
K = 9, Rate 1/4 Convolutional Encoder



K = 9, Rate 1/6 Convolutional Encoder

The CDMA2000 Turbo Coder

- The IS-2000 general turbo coder is shown at right
- The turbo coder produces five output streams - the original stream plus four others using a combination of feedback shift register and interleaving techniques
  - A fifth-rate Turbo Coder
- Puncturing reduces the output rate to 3 times original
- This turbo coder has approximately 0.5 db better error performance than a convolutional encoder of similar rate



Symbol Puncturing with Turbo and Convolutional Codes

- Symbol puncturing is used to reduce the symbol rate after Turbo Encoding and after Convolutional Encoding
- Even after puncturing, sufficient symbols remain for reliable operation -- the encoding is powerful enough to correct the values of the missing symbols

Table 3.1.3.1.6.2-1. Punctured Codes Used with Turbo Codes

Base Code Rate	Puncturing Ratio	Puncturing Pattern	Associated Radio Configurations
1/2	2 of 18	'111110101 111111111'	9
1/4	4 of 12	'110111011010'	5

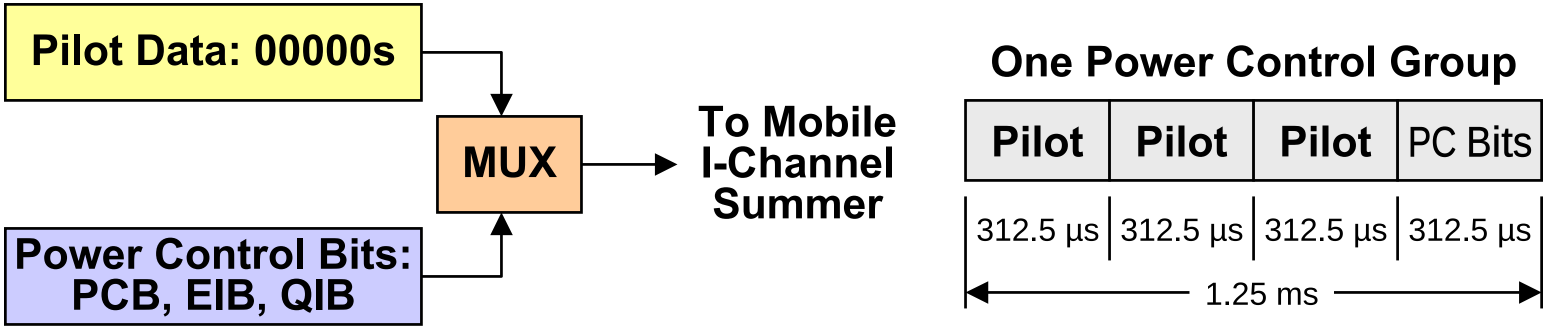
Table 3.1.3.1.6.1-1. Punctured Codes Used with Convolutional Codes

Base Code Rate	Puncturing Ratio	Puncturing Pattern	Associated Radio Configurations
1/2	2 of 6	'110101'	2
1/2	1 of 5	'11110'	4
1/2	1 of 9	'111111110'	4
1/2	2 of 18	'111011111 111111110'	9
1/3	1 of 5	'11110'	7
1/3	1 of 9	'111111110'	7
1/4	4 of 12	'110110011011'	5
1/4	1 of 5	'11110'	3
1/4	1 of 9	'111111110'	3
1/6	1 of 5	'11110'	6
1/6	1 of 9	'111111110'	6

Frame Rate Detection

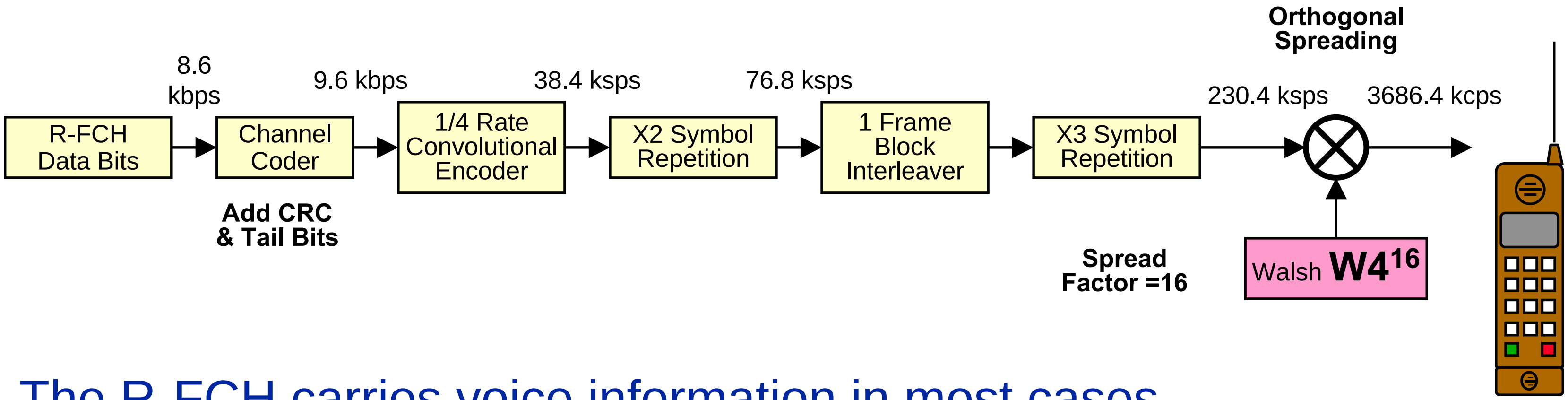
- The original IS-95 CDMA traffic channels use “blind rate detection”
  - The receiver has no idea what data rate is being transmitted in a frame until the whole frame can be examined after reception
    - Symbol repetition patterns and CRC bits are examined for each possibility, and the actual rate is chosen as the one with the lowest apparent errors
    - This requires substantial processing in the receiver!
- The SCH (supplemental channels) of IS-2000 will normally be carrying fast packet data
  - Blind rate detection would require substantial processing and battery power
  - Rates of SCHs will usually “float” depending on available capacity on the cell
    - The cell will attempt to satisfy the offered voice loading by varying the throughput for data users
- The F-DCCH will normally inform users of the rates to expect on their F-SCHs so they do not need to do blind rate detection
  - SCH rates will be controlled by the appropriate layers of the protocol stack, in accordance with the individual user’s priorities

Reverse Pilot & Power Control Bit Multiplexing



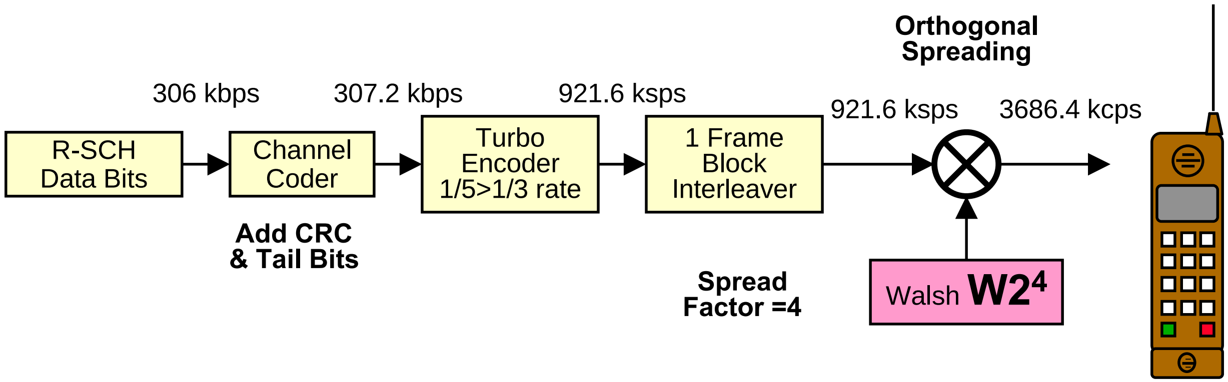
- The reverse pilot R-PCH includes a power control subchannel used to power control the Forward Link. Depending on the Forward Power Control Mode (FPC), the channel may contain combinations of:
  - Power Control Bits
  - Erasure Indicator Bits
  - Quality Indicator Bits
- The time-structuring of the power control is similar to that transmitted on the IS-95B forward traffic channel
  - A frame is divided into 16 Power Control Groups, 1.25 ms each
  - 1 Power Control Bit is sent per Power Control Group
- Each Power Control Group is divided into 4 subgroups
  - 3 groups of pure pilot, one group of power control bits

SR3, RC5 R-FCH Channel Coding



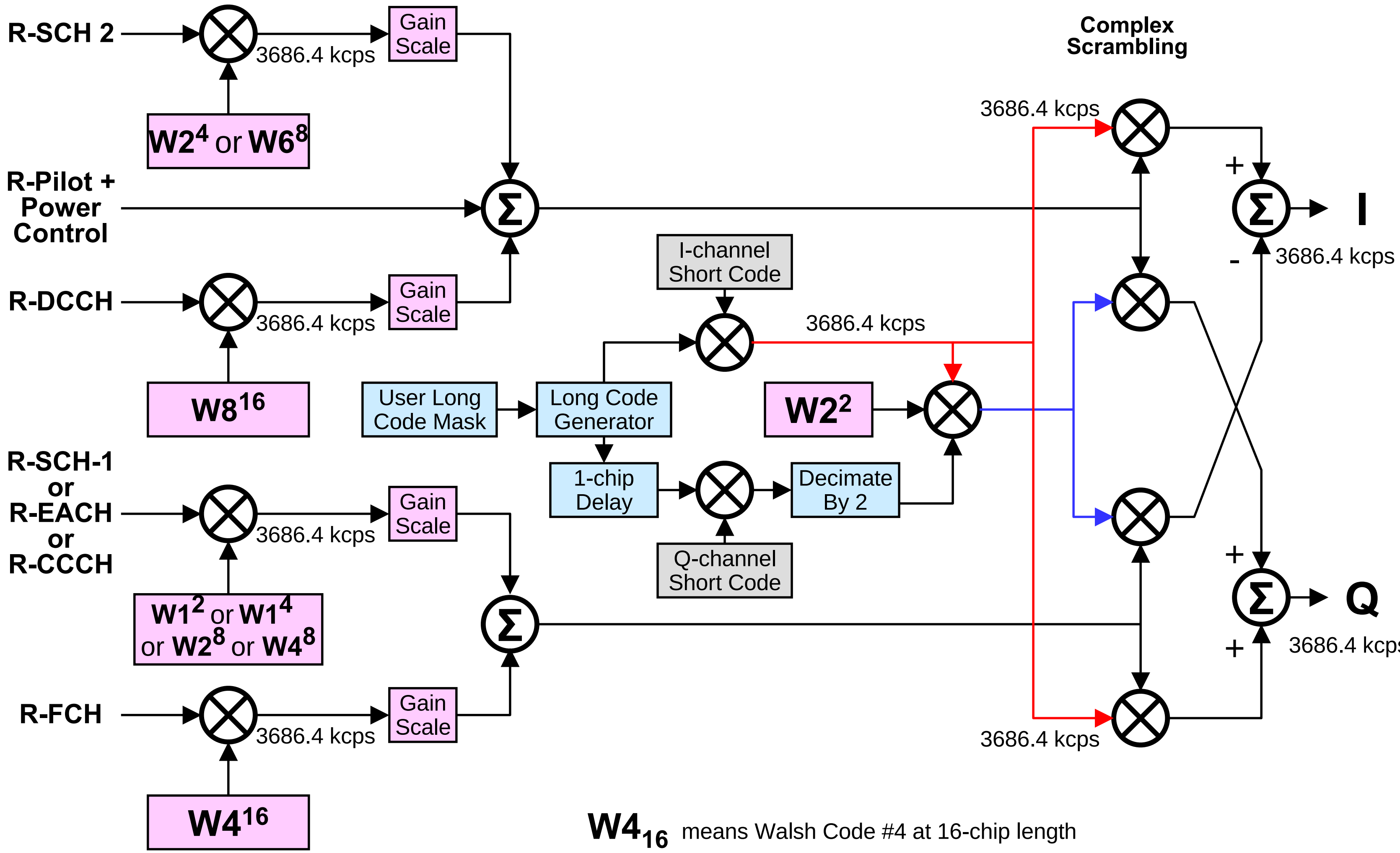
- The R-FCH carries voice information in most cases
  - When in voice mode, frames are 20 ms long
  - When in data mode, frames are 5 ms long
- Unlike the SR1 case, an additional 3X symbol repetition is applied after block interleaving
- Walsh spreading raises the chip rate to the SR3 level
- Walsh Code 4, 16-chip length, is always used for the R-FCH

SR3, RC5 R-SCH Channel Coding



- The R-SCH supplemental channel usually carries high speed data
  - Its frames are always 20 ms long
- There is an option for using convolutional coding or turbo coding when sending high speed data
- The diagram above shows the turbo coding option in use
  - Fifth rate turbo coder, punctured to one-third rate
- Walsh Code 2, 4-chip length, is used in this case
  - The coding gain of this channel is much less than that of a voice channel, so it will consume much more power than the accompanying R-FCH

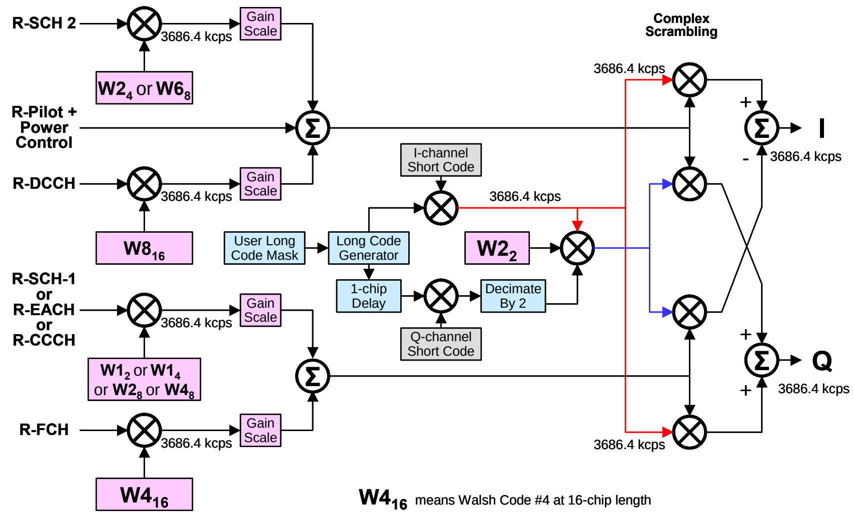
SR3 Reverse Channel Spreading



$W4_{16}$ means Walsh Code #4 at 16-chip length

Some Fine Points on SR3 Reverse Channels

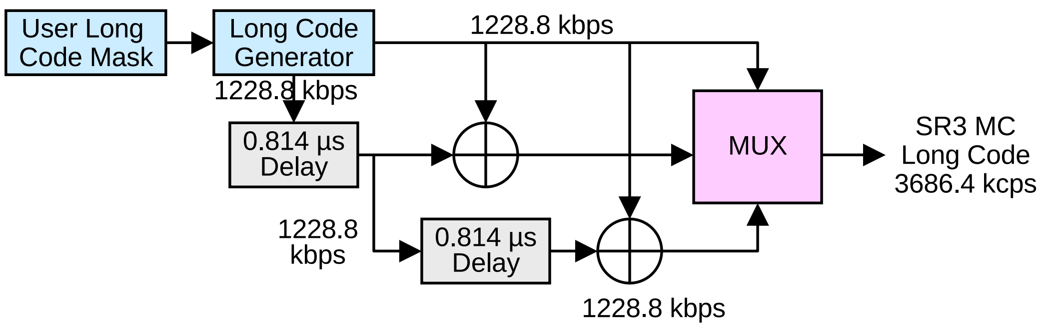
- The SR3 mode uses the same spreading technique as SR1
- Since multiple reverse channels are summed together, the offset QPSK does not help reduce the dynamic range of the signal and linear amplifiers are needed
- HPSK modulation is used to reduce the dynamic range somewhat, but linear amplifiers will still be necessary
- Therefore, CDMA2000 mobiles with data capability will have poorer battery efficiency and more costly power amplifiers



SR3 Multicarrier Reverse PN Short Codes

- Since the SR3 chip rate is 3x SR1, SR1 short PN codes cannot be used in building reverse-link SR3 signals
- New Short PN codes are selected to preserve the 75-repetitions per two seconds characteristic
  - This is accomplished by changing the short code patterns from a 2^{15} length to a 2^{20} length sequence
  - A 2^{20} length sequence has 1,048,576 chips in its pattern
  - Therefore, only the first 26 2/3 ms. is used (98,304 chips) and then the sequence is restarted
  - The I code is aligned to begin with even-second clock and the Q code is delayed 2^{19} chips from the I code
- End result: 75 repetitions every 2 seconds

SR3 Reverse Long Code



- Just when you thought things were settling down, we have a change to tell you concerning the Reverse Long Code in SR3
- A new SR3 Reverse Long Code must be used since the Chip Rate is 3x faster than the old SR1 case
- To achieve this change, the original SR1 Long Code is delayed and mixed with itself twice to generate the additional 1.2288 MCPS long codes
  - The delay is 1 chip at SR1, 814 nanoseconds
  - The three long codes are then time-multiplexed together to produce a new long code that runs at 3.6864 MCPS and repeats in the exact same period as the original SR1 Long Code
- Don't worry, all this stuff happens inside chipsets we buy; we don't have to do it ourselves.

Walsh Code Selection for the SR3 R-SCH

- When there is 1 operating SCH
  - Mobile should use R-SCH 1 with Walsh Code $W2_4$
  - Walsh Code $W1_2$ is used only for the highest data rates
- When there are 2 operating SCHs:
  - R-SCH 1 uses:
    - Either Walsh $W1_2$ or $W2_4$
  - R-SCH 2 uses:
    - Either Walsh $W2_4$ or $W6_8$
- Using two-bit Walsh codes will defeat the peak-to-average reductions of HPSK; this should be avoided if possible