Course 332+

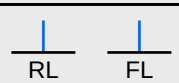
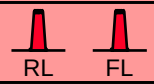
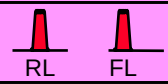
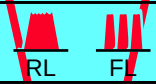
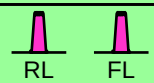
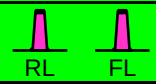
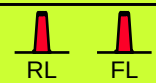
Technical Introduction to CDMA2000 1xRTT

Including Performance Optimization Basics

Contents of Course 332+

- 2G-3G Progression Overview
- The RF Side of CDMA2000 developments
  - A Story of Two Hotels
  - CDMA2000 Compatibility with IS-95
  - New features and improvements
    - Radio Configurations & channels
    - Improvements: access, power control, coding, etc
    - OTD, pilots for smart antenna beamforming, etc.
- The Data Side of new CDMA2000 developments
  - Circuit-switched vs. packet-switched access
  - The data backbone
    - Physical structure: PDSNs, OSSN, AAA, administration
    - Operational features: Simple IP, Mobile IP, QoS
    - The Protocol Stack, Packet Data States, Link Management
- Performance Optimization Principles and Practice

The CDMA Migration Path to 3G

		CDMAone		CDMA2000 / IS-2000				
Generation	**1G**	**2G**	**2G**	**2.5G? 3G**	**3G**	**3G**		
Technology	AMPS	IS-95A/ J-Std008	**IS-95B**	**IS-2000: 1xRTT**	**IS-2000: 3xRTT**	**1xEV-DO Rev. 0** IS-856	**1xEV-DO Rev. A** IS-856	**1xEV-DV 1xTreme**
Spectrum								
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. 59 active users	1250 kHz. 59 active users	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 DL** 153 Kb/s UL	**3.1 Mb/s DL 1.8 Mb/s UL**	**5 Mb/s**
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	High data rates on data-only CDMA carrier	Higher data rates on data-only CDMA carrier	High data rates on Data-Voice shared CDMA carrier

GSM Technology Migration Path to 3G

Generation	1G	2G	2.5G or 3?	3G	3G
Technology	**various analog**	**GSM**	**GPRS**	**EDGE**	**UMTS UTRA WCDMA**
Signal Bandwidth, #Users	various	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	200 kHz. fast data many users	3.84 MHz. up to 200+ voice users and data
Data Capabilities	various	none	9-160 Kb/s (conditions determine)	384 Kb/s mobile user	2Mb/s static user
Features: Incremental Progress	various	Europe's first Digital wireless	•Packet IP access •Multiple attached users	Faster data rates on dedicated 200 kHz data carrier	Integrated voice and data

This is T-Mobile's development path!

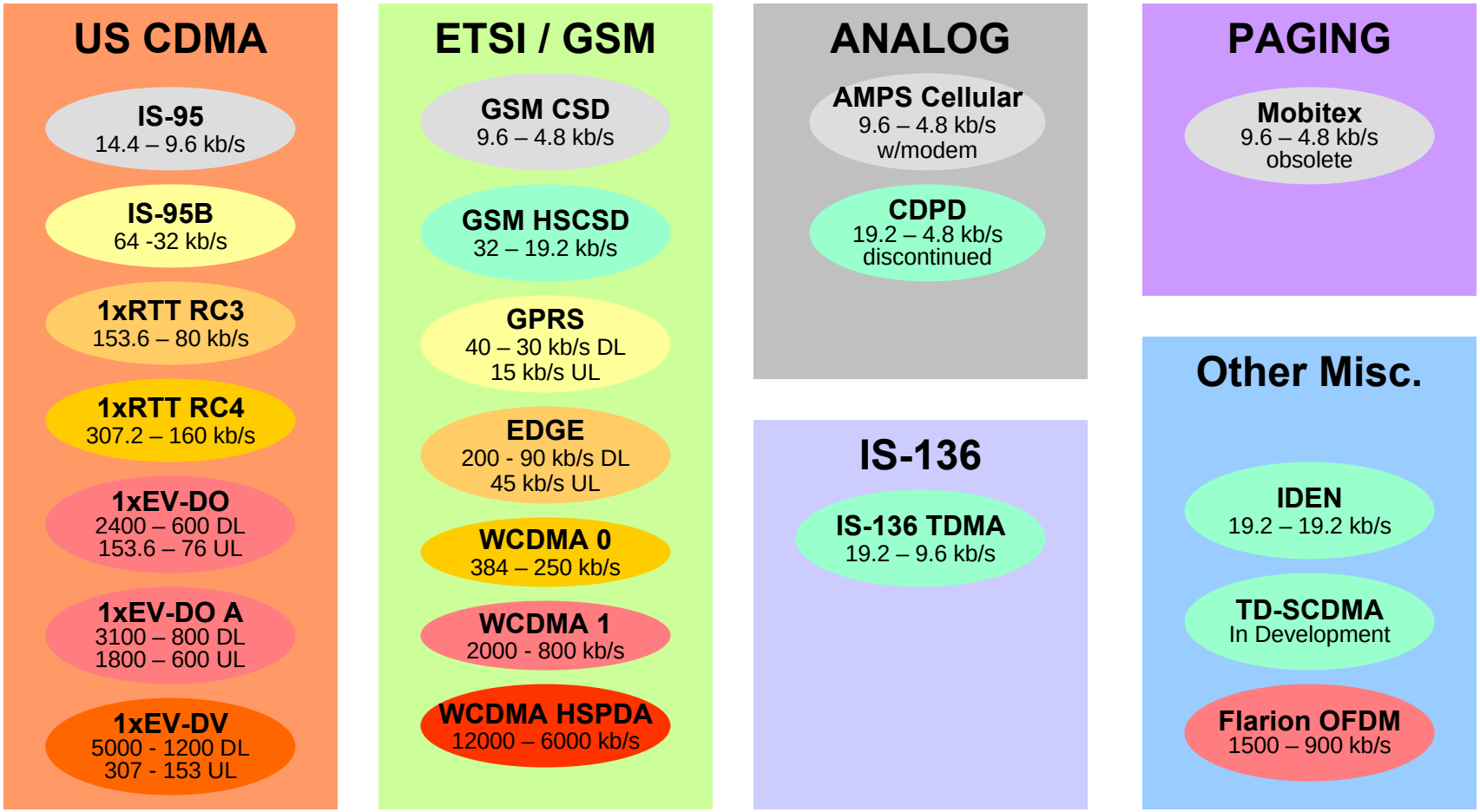
TDMA IS-136 Technology Migration Path to 3G

familiar GSM path!

Generation	1G	2G	2G	2G	2.5G or 3?	3G	3G
Technology	**AMPS**	**CDPD**	**TDMA IS-54 IS-136**	**GSM**	**GPRS**	**EDGE**	**UMTS UTRA WCDMA**
Signal Bandwidth, #Users	30 kHz. 1	30 kHz. Many Pkt Usrs	30 kHz. 3 users	200 kHz. 7.5 avg.	200 kHz. Many Pkt. users	200 kHz. fast data many users	3.84 MHz. up to 200+ voice users and data
Data Capabilities	None, 2.4K by modem	19.2 kbps	none	none	9-160 Kb/s (conditions determine)	384 Kb/s mobile user	2Mb/s static user
Features: Incremental Progress	First System, Capacity & Handoffs	US Packet Data Svc.	USA's first Digital wireless	Europe's first Digital wireless	•Packet IP access •Multiple attached users	Faster data rates on dedicated 200 kHz data carrier	Integrated voice and data

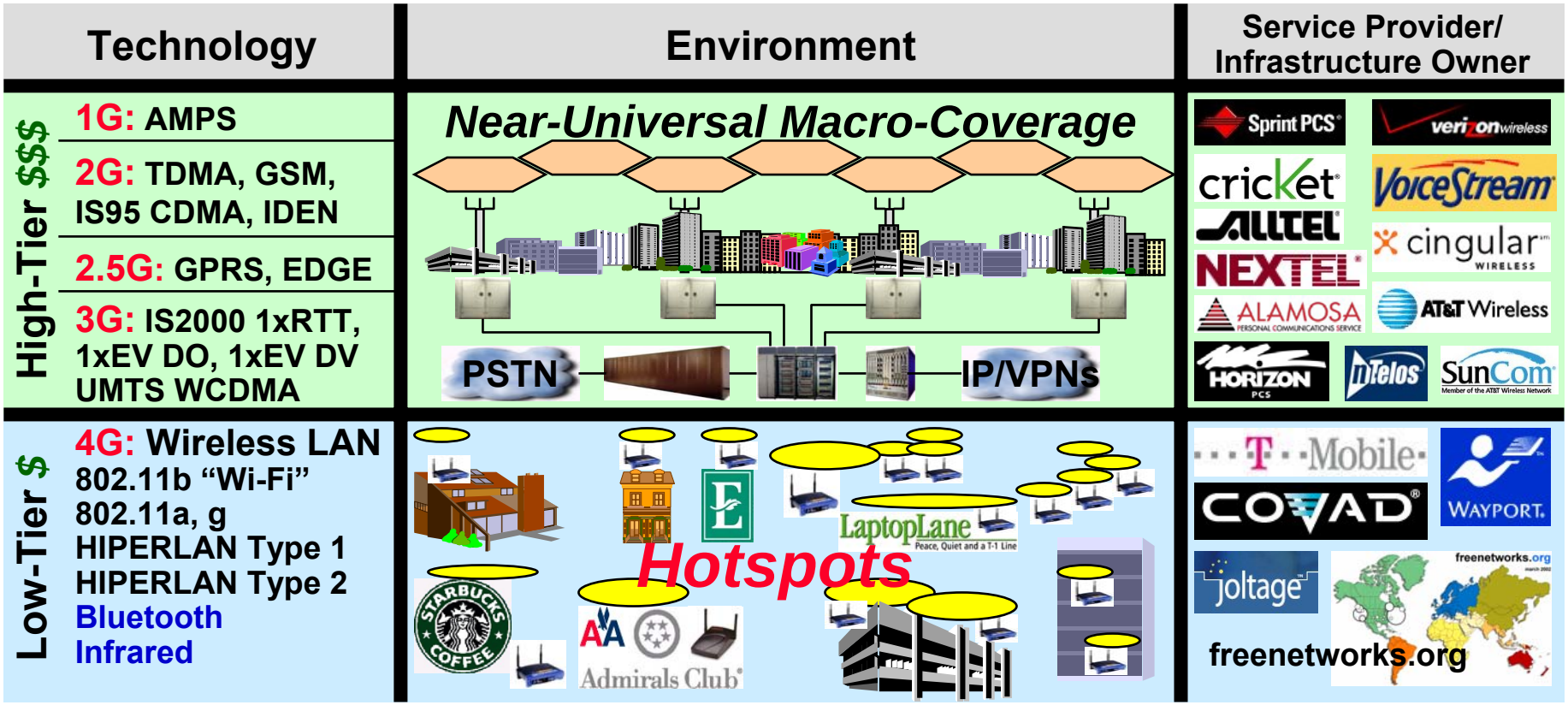
This is AT&T Wireless+Cingular's development path!

A Quick Survey of Wireless Data Technologies



- This summary is a work-in-progress, tracking latest experiences and reports from all the high-tier (provider-network-oriented) 2G and 3G wireless data technologies
- Have actual experiences to share, latest announced details, or corrections to the above? Email to Scott@ScottBaxter.com. Thanks for your comments!

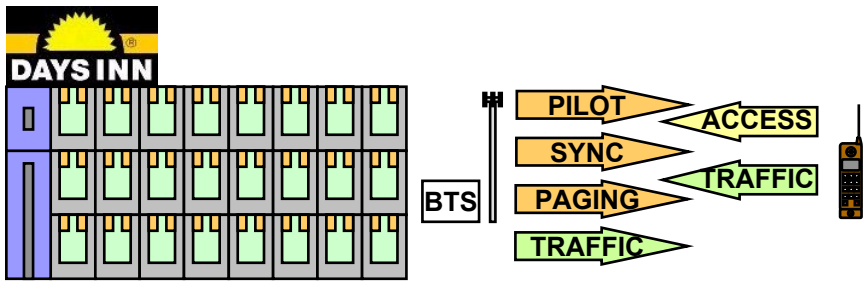
4G – Evolution or Revolution?

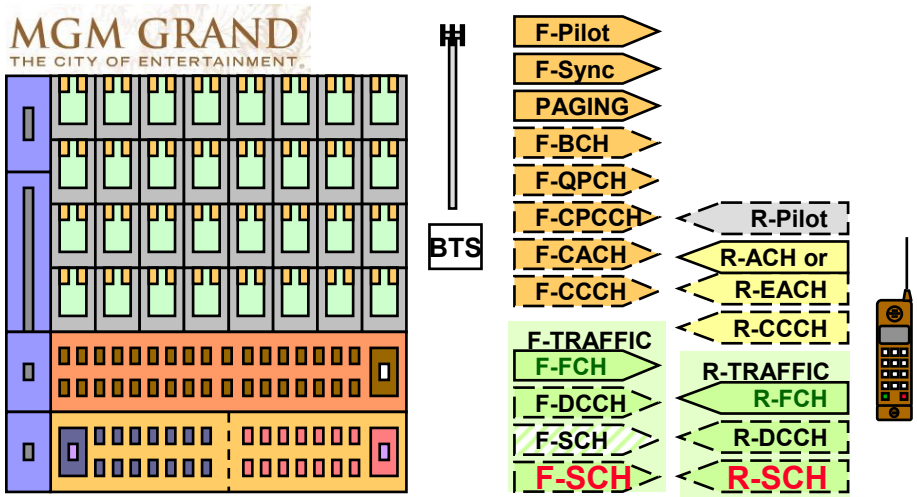


- There's a revolution going on!
  - New 2.5G services arriving now, new 3G arriving 2002 through 2005
  - A groundswell of commercial (and even free!) WILAN deployment
- 3G networks and 4G networks have their own unique advantages
- Ultimately 3G and 4G will be integrated by wireless operators!

The RF Side of 3G Networks

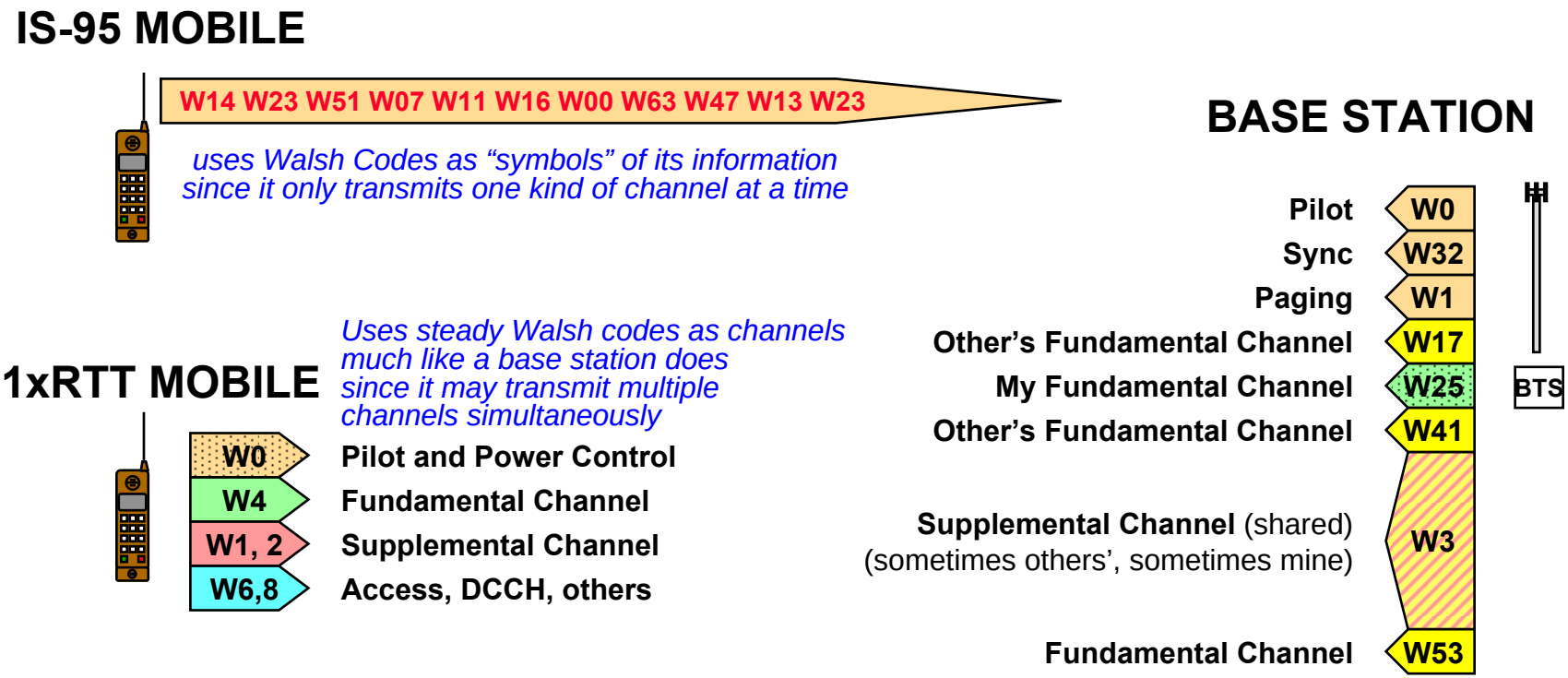
It's a Story of Two Hotels





- A sector on an IS-95 CDMA BTS runs like a discount hotel today
  - There's a Sign outside, a covered entranceway, Lobby
  - Only Two kinds of rooms: one king bed or two doubles
  - There are no meeting rooms or ballrooms
- New 1xRTT CDMA BTS sectors are like a convention resort!
  - Twice as big in square feet
  - Sign, Entranceway, Lobby
  - Restaurants, Bars, Nightclub
  - Guest rooms: one king bed or two doubles, maybe suites
  - Meeting Rooms with adjustable walls -- for use as Classrooms, Auditorium, Ballrooms, Banquets, Parties, Meetings

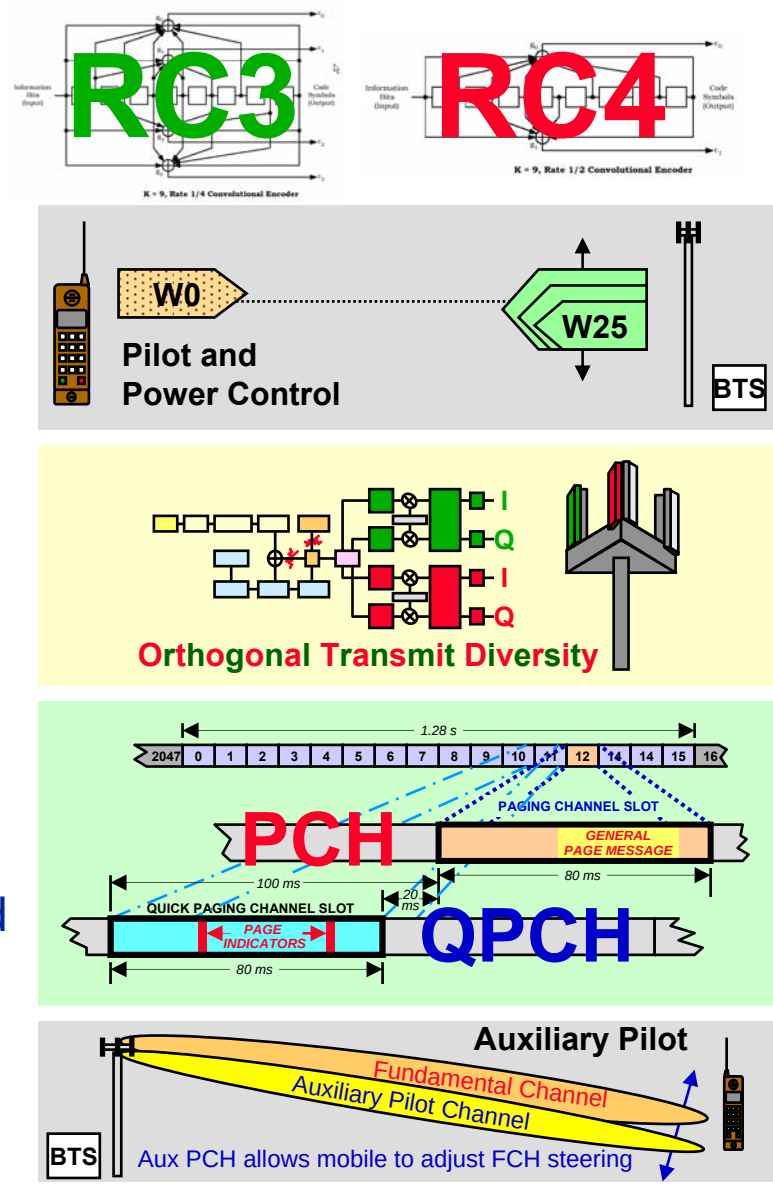
Mobile Improvements in 1xRTT



- Reverse Link Pilot transmitted by mobile in advanced modes
  - synchronous demodulation improves reverse link budget
- 1x Mobile transmits continuous waveform, no blind rate detection
  - Not like today's mobile and its TX data burst randomizing

Other Major 1xRTT Features

- Improved convolutional encoding for more robust channels
  - Much better protection against FER
- Faster power control on forward link
  - Finally the mobile can say what it wants 800x per second
- Forward Link Orthogonal Transmit Diversity (OTD)
  - Complex, but can give diversity gain
- Quick-paging channel improves slotted-mode paging, increases battery life
  - Quick Paging Channel indicator bits wake up mobiles to receive pages
- Auxiliary pilots support beam-forming and smart antennas
  - Expect advanced smart antenna products in 3-5 years

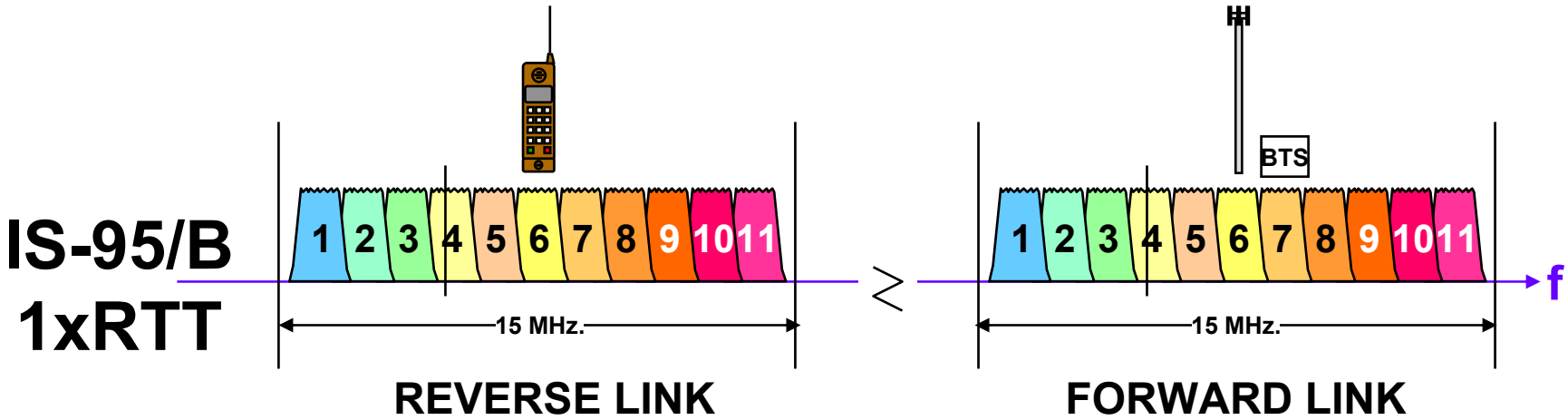


CDMA2000 Compatibility with IS-95B & IS-95



- A new 1xRTT base station can handle both old IS-95 mobiles and 1xRTT mobiles at the same time
  - the old mobiles can only operate in the old IS-95 mode
- A new 1xRTT mobile can operate even on an old IS-95 base station
  - but it will only be able to do old IS-95 calls while on the IS-95 base station
- CDMA2000 1xRTT systems still support all the old IS-95 features
  - IS-95B radio interface operation is still fully supported
  - IS-707 data services standard still fully implemented
  - Popular vocoders in widespread use are still supported
    - IS-127 8K EVRC
    - IS-733 13K vocoder
  - IS-637 SMS is supported
  - IS-683 Over-The-Air (OTA) Activation is fully supported
  - IS-98 and IS-97 BTS and Mobile performance specs still apply
  - Pilot, Sync and Paging channels of IS-95 are still used by all mobiles

Same Spectrum, Multiple Uses



- If a CDMA base station has 1xRTT capability, it can serve both new 1xRTT mobiles and old IS-95 mobiles
- Some carriers can be configured with only IS-95 capability
- Other carriers can be configured to serve both IS-95 and 1xRTT
  - Each mobile negotiates for whatever type of call is its best capability
- IS-95 and 1xRTT mobiles can be sent to different carriers by the Sync Channel message in idle mode, or by MCTA at time of call setup

Spreading Rates & Radio Configurations



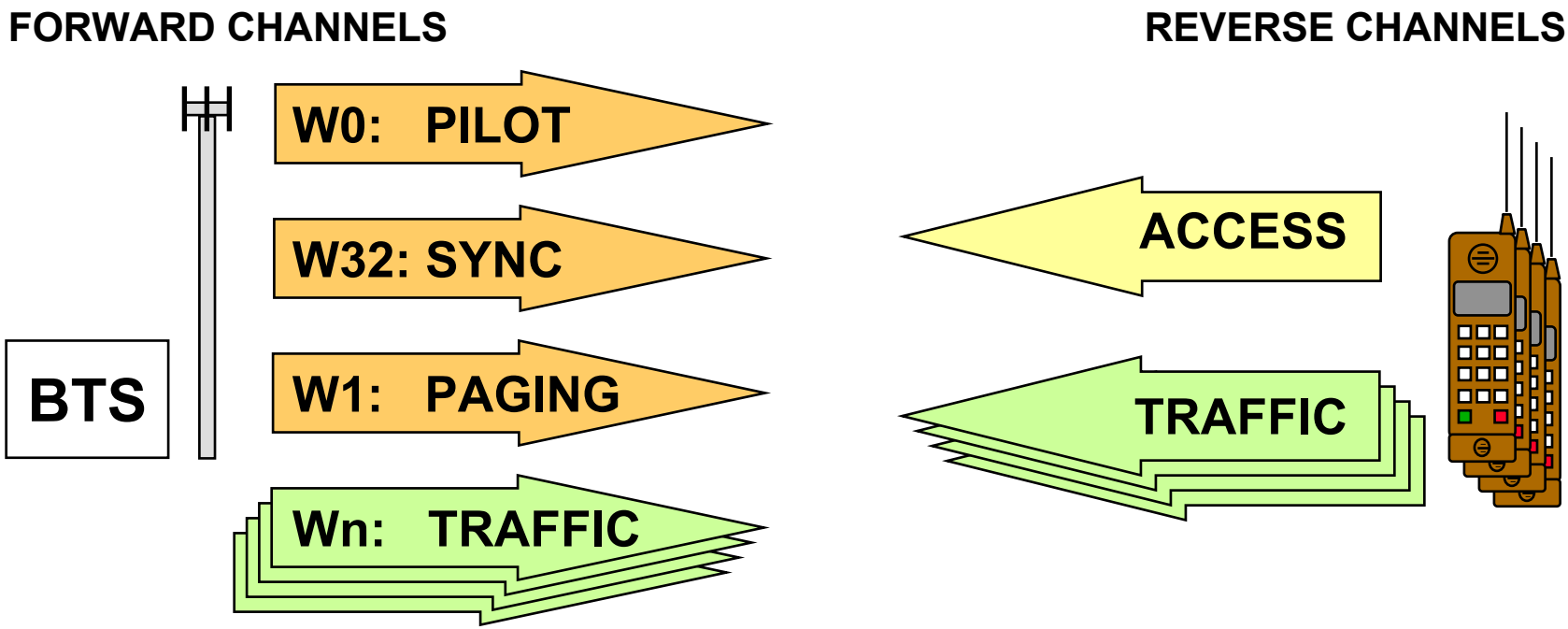


Spreading Rate	Forward Link	Radio Configuration	Data Rates	Data Rates	Radio Configuration	Reverse Link
SR1 1xRTT 1 carrier 1.2288 MCPS	Required. IS-95B Compatible No CDMA2000 coding features	RC1	9600	9600	RC1	Required. IS-95B Compatible No CDMA2000 coding features
	Compatible with IS-95B RS2 No CDMA2000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

Physical Layer

IS-2000 CDMA Code Channels

2G CDMA: IS-95 Code Channels

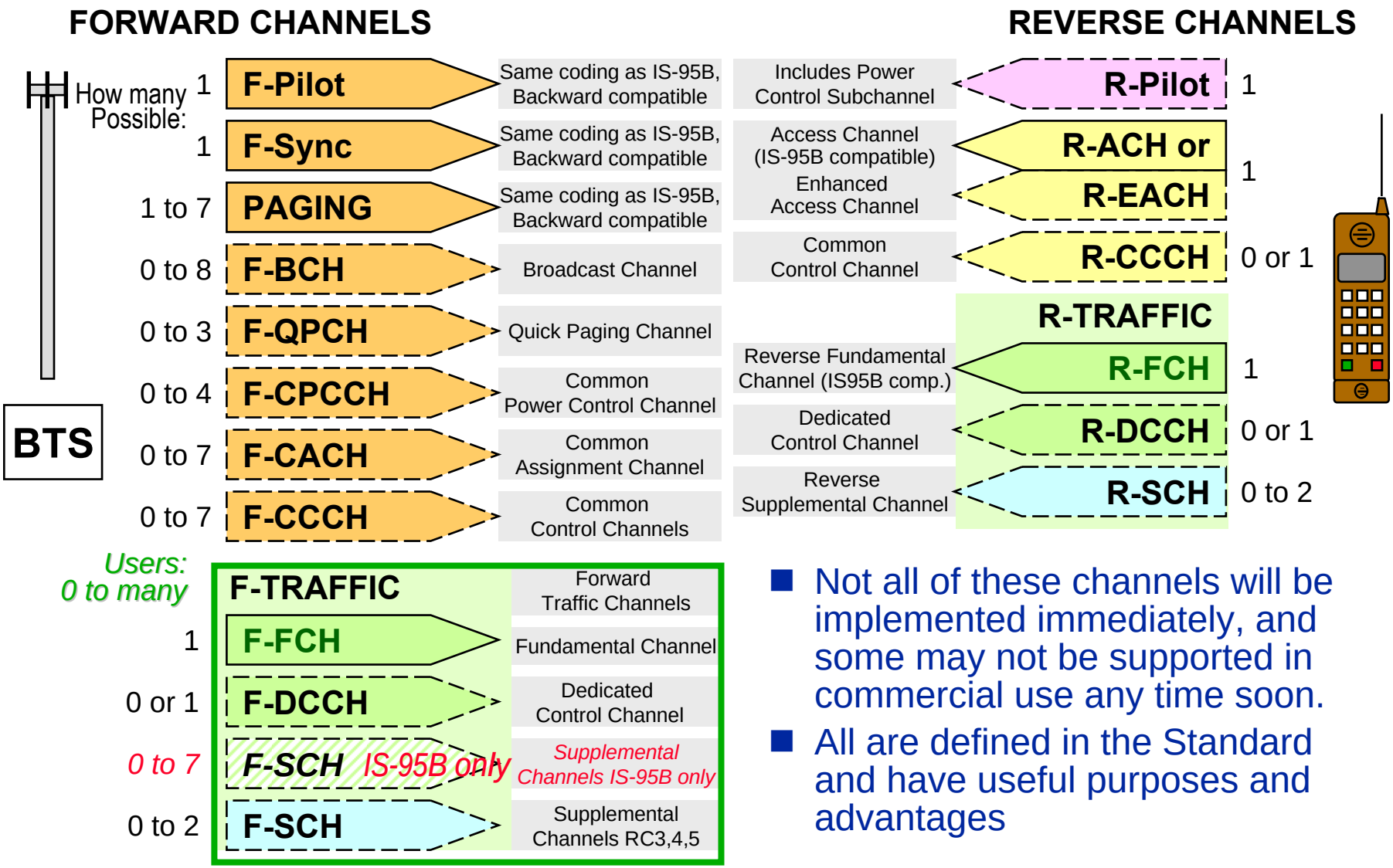


- Old IS-95A/JStd-008 CDMA offers only the channels shown above
  - 9600 bps traffic channels are called Rate Set 1
  - 14400 bps traffic channels are called Rate Set 2
- 1xRTT CDMA is backward-compatible with IS-95, but 1xRTT offers additional radio configurations with additional channels
  - These additional modes are called Radio Configurations
  - IS-95 Rate Set 1 and 2 are IS-2000 Radio Configurations 1 & 2

The Big Improvements in 1xRTT

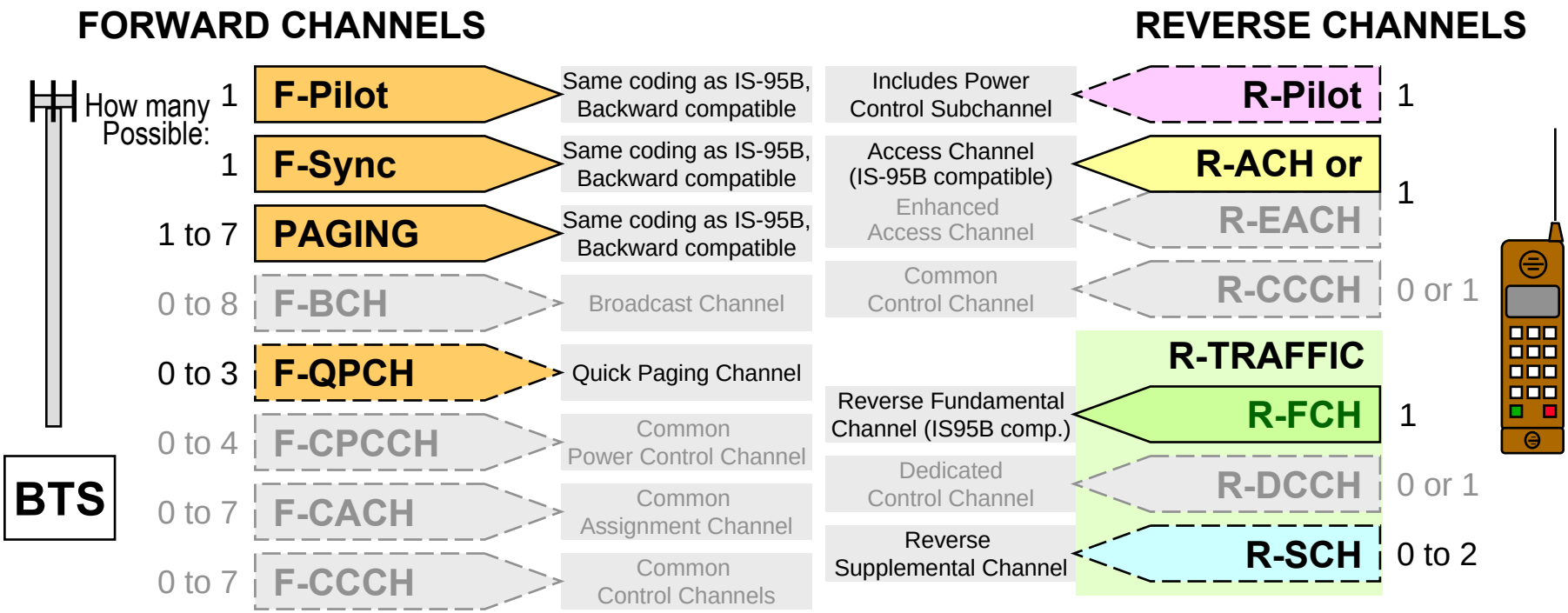
- the **FUNDAMENTAL** Channel (FCH) carries Voice and/or Low Speed Data just like today
- New **SUPPLEMENTAL** Channel (SCH) carries high-speed data
  - High-speed data channels ***allocated on a burst-by-burst basis***
  - Raw rates of 19.2, 38.4, 76.8, and 153.6 kbps and higher
  - ***Independent*** Forward and reverse supplemental channel rates
  - Airlink Dormant State is supported
  - voice on fundamental channel possible while dormant!
- Signaling can be either on
  - Fundamental Channel (FCH) [bearer profile P1], or
  - Dedicated Control (DCCH) [bearer profile P2]
  - using a new 4 state MAC protocol to increase efficiency
- Reverse Pilot Channel (RPCH) provides extra link budget margin
- Fast Forward Power Control
  - From old IS-95 max of 50 Hz to new constant 800 Hz!
- Enhanced Access Channels increase occupancy, more efficient

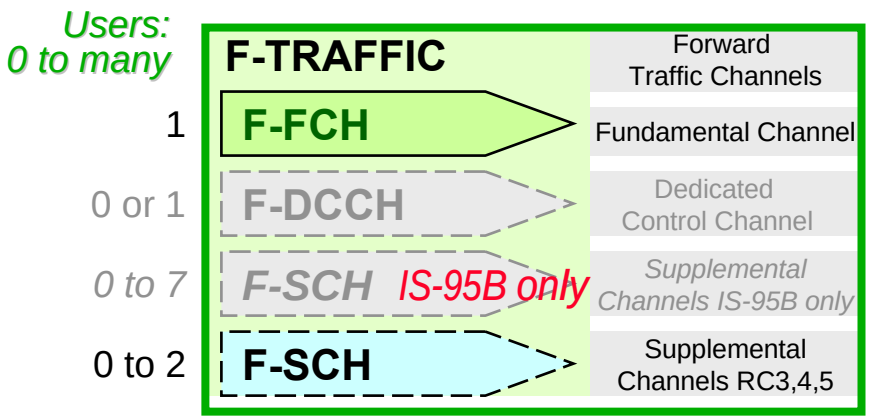
CDMA2000 SR1 CDMA Channels



- Not all of these channels will be implemented immediately, and some may not be supported in commercial use any time soon.
- All are defined in the Standard and have useful purposes and advantages

The Channels at Phase One 1xRTT Launch



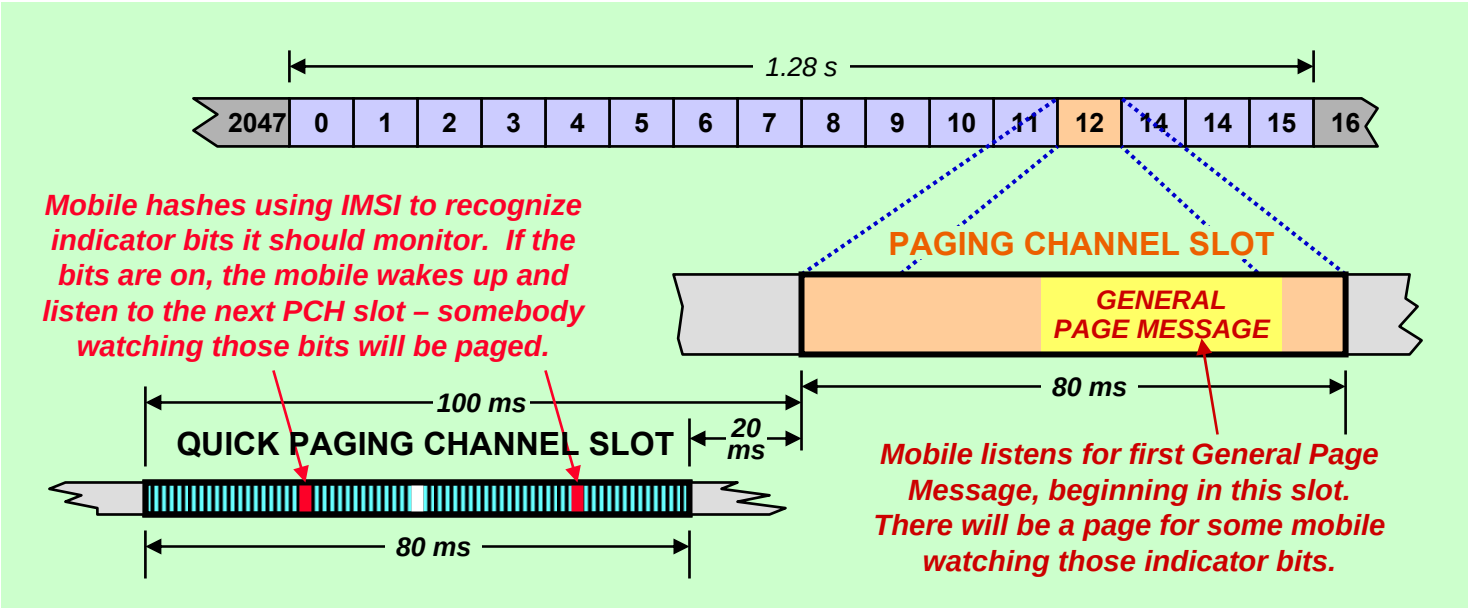


- At initial 1xRTT launch, many IS-95 mobiles will still exist
- IS-95 mobiles still get config. info. on the existing channel
- F-BCH, F-CPCCH, F-CACH, F-CCCH and F-DCCH will be implemented later on carriers for 1xRTT mobiles only

CDMA2000 1xRTT Forward Control Channels

- The Forward channels can be a mix of old IS-95B and new CDMA2000
  - the wireless Operator can choose which channels to implement
- First-Phase Implementation, serving IS-95 and CDMA2000 mobiles:
  - F-Pilot and F-Sync same as IS-95B (+updated Sync message)
  - Paging channel same as IS-95B (incl. config., orders, assignments)
  - Optional: F-QPCH quick paging channel ‘flags’ for better battery life
- Second-Phase Implementation, serving only CDMA2000 mobiles:
  - F-Pilot and F-Sync identical to IS-95B (+updated Sync message)
  - Paging channel now carries ONLY pages
  - F-BCH carries configuration
  - F-CCCH common control channel carries orders & assignments
  - F-QPCH quick paging ‘flags’ for deeper mobile sleep, longer battery
  - F-CPCCH common power control channel: more ‘polite’ access
  - F-CACH common assignment channel for improved access

F-QPCH: The Quick Paging Channel



- The Quick Paging Channel indicator bits tell 1xRTT mobiles whether they need to wake up during the next Paging Channel slot
- Each sector can have up to three F-QPCH walsh codes assigned
  - Walsh Code 80 (128-bit) (if there is only one, this must be it)
  - Walsh Code 48 (128-bit) (this must be second, if used)
  - Walsh Code 112 (128-bit) (this must be third, if used)
- QPCH and PCH slots are 80 ms long; QPCH slots begin 100 ms before the corresponding PCH slot

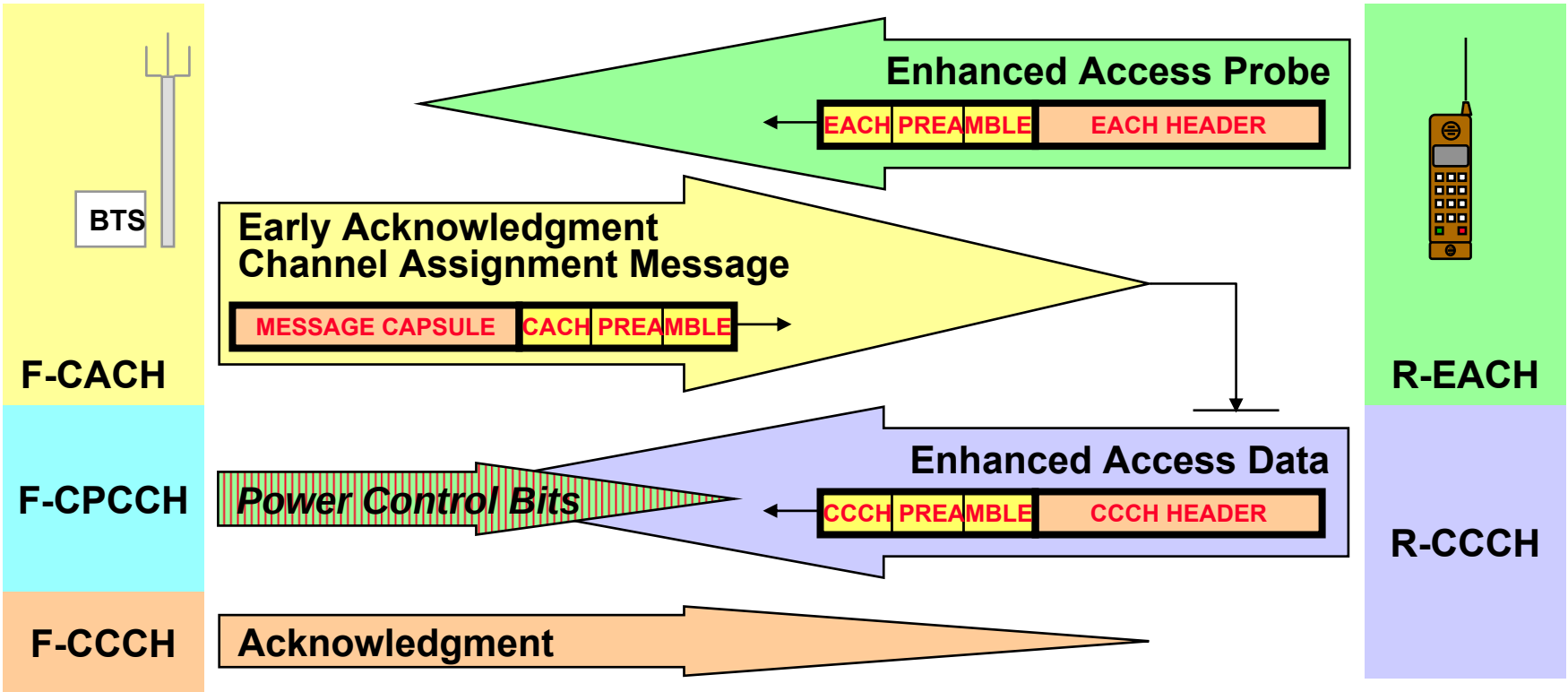
1xRTT Access Procedures

- IS-2000 adds two new Access methods, for three ways to access:
- Basic Access Mode:
  - (Existing Aloha Method from IS-95)
  - there's no closed-loop power control
  - Mobiles may transmit on top of each other
  - Mobile Power control is by repeated trial and error
  - Accessing mobiles sometimes transmit louder than necessary



- Power Controlled Aloha Mode
  - The mobiles' R-ACH is power controlled by the new F-CPCCH
  - Better power control, but still collisions happen sometimes
- Power Controlled Reservation Mode
  - The mobiles' R-CCCH channel is Power Controlled
  - Access to system on R-CCCH is Reservation-based (no collisions)
  - This Maximizes feasible occupancy level of access channels

Power Controlled Reservation Access Mode

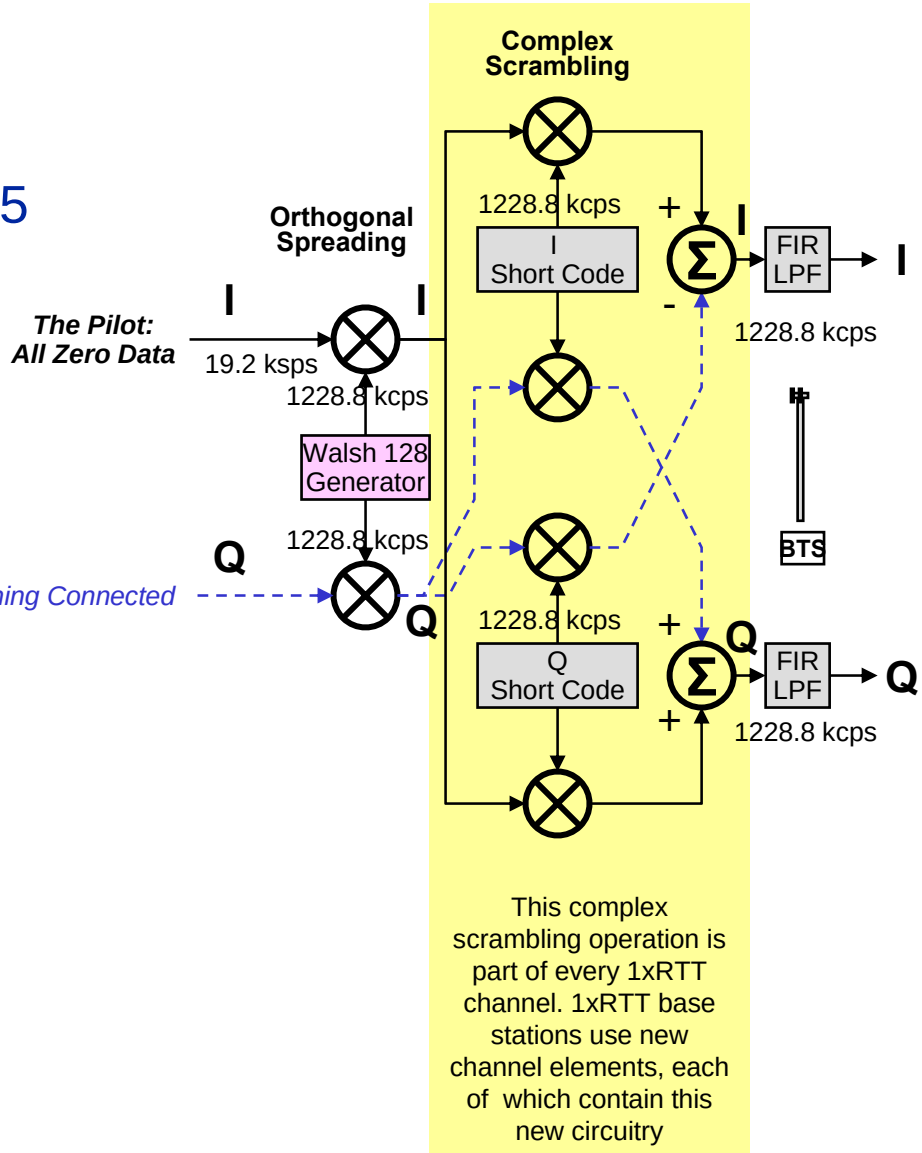


- Reservation Access Mode procedures:
  - On R-EACH, mobile asks permission to transmit
  - The associated F-CACH gives permission
  - Mobile transmits on R-CCCH during scheduled slot
  - F-CPCCH gives power control during R-CCCH transmission
  - F-CCCH gives acknowledgment and TCH assignment, if needed

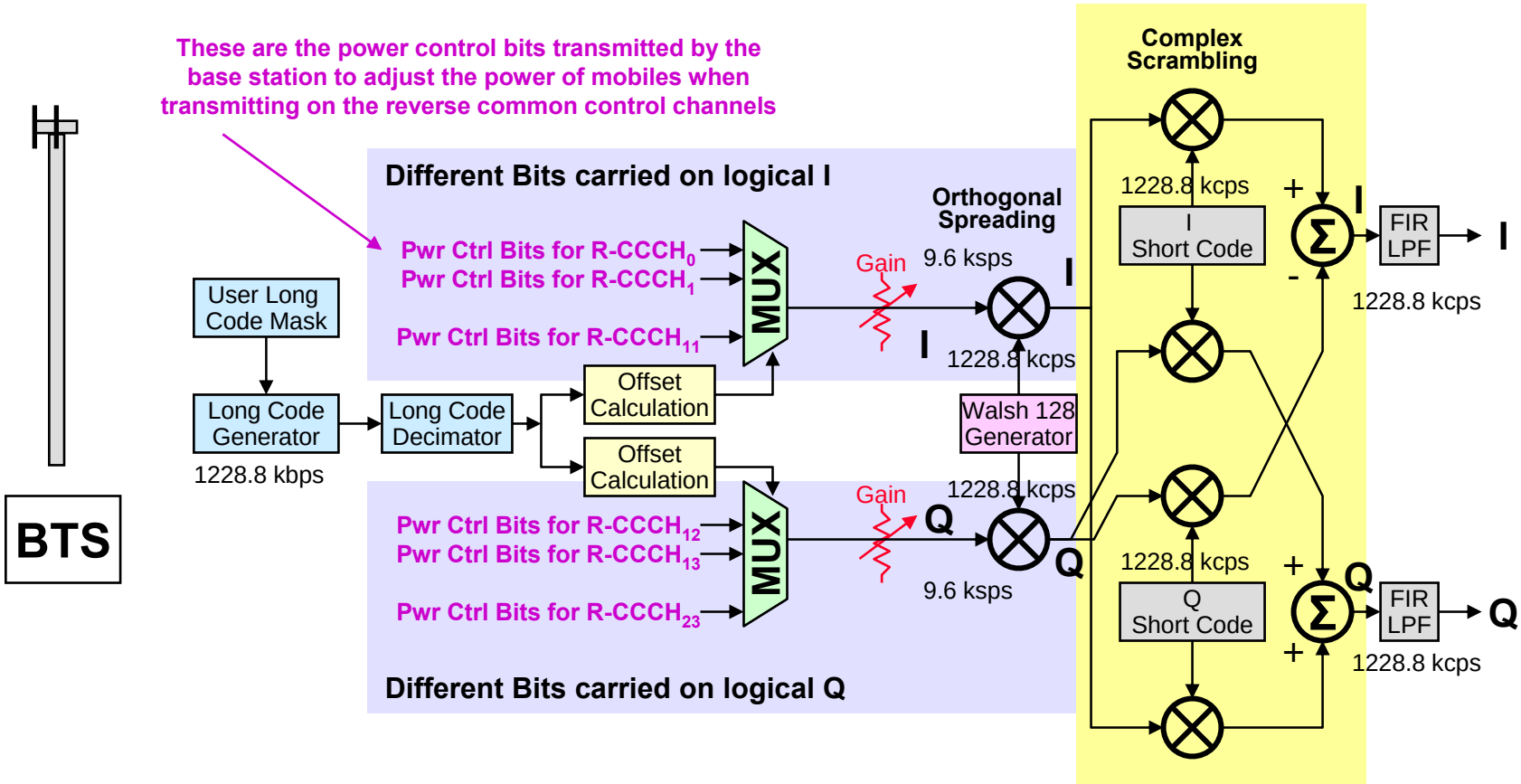
How 1xRTT Forward Channels are Coded

How 1xRTT Channel Elements make the Old-Fashioned IS-95 Pilot

- The backward-compatible IS-95 Pilot, Sync, and Paging Channels are applied to the I channel of the complex short code spreader.
- No input is applied to the Q channel
- This produces parallel BPSK modulation for these channels just like IS-95

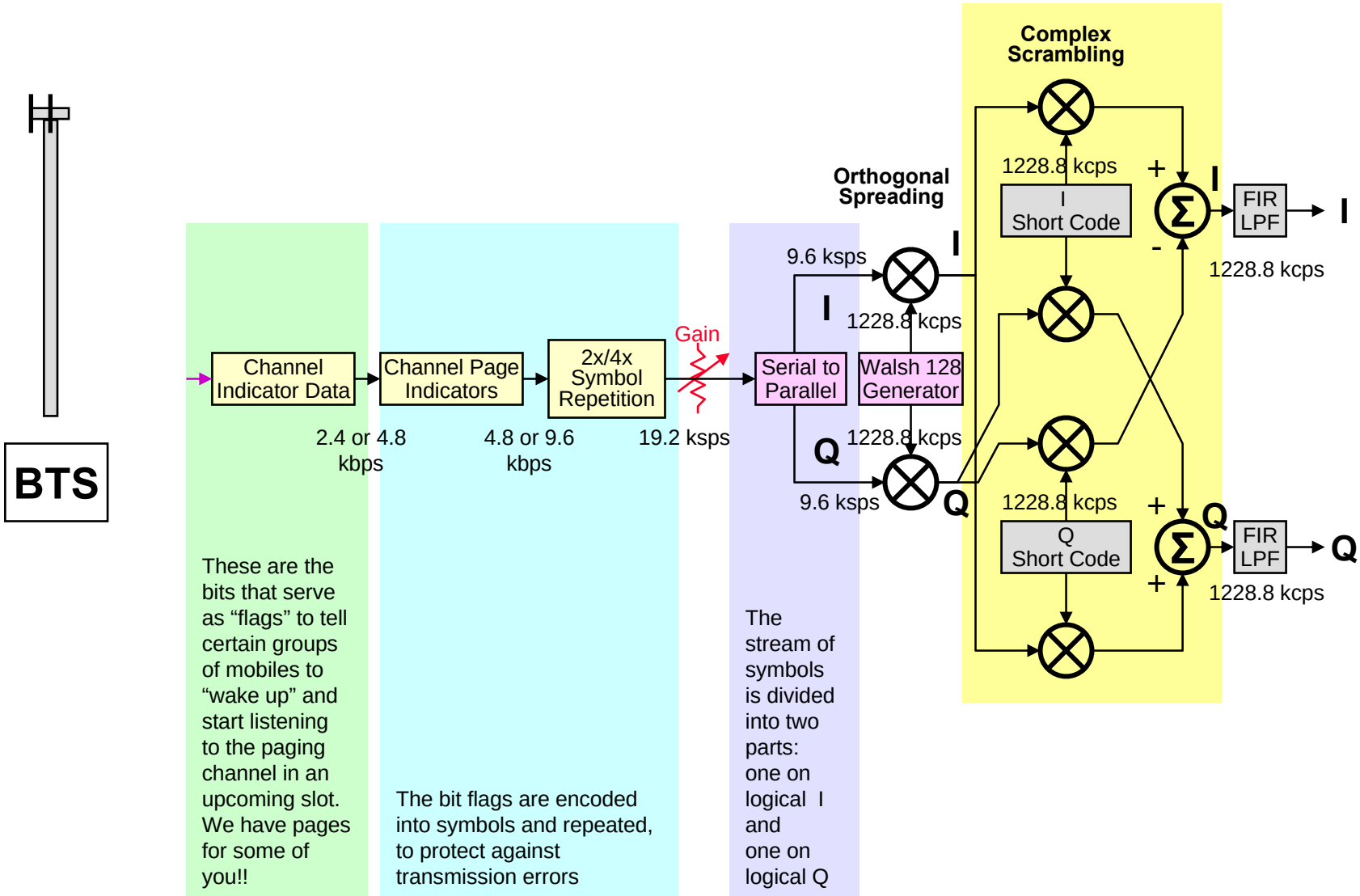


CPCCH: 1xRTT Common Power Control Channel

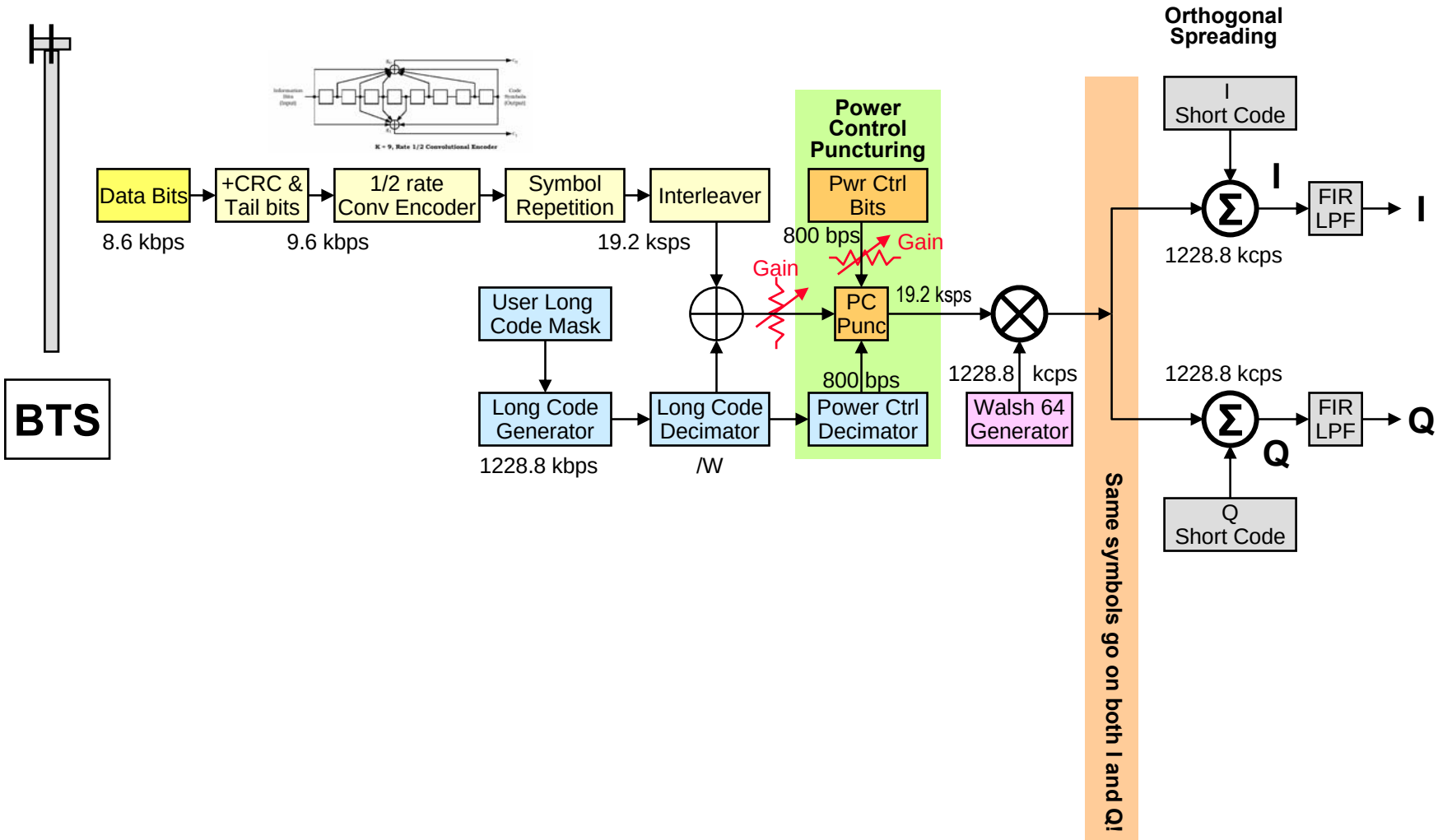


- No convolutional or turbo coding is used on the power control data
- Time offset of each power control subchannel is determined by the long code offset of the reverse channel of the associated mobile

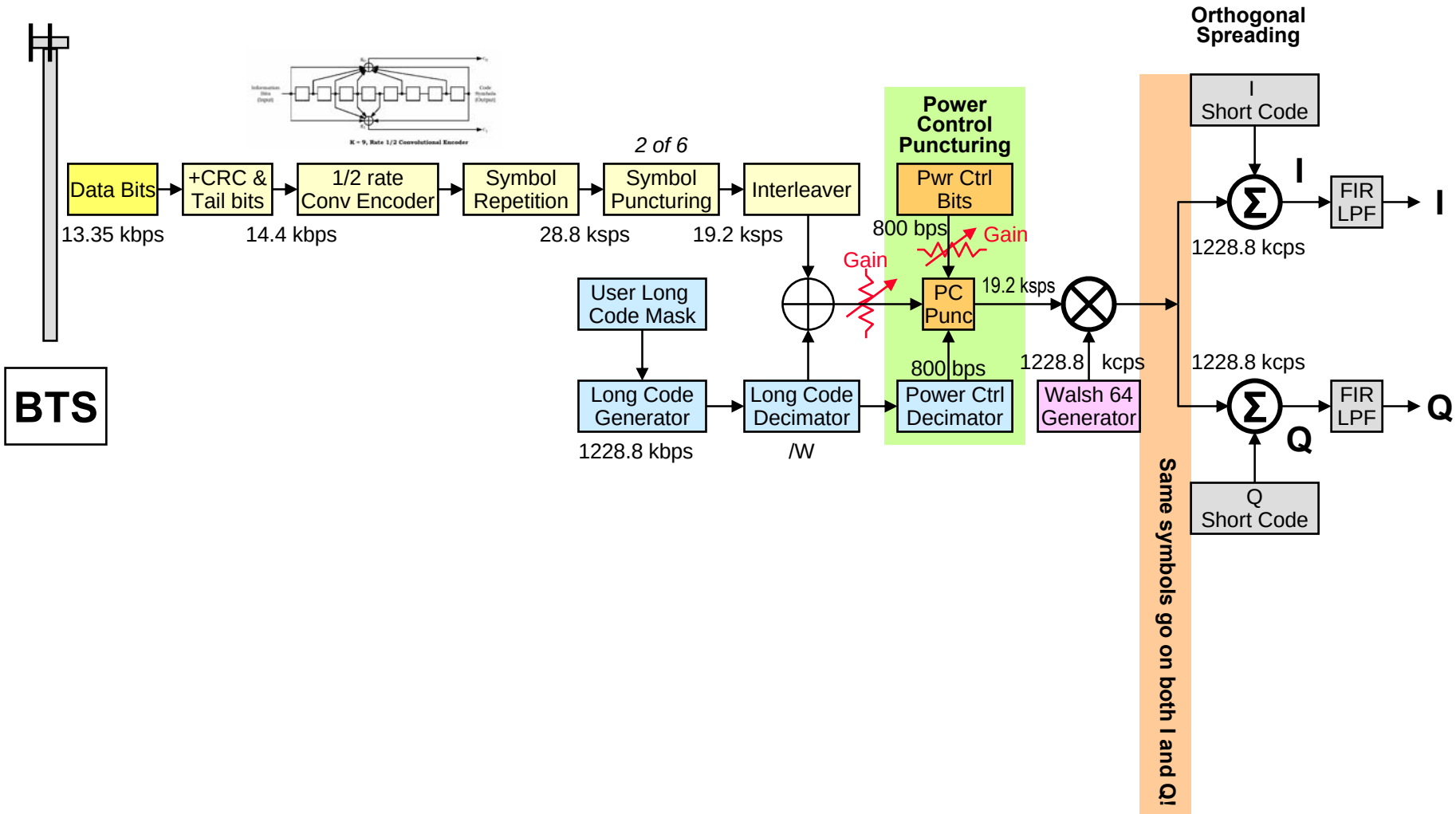
QPCH – the 1xRTT Quick Paging Channel



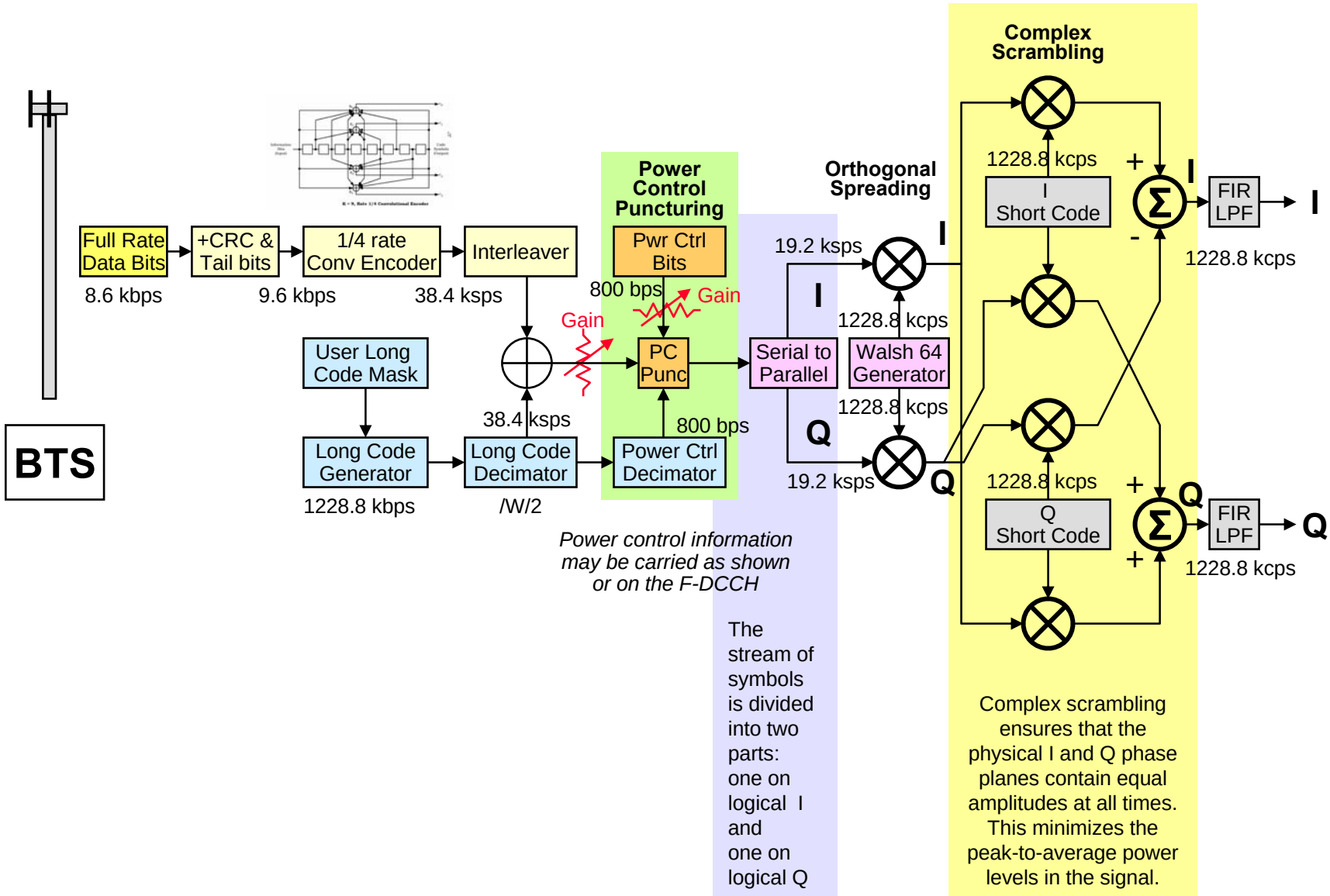
SR1, RC1 9,600 bps F-FCH (IS-95-Compatible)



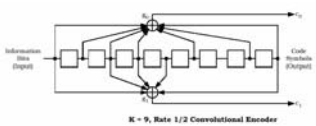
SR1, RC2 14,400 bps F-FCH (IS-95-Compatible)



SR1, RC3 F-FCH (9,600 bps)



SR1, RC4 F-FCH (9,600 bps)



BTS

Full Rate Data Bits
8.6 kbps

+CRC & Tail bits
9.6 kbps

1/2 rate Conv Encoder
19.2 ksps

Interleaver

User Long Code Mask

Long Code Generator
1228.8 kbps

Long Code Decimator
/W/2

19.2 ksps

Power Control Puncturing

Pwr Ctrl Bits
800 bps

Gain

Gain

PC Punc

Power Ctrl Decimator
800 bps

Power control information may be carried as shown or on the F-DCCH

Orthogonal Spreading

Serial to Parallel

9.6 ksps

I

Q

9.6 ksps

Walsh 128 Generator

1228.8 kcps

1228.8 kcps

I

Q

Complex Scrambling

1228.8 kcps

I Short Code

1228.8 kcps

Q Short Code

+

-

Σ

I

FIR LPF

I

1228.8 kcps

+

+

Σ

Q

FIR LPF

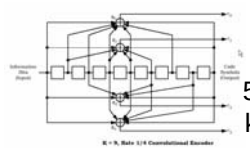
Q

1228.8 kcps

The stream of symbols is divided into two parts: one on logical I and one on logical Q

Complex scrambling ensures that the physical I and Q phase planes contain equal amplitudes at all times. This minimizes the peak-to-average power levels in the signal.

SR1, RC5 F-FCH (14.4 kbps)



57.6 ksps

Full Rate Data Bits → +CRC & Tail bits → 1/4 rate Conv Encoder → Puncture 4/12 → Interleaver

13.35 kbps | 14.4 kbps | 38.4 ksps

Power Control Puncturing

Pwr Ctrl Bits — 800 bps — Gain

Gain

User Long Code Mask → Long Code Generator → 1228.8 kbps

Long Code Decimator — /W/2 — 38.4 ksps

Power Ctrl Decimator — 800 bps

PC Punc

Serial to Parallel

Orthogonal Spreading

Walsh 64 Generator — 1228.8 kcps

19.2 ksps | I | Q | 19.2 ksps

Complex Scrambling

1228.8 kcps — I Short Code — 1228.8 kcps

1228.8 kcps — Q Short Code — 1228.8 kcps

Σ → FIR LPF → I

Σ → FIR LPF → Q

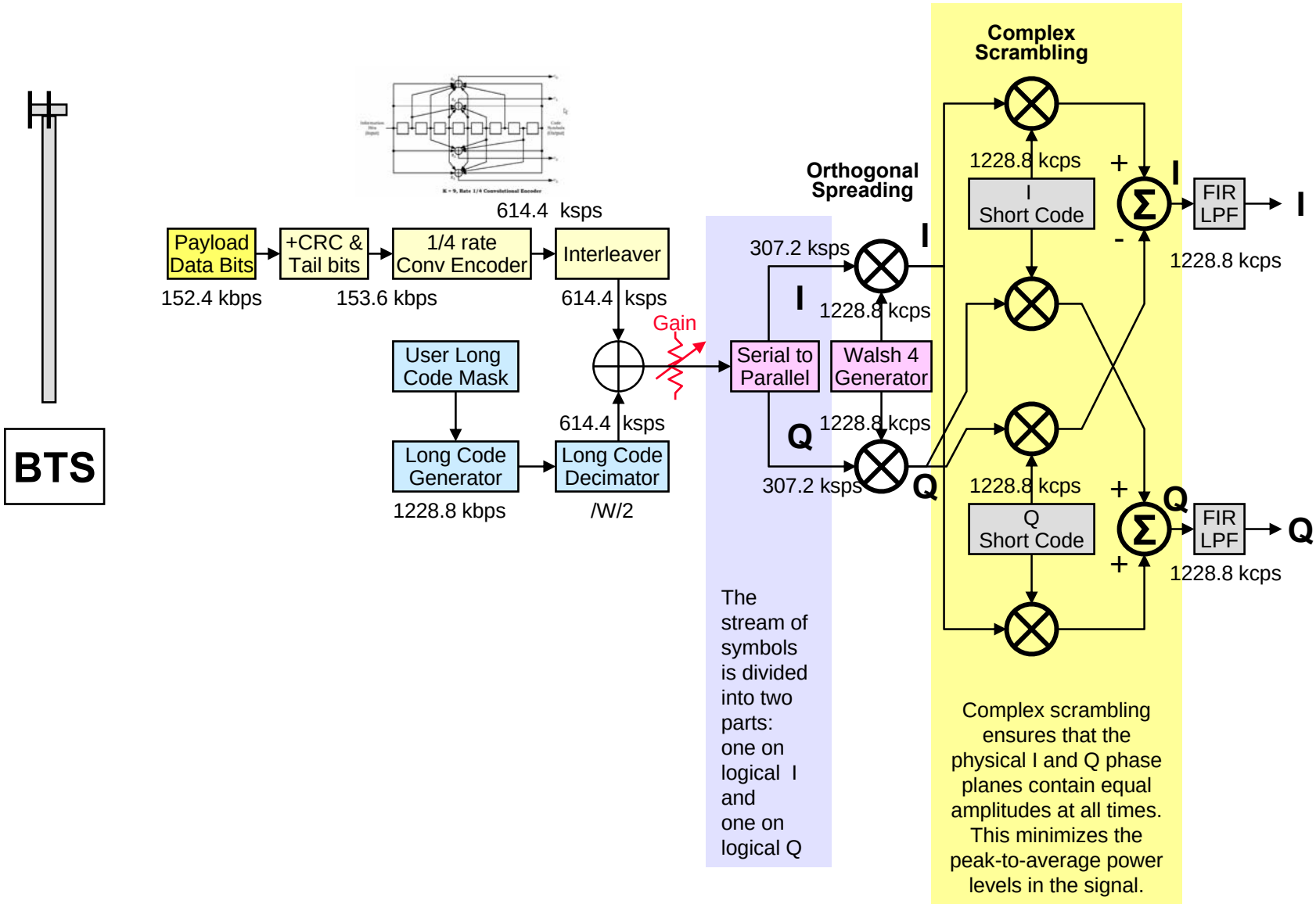
BTS

Power control information may be carried as shown or on the F-DCCH

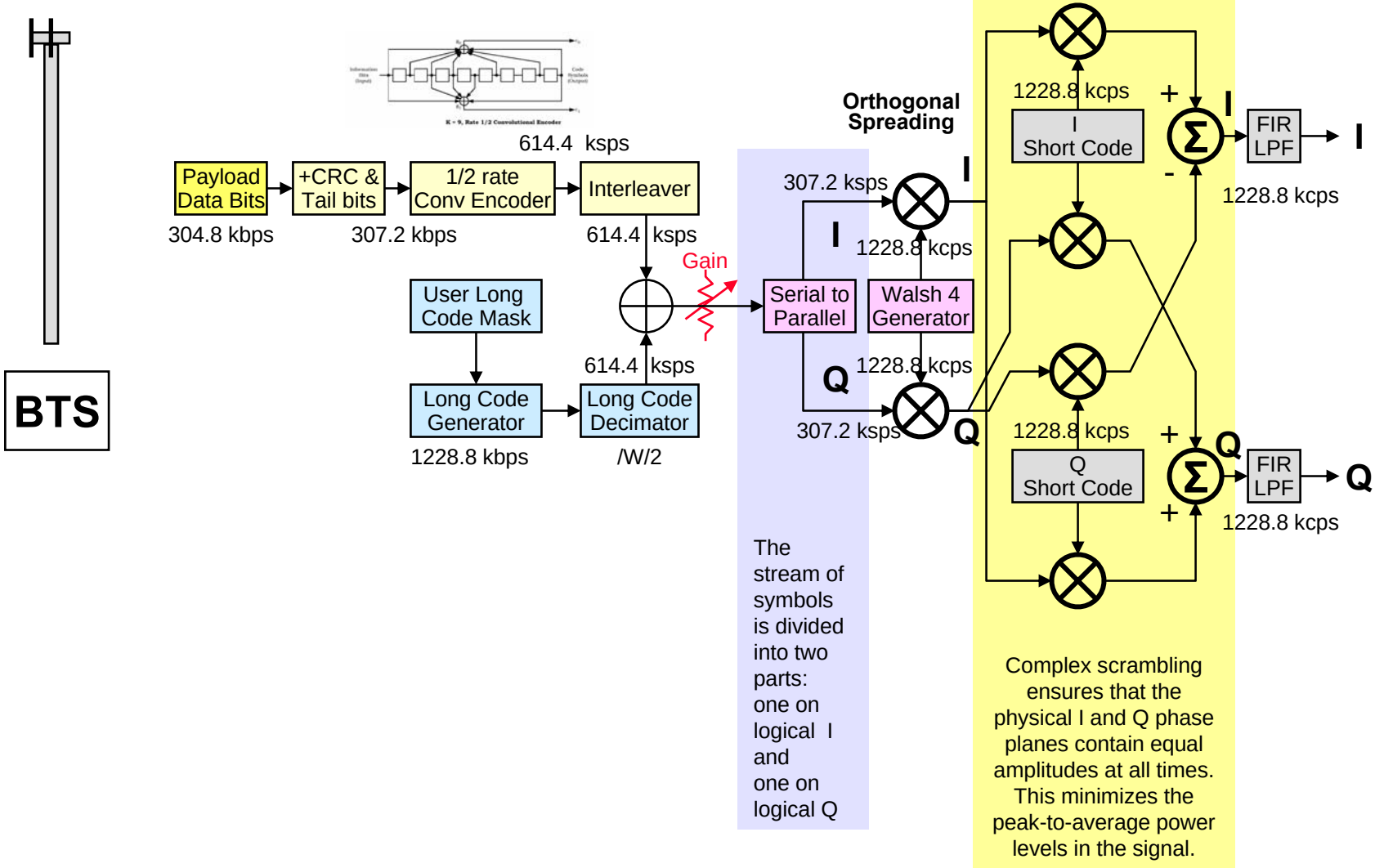
The stream of symbols is divided into two parts: one on logical I and one on logical Q

Complex scrambling ensures that the physical I and Q phase planes contain equal amplitudes at all times. This minimizes the peak-to-average power levels in the signal.

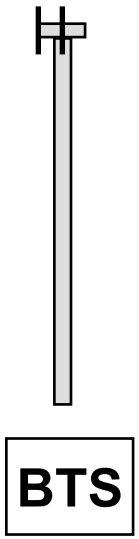
SR1, RC3 F-SCH (153,600 bps)

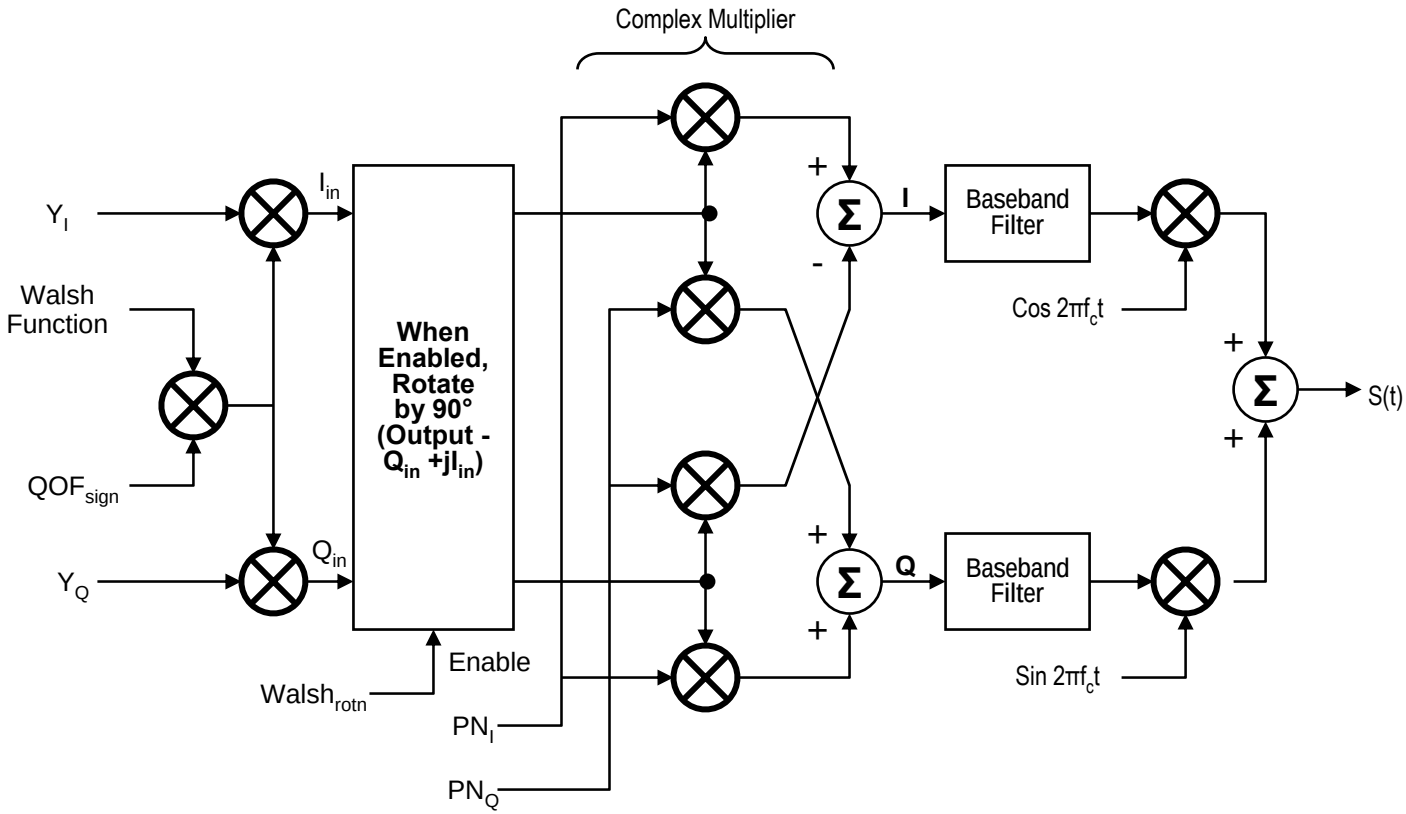


SR1, RC4 F-SCH (307,200 bps)



SR1 Forward Channel Complex Spreading





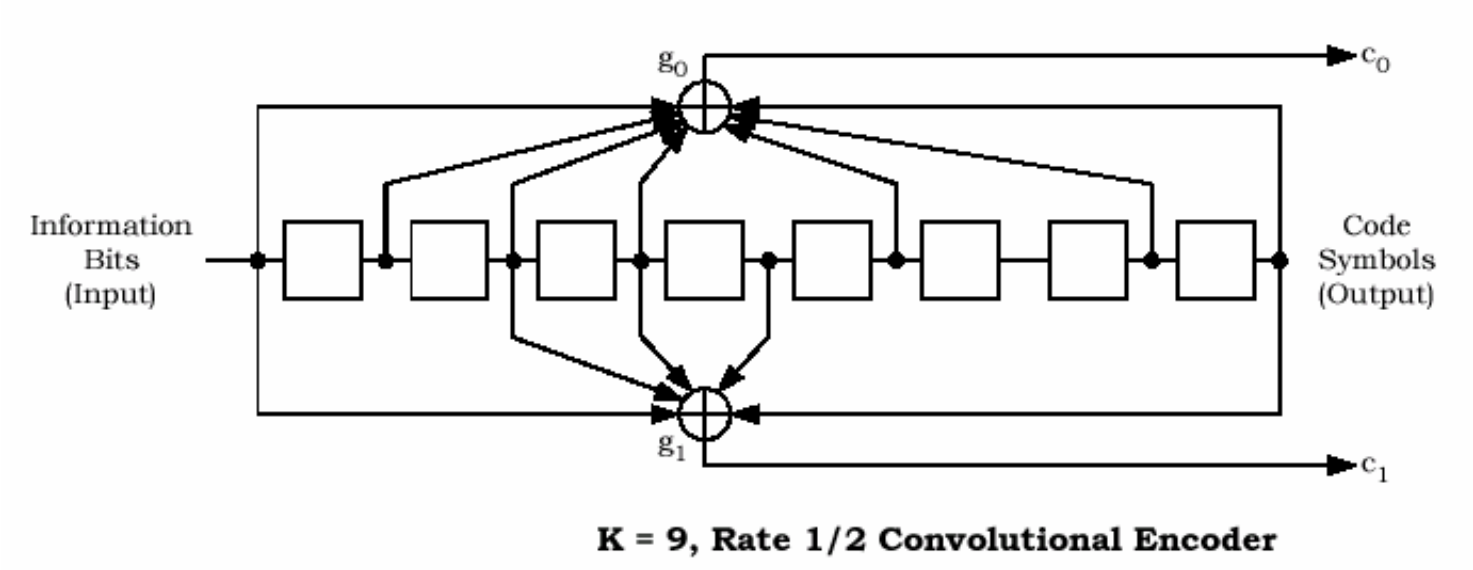
Walsh function = ±1 (mapping: '0'⇒+1, '1' ⇒-1)
QOF_{sign}= ±1 sign multiplier QOF mask (mapping: '0'⇒+1, '1' ⇒-1)
$Walsh_{rot}$ = '0' or '1' 90°-rotation-enable Walsh function
$Walsh_{rot}$ = '0' means no rotation
$Walsh_{rot}$ = '1' means rotate by 90°
The null QOF has QOF_{sign} = +1 and $Walsh_{rot}$ = '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

Channel Coding for Protection: Convolutional and Turbo Codes

Data Protection: Convolutional vs. Turbo Coding

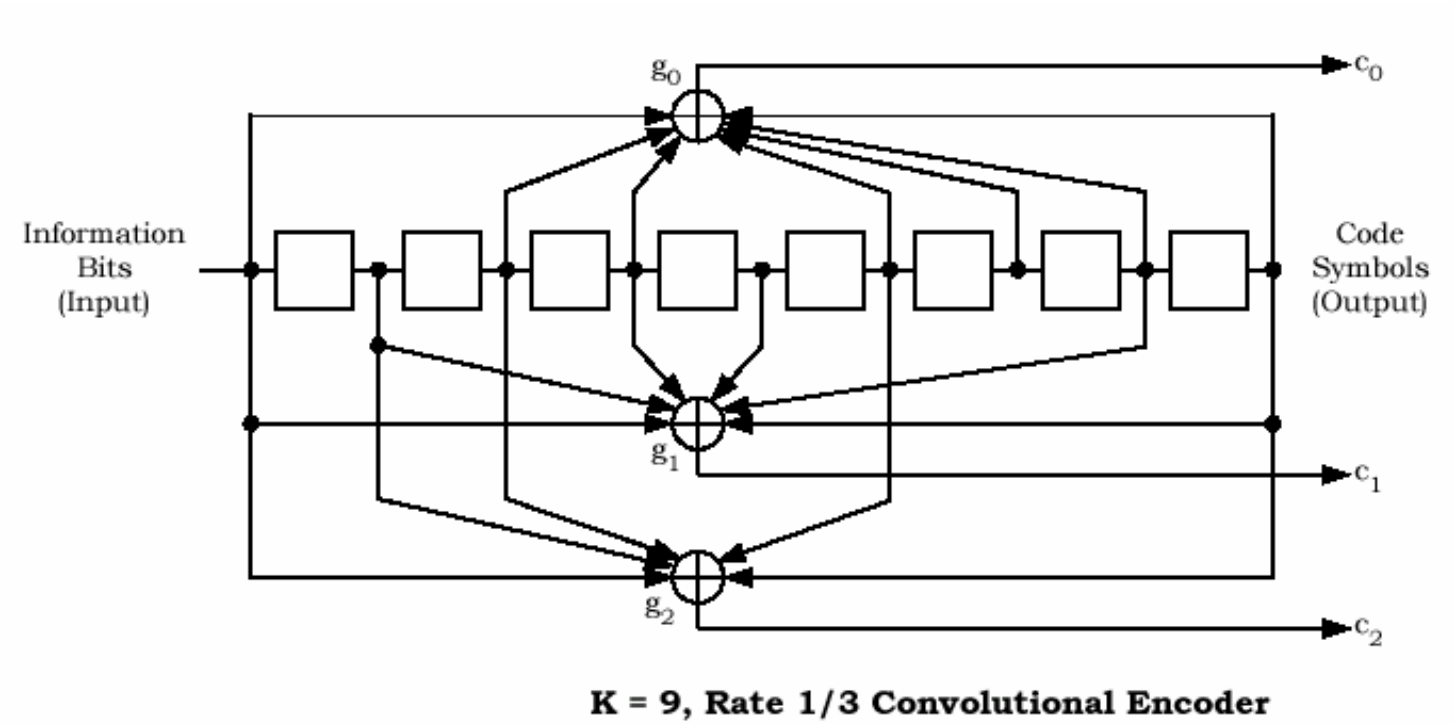
- In CDMA, bits are protected against transmission errors using channel coding, turning them into symbols before transmission. After reception, the decoding process to recover the bits is highly tolerant of bad symbols. The correct bits can be recovered despite symbol errors
- Many different channel 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, there is only one chance to pass the voice frames through. We adjust the power of voice channels trying to achieve an FER of about 1% or 2%; anything higher produces gives bad-sounding speech.
- Data applications are more forgiving of lost frames. The main objective is throughput: a few bad frames can be retransmitted to fix errors, and throughput remains nearly as good as before.
- Turbo coders are a class of coders that work better for larger groups of symbols, such as our large frames high CDMA2000 data rates
  - Their design is experimental; optimal algorithms are not yet known
- CDMA2000 gets its best results using a mixed selection of coding types:
  - Adjust voice channel powers to achieve target 1-2% FER; use Convolutional coders
  - Adjust data channel powers at approx. 5% FER with Turbo coding, using packet retransmission to correct lost frames

Rate ½, K=9 Convolutional Coder



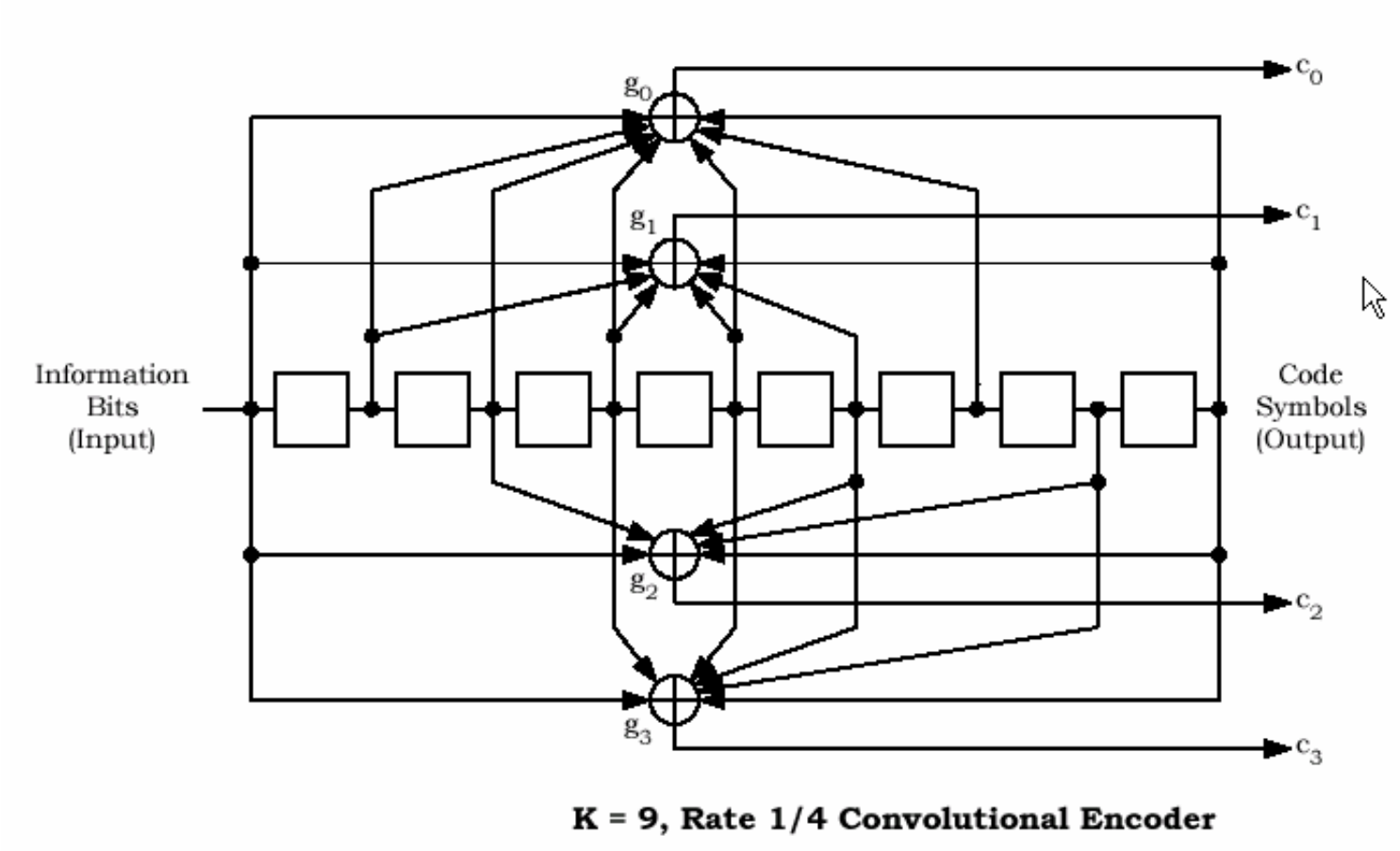
K = 9, Rate 1/2 Convolutional Encoder

Rate $^1/_3$, K=9 Convolutional Coder

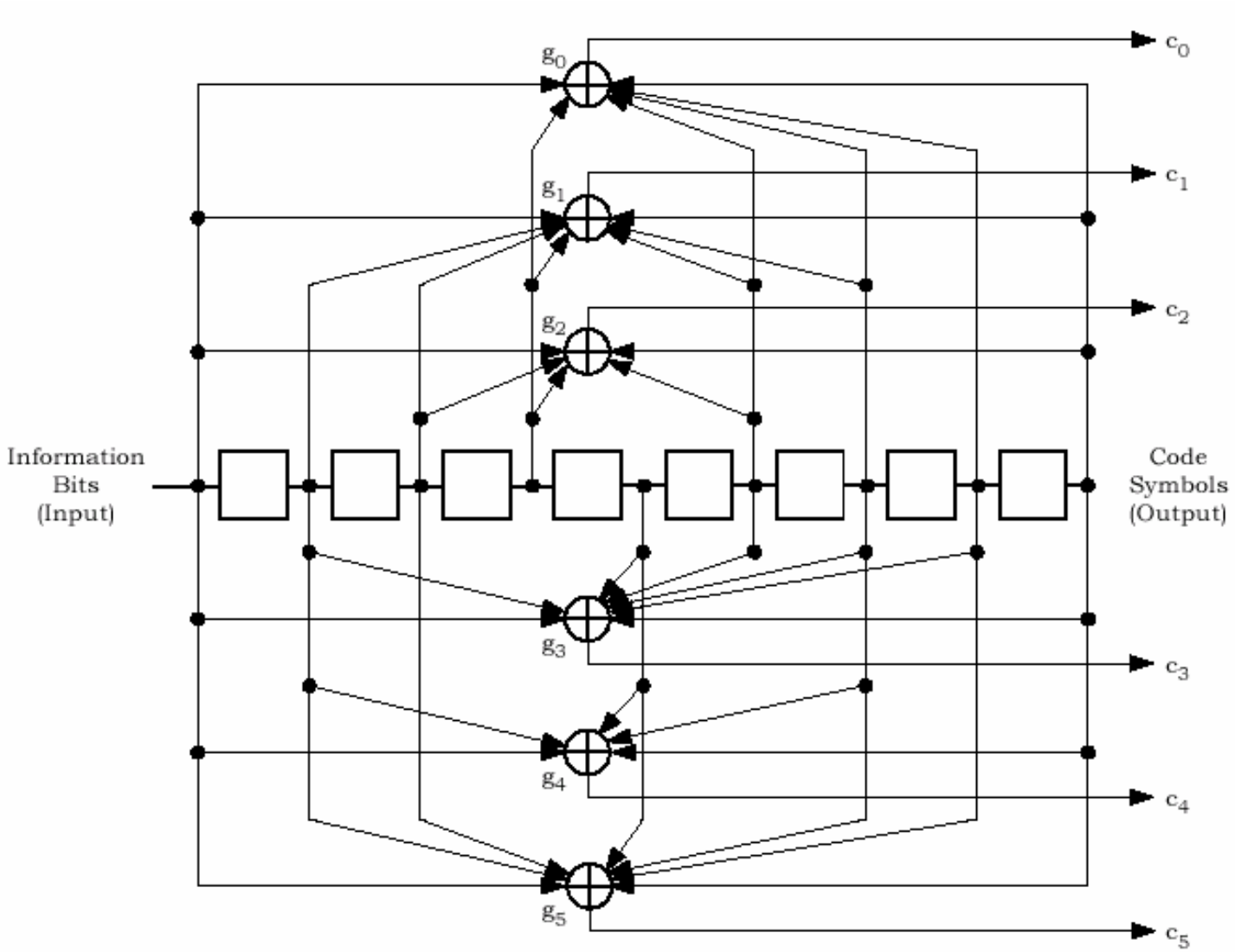


K = 9, Rate 1/3 Convolutional Encoder

Rate ¼, K=9 Convolutional Coder



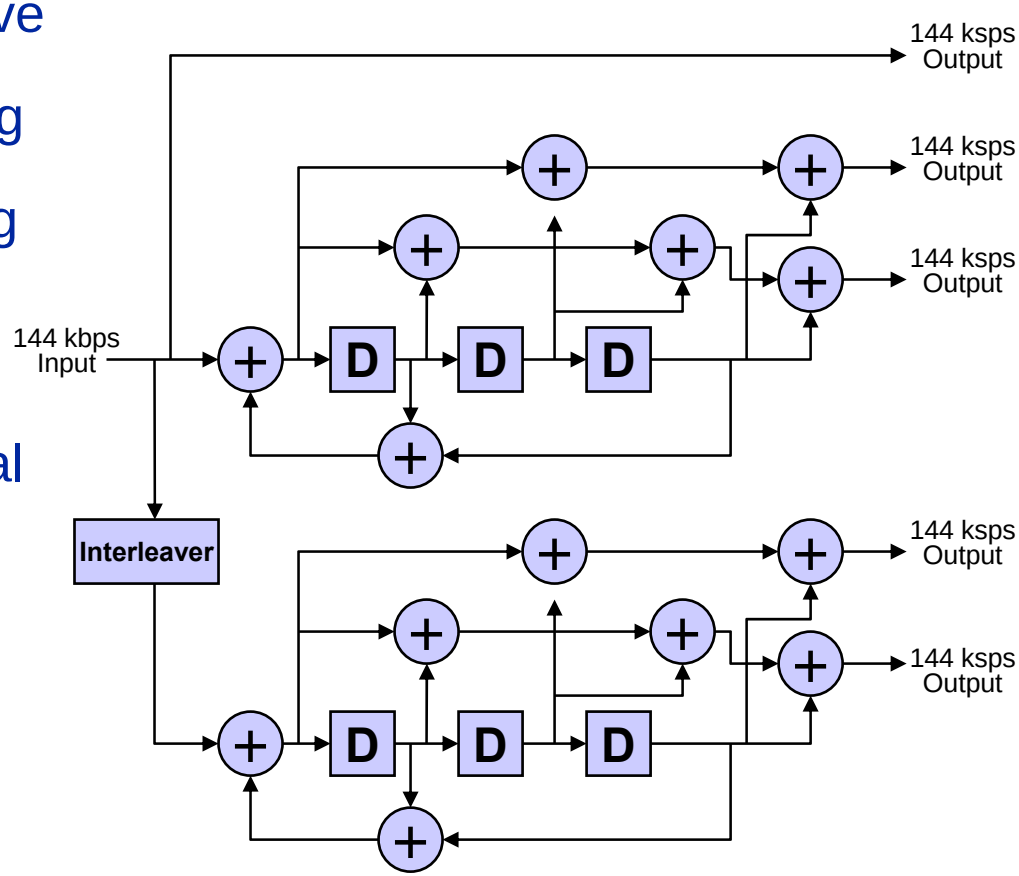
Rate $^1/_6$, K=9 Convolutional Coder

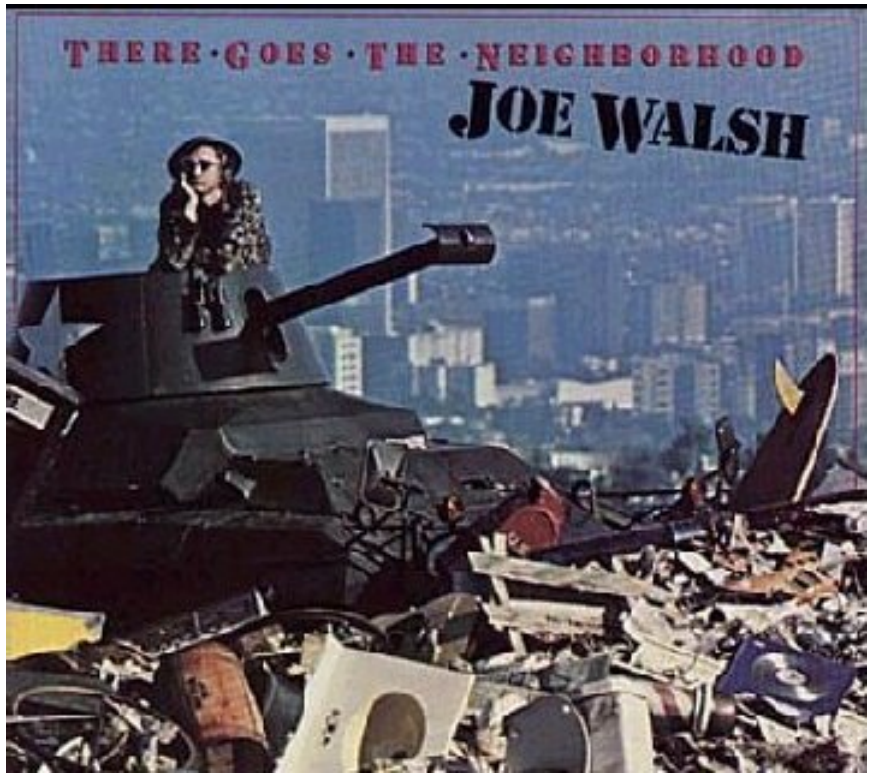


K = 9, Rate 1/6 Convolutional Encoder

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





CDMA2000

Walsh in the Fast Lane

(Supplemental Channels F-SCH & R-SCH, that is)

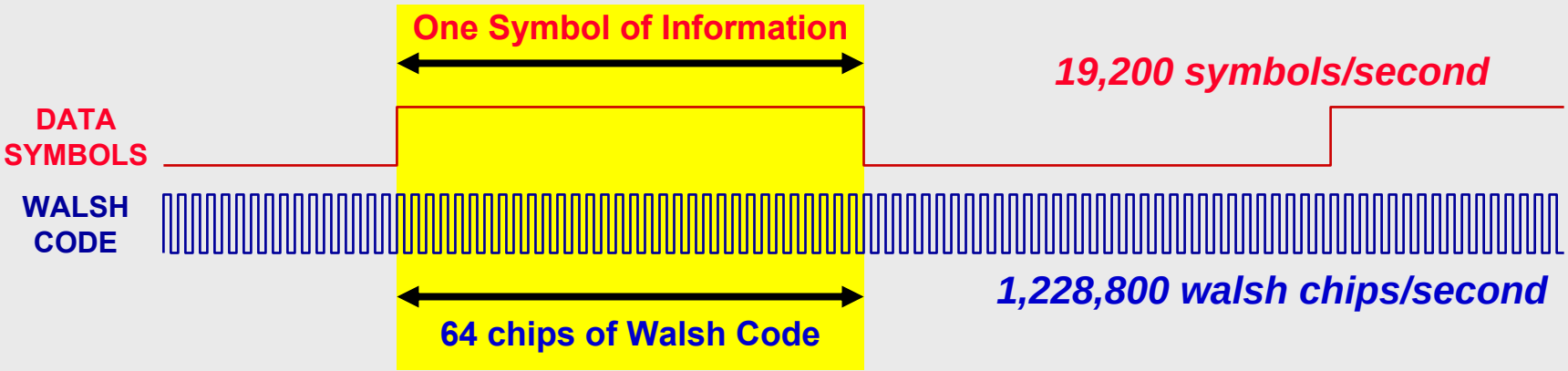
Disclaimer: Any relationship perceived between Joe Walsh and any Walsh Codes living or dead is purely Orthogonal.

Faster Data, Shorter Walsh Codes, Complications

- New cdma2000 channels operate at substantially faster data rates than current IS-95 channels
- These faster symbol rates require shorter Walsh codes, so the Walsh codes can occur as rapidly as the symbols being transmitted
- It's worth a re-visit to the basics of Walsh codes to understand the implications of this change
  - Shorter faster Walsh codes do carry faster symbols, but with less spreading gain
  - When a Walsh code of a particular length is in use, none of its descendents (longer lengths) or its ancestors (shorter lengths) can be used for any other purpose
  - With so many Walsh codes in use and so many new channels, we must even face the possibility we'll run out and have to use other codes to carry any additional traffic

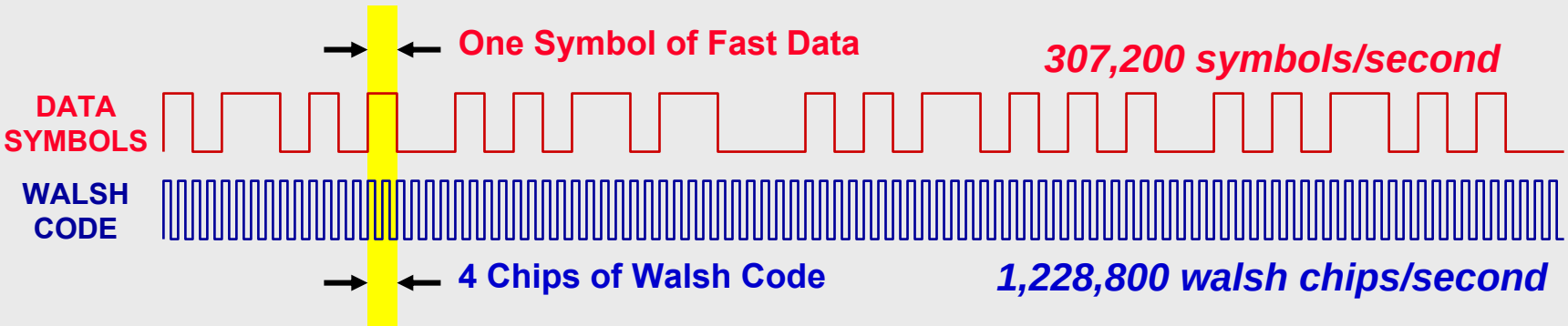
Walsh Codes in 1xRTT

2G VOICE AND DATA



Data Rates are different, but
Chip Rates must stay the same!

3G 153.6 kb/s DATA



The Famous Walsh Codes from IS-95 Days

- 64 “Magic” Sequences, each 64 chips long
- Each Walsh Code is precisely Orthogonal with respect to all other Walsh Codes and their opposites too!
  - it’s simple to generate the codes, or
  - they’re small enough to use from ROM

Unique Properties:
Mutual Orthogonality

EXAMPLE:

Correlation of Walsh Code #23 with Walsh Code #59

```
#23   01101001011010011001011010010110011010010110100110010110100101 10
#59   01100110100110011001100101100110100110010110011001100101100110 01
Sum   00001111111110000000011111111100001111000000001111111100000000 1111
```

Correlation Results: 32 1’s, 32 0’s: Orthogonal!!

WALSH CODES

#	64-Chip Sequence
0	0000000000000000000000000000000000000000000000000000000000000000
1	0101010101010101010101010101010101010101010101010101010101010101
2	0011001100110011001100110011001100110011001100110011001100110011
3	0110011001100110011001100110011001100110011001100110011001100110
4	0000111100001111000011110000111100001111000011110000111100001111
5	0101101001011010010110100101101001011010010110100101101001011010
6	0011111000111100001111000011110000111100001111000011110000111100
7	0110100101101001011010010110100101101001011010010110100101101001
8	0000000011111111000000001111111100000000111111110000000011111111
9	0101010110101010010101011010101001010101101010100101010110101010
10	0011001111001100001100111100110000110011110011000011001111001100
11	0110011010011001101100110100110010110011010011001011001101001101
12	0000111111110000000011111111000000001111111100000000111111110000
13	0101101010100101010110101010010101101010100101010110101010100101
14	0011110011000011001111001100001100111100110000110011110011000011
15	0110100110010110011010011001011001101001100101100110100101100110
16	0000000000000000111111111111111100000000000000001111111111111111
17	0101010101010101101010101010101001010101010101011010101010101010
18	0011001100110011110011001100001100110011001111000011001100110011
19	0110011001100110100110011001101001100110011010010110011001101001
20	0000111100001111111100001111000000001111000011111111000011110000
21	0101101001011010100101101001010110100101101001011010101001011010
22	0011110000111100110000111100001100111100001111001100001111000011
23	0110100101101001100101101001011001101001011010011001011010010110
24	0000000011111111111111110000000000000000111111111111111100000000
25	0101010110101010101010100101010101010101101010101010101001010101
26	0011001111001100110011000011001100110011110011001100110000110011
27	0110011010011001100110010110011001100110100110011001101011001100
28	0000111111110000111100000000111100001111111100000111100000000111
29	0101101010100101101001010101101001011010101001011010010101011010
30	0011110011000011110000110011110000111100110000111100001100111100
31	0110100110010110100101100110100101101001100101101001011001101001
32	0000000000000000000000000000000011111111111111111111111111111111
33	0101010101010101010101010101010110101010101010101010101010101010
34	0011001100110011001100110011001111001100110011001100110011001100
35	0110011001100110011001100110011001100110011001100110011001100110
36	0000111100001111000011110000111111110000111100001111000011110000
37	0101101001011010010110100101101001011010010110100101101001011010
38	0011110000111100001111000011110011000011110000111100001111000011
39	0110100101101001011010010110100110010110100101101001011010010110
40	0000000011111111000000001111111111111111000000001111111100000000
41	0101010110101010010101011010101010101010010101011010101001010101
42	0011001111001100001100111100110011001100001100111100110000110011
43	0110011010011001011001101001100110010110011010011001011001101001
44	0000111111110000000011111111000011110000000111111110000000011111
45	0101101010100101010110101010010110100101011010101001010110101010
46	0011110011000011001111001100001111000011001111000011001111001100
47	0110100110010110011010011001011010010110011010011001011001101001
48	0000000000000000111111111111111111111111111111110000000000000000
49	0101010101010101101010101010101010101010101010101010101010101010
50	0011001100110011110011001100110011001100110011000011001100110011
51	0110011001100110100110011001101001100110011001011001100110011001
52	0000111100001111111100001111000011110000111100000000111100001111
53	0101101001011010101001011010010110100101101001010110100101011010
54	0011110000111100110000111100001111000011110000111100001100111100
55	0110100101101001100101101001011010010110100101100110100101101001
56	0000000011111111111111110000000011111111000000000000000011111111
57	0101010110101010101010010101011010101001010101010101011010101010
58	0011001111001100110011000011001111001100001100111100110000111001
59	0110011010011001100110010110011001100101100110011001101001101001
60	0000111111110000111100000000111111110000000011110000111111110000
61	0101101010100101101001010101101010100101010110100101101010010101
62	0011110011000011100001100111100110000110011110000111100110000011
63	0110100110010110100101100110100110010110011010010110100110010110

Families of the Walsh Codes

WALSH (1-Chip)

#	1-Chip
0	0

WALSH (2-Chips)

#	2-Chips
0	00
1	01

2x2

WALSH (4-Chips)

#	4-Chips
0	0000
1	0101
2	0011
3	0110

4x4

WALSH (8-Chips)

#	8-Chips
0	00000000
1	01010101
2	00110011
3	01100110
4	00001111
5	01011010
6	00111100
7	01101001

8x8

WALSH (16-Chips)

#	---- 16-Chips -------
0	0000000000000000
1	0101010101010101
2	0011001100110011
3	0110011001100110
4	0000111100001111
5	0101101001011010
6	0011110000111100
7	0110100101101001
8	0000000011111111
9	0101010110101010
10	0011001111001100
11	0110011010011001
12	0000111111110000
13	0101101010100101
14	0011110011000011
15	0110100110010110

16x16

WALSH CODES (32-Chip Sequence)

#	---------- 32-Chip Sequence ----------
0	00000000000000000000000000000000
1	01010101010101010101010101010101
2	00110011001100110011001100110011
3	01100110011001100110011001100110
4	00001111000011110000111100001111
5	01011010010110100101101001011010
6	00111100001111000011110000111100
7	01101001011010010110100101101001
8	00000000111111110000000011111111
9	01010101101010100101010110101010
10	00110011110011000011001111001100
11	01100110100110010110011010011001
12	00001111111100000000111111110000
13	01011010101001010101101001010101
14	00111100110000110011110011000011
15	01101001100101100110100110010110
16	00000000000000001111111111111111
17	01010101010101011010101001010101
18	00110011001100111100110011001100
19	01100110011001101001100110011001
20	00001111000011111111000011110000
21	01011010010110101010010110100101
22	00111100001111001100001111000011
23	01101001011010011001011010010110
24	00000000111111111111111100000000
25	01010101101010101010101001010101
26	00110011110011001100001100110011
27	01100110100110011001101100110011
28	00001111111100001111000000001111
29	01011010100101011010010101011010
30	00111100110000111100001100111100
31	01101001100101101001011001101001

32x32

WALSH CODES (64-Chip Sequence)

#	---------- 64-Chip Sequence ----------
0	0000000000000000000000000000000000000000000000000000000000000000
1	0101010101010101010101010101010101010101010101010101010101010101
2	0011001100110011001100110011001100110011001100110011001100110011
3	0110011001100110011001100110011001100110011001100110011001100110
4	0000111100001111000011110000111100001111000011110000111100001111
5	0101101001011010010110100101101001011010010110100101101001011010
6	0011110000111100001111000011110000111100001111000011110000111100
7	0110100101101001011010010110100101101001011010010110100101101001
8	0000000011111111000000001111111100000000111111110000000011111111
9	0101010110101010010101011010100101010110101010010101011010101010
10	0011001111001100001100111100110000110011110011000011001111001100
11	0110011010011001011001101001100101100110100110010110011010011001
12	0000111111110000000011111111000000001111111100000000111111110000
13	0101101010100101010110100101010101011010010101010101101001010101
14	0011110011000011001111001100111100110000110011110011000011001111
15	0110100110010110011010011001011001101001100101100110100110010110
16	0000000000000000111111111111111100000000000000001111111111111111
17	0101010101010101101010100101010101010101011010101001010101010101
18	0011001100110011110011001100110000110011001111001100110011001100
19	0110011001100110011001100110011001100110011001100110011001100110
20	0000111100001111111100001111000000001111000011111111000011110000
21	0101101001011010101001011010010101101001011010101001011010010101
22	0011110000111100110000111100001100111100001111001100001111000011
23	0110100101101001100101101001011001101001011010011001011010010110
24	0000000011111111111111110000000000000000111111111111111100000000
25	0101010110101010101010010101010101010101101010101010101001010101
26	0011001110011001100001100110011001100110011001100001100110011001
27	0110011010011001100110011001100110011001101001100110011001011001
28	0000111111110000111100000000111100001111111100001111000000001111
29	0101101010010010110100101010110101001011010010101101001010101010
30	0011110011000011110000110011110000111100110000111100001100111100
31	0110100110010110100101100110100101100110100110010110100101100101
32	0000000000000000000000000000000011111111111111111111111111111111
33	0101010101010101010101010101010110101010101010101010101010101010
34	0011001100110011001100110011001111001100110011001100110011001100
35	0110011001100110011001100110011010011001100110011001100110011001
36	0000111100001111000011110000111111110000111100000111100001111000
37	0101101001011010010110100101101010100101101001011010010110100101
38	0011110000111100001111000011110011000011110000111100001111000011
39	0110100101101001011010010110100110010110100101101001011010010110
40	0000000011111111000000001111111111111111000000001111111100000000
41	0101010110101010010101011010101010101010010101011010101001010101
42	0011001110011000011001111001100110011000011001111001100000110011
43	0110011010011001011001101001100110011001101001100101100110011001
44	0000111111110000000011111111000011110000000011111111000000001111
45	0101101010100101010110101010010110100101010110101001010101011010
46	0011110011000011001111001100001111000011001111001100001100111100
47	0110100110010110011001100101100101100110100101100110010110100101
48	0000000000000000111111111111111111111111111111110000000000000000
49	0101010101010101101010101010101010101010101010010101010101010101
50	0011001100110011110011001100110011001100001100111100110000110011
51	0110011001100110100110011001100110011001100101100110011001100110
52	0000111100001111111100001111000011110000111100000000111100001111
53	0101101001011010010110100101101001011010010101011010010101101010
54	0011110000111100110000111100001111000011110000110011110000111100
55	0110100101101001100101101001011001101001011001101001011010010110
56	0000000011111111111111110000000011111111000000000000000011111111
57	0101010110101010101010010101010110101001010101010101010101101010
58	0011001110011001100110000110011110011000011001100110011110011100
59	0110011010011001100110011001101100101100110011001100110100110001
60	0000111111110000111100000000111111110000000011110000111111110000
61	0101101010100101101001010101101010010101101001010101010101010101
62	0011110011000011110000110011110011000011001111000011110011000011
63	0110100110010110100101100110100110010110011010010110100110010110

64x64

Walsh Code Names

$W12^{32}$ = "Walsh Code #12, 32 chips long."

Walsh Level Mapping

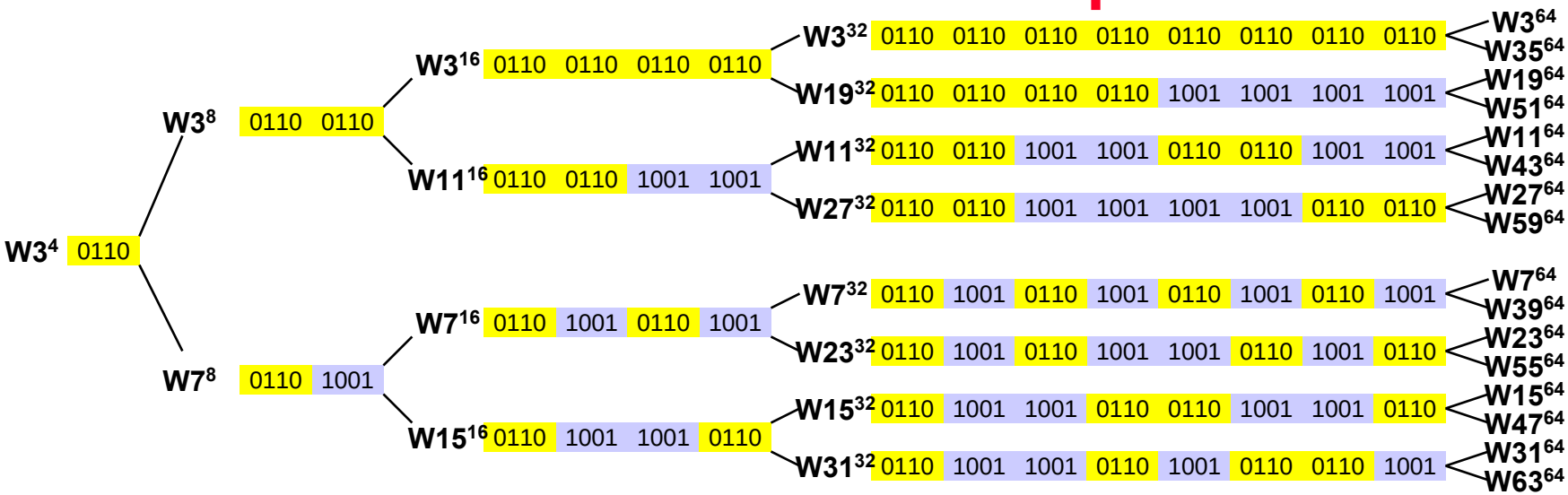
The Walsh Codes shown here are in logical state values 0 and 1.

Walsh Codes also can exist as physical bipolar signals. Logical zero is the signal value +1 and Logical 1 is the signal value -1.

Mapping: Logical 0,1 > +1, -1 Physical

- All Walsh codes can be built to any size from a single zero by replicating and inverting
- All Walsh matrixes are square -- same number of codes and number of chips per code

Walsh Code Trees and Interdependencies



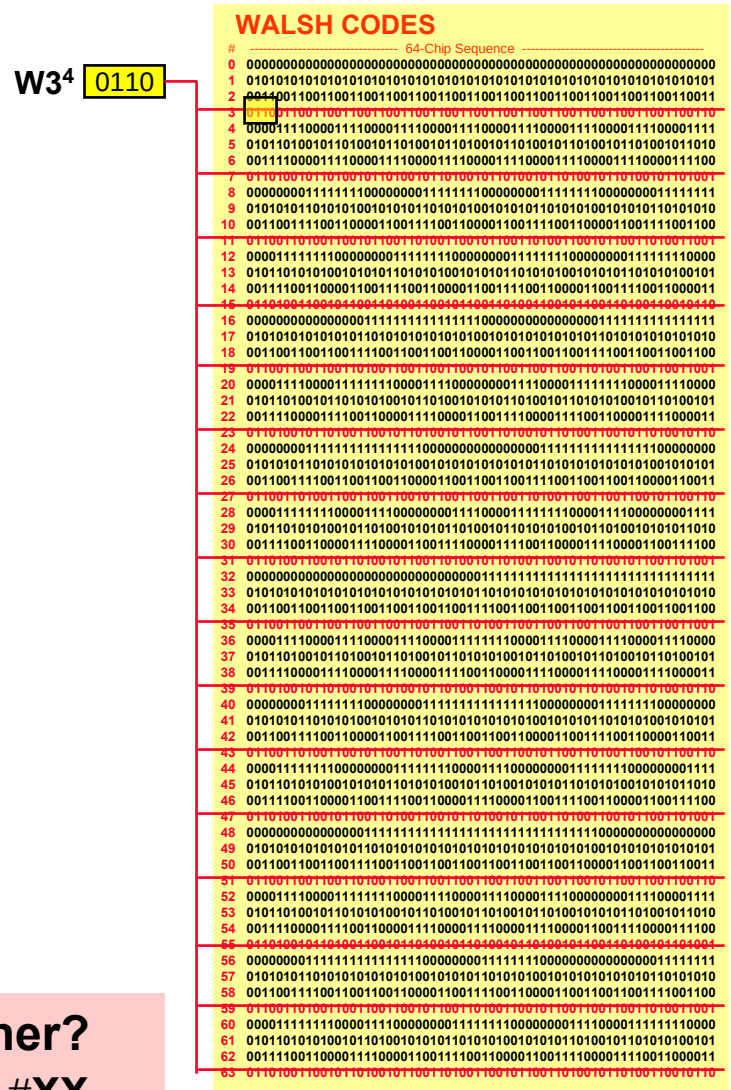
- Entire Walsh matrices can be built by replicating and inverting -- Individual Walsh codes can also be expanded in the same way.
- CDMA adds each symbol of information to one complete Walsh code
- Faster symbol rates therefore require shorter Walsh codes
- If a short Walsh code is chosen to carry a fast data channel, that walsh code and all its replicative descendants are compromised and cannot be reused to carry other signals
- Therefore, the supply of available Walsh codes on a sector diminishes greatly while a fast data channel is being transmitted!
- *CDMA2000 Base stations can dip into a supply of quasi-orthogonal codes if needed to permit additional channels during times of heavy loading*

Walsh Code Families and Exclusions

- Consider a forward link supplemental channel being transmitted with a data rate of 307,200 symbols/second
  - Each symbol will occupy 4 chips at the 1x rate of 1,228,800 c/s.
  - A 4-chip walsh code will be used for this channel
- If Walsh Code #3 (4 chips) is chosen for this channel:
  - Use of $W3^4$ will preclude other usage of the following 64-chip walsh codes:
  - 3, 35, 19, 51, 11, 43, 27, 59, 7, 39, 23, 55, 15, 47, 31, 63 -- all forbidden!
  - 16 codes are tied up since the data is being sent at 16 times the rate of conventional 64-chip walsh codes
- The BTS controller managing this sector must track the precluded walsh codes and ensure they aren't assigned

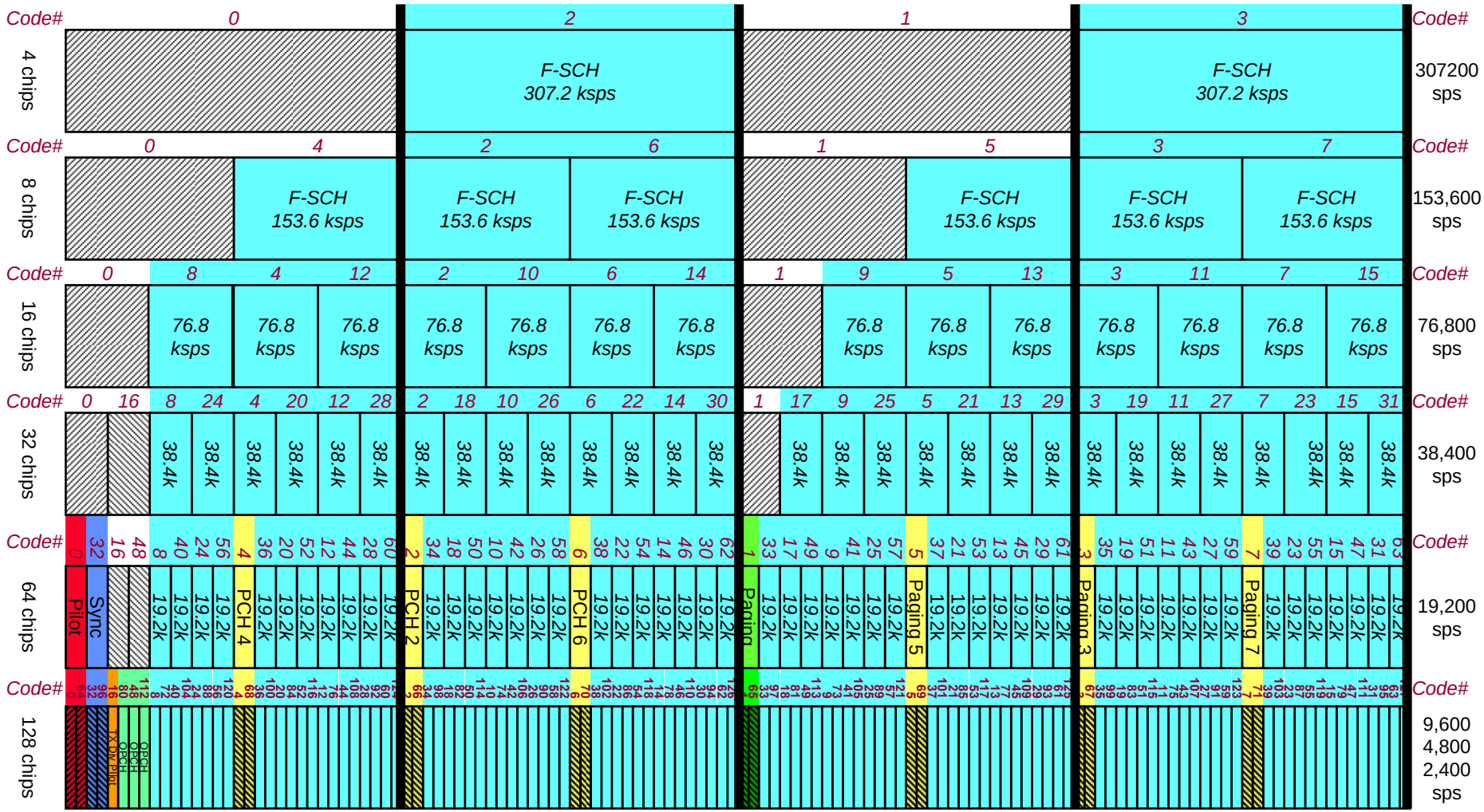
Which Walsh Codes get tied up by another?

Wxx^{yy}ties up every **YY**th Walsh Code starting with #**XX**.



Forward Link Walsh Codes in 1xRTT

This way of arranging Walsh codes is called “bit reversal order”. It shows each Walsh code’s parents and children. Remember, we cannot use any Walsh code if another Walsh code directly above it or below it is in use.

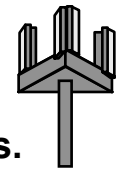


IS-95 Busy Sector

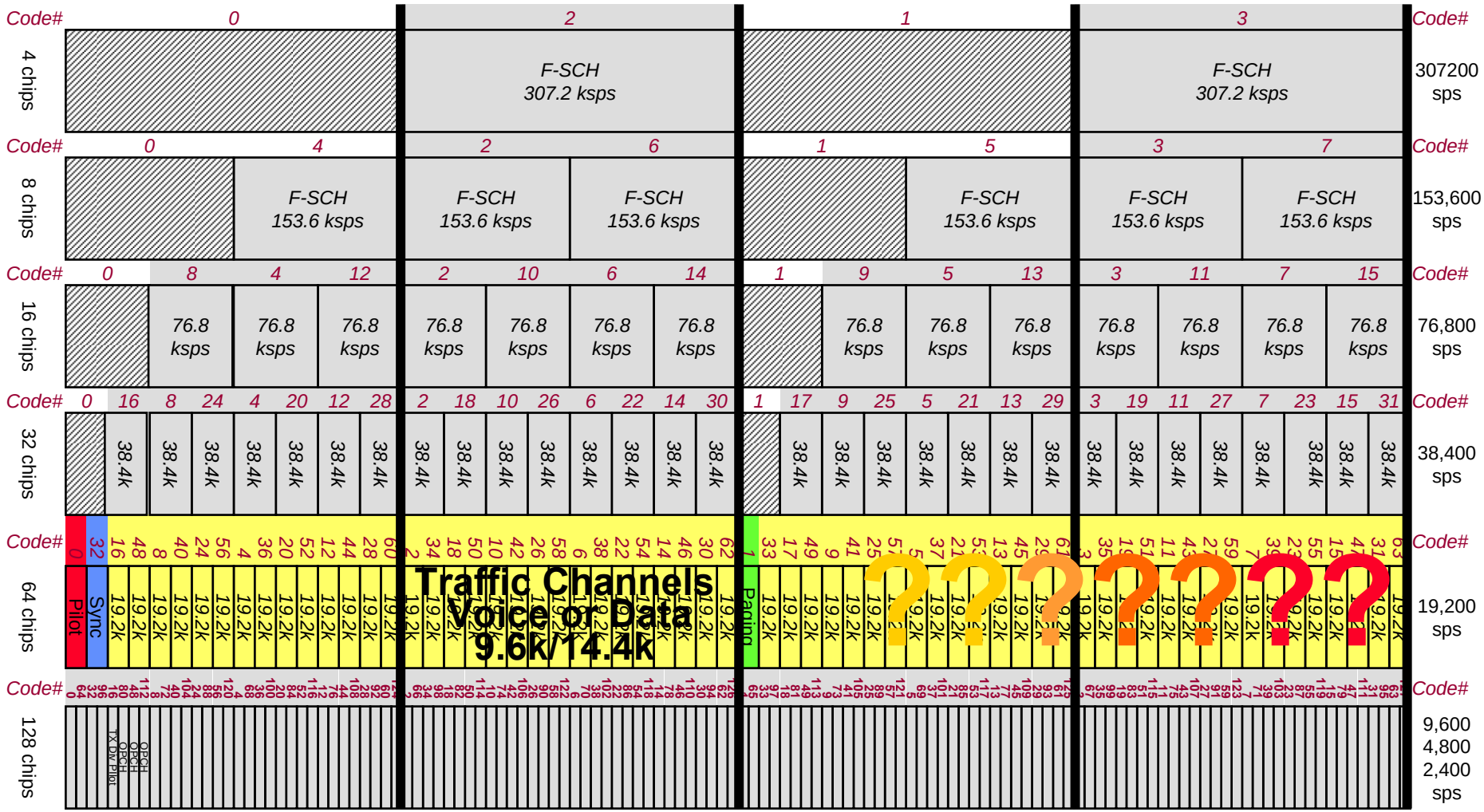
Snapshot of Walsh Usage



IS-95 Today Typical Usage:
Pilot, Paging Sync, up to 61 Voice Users

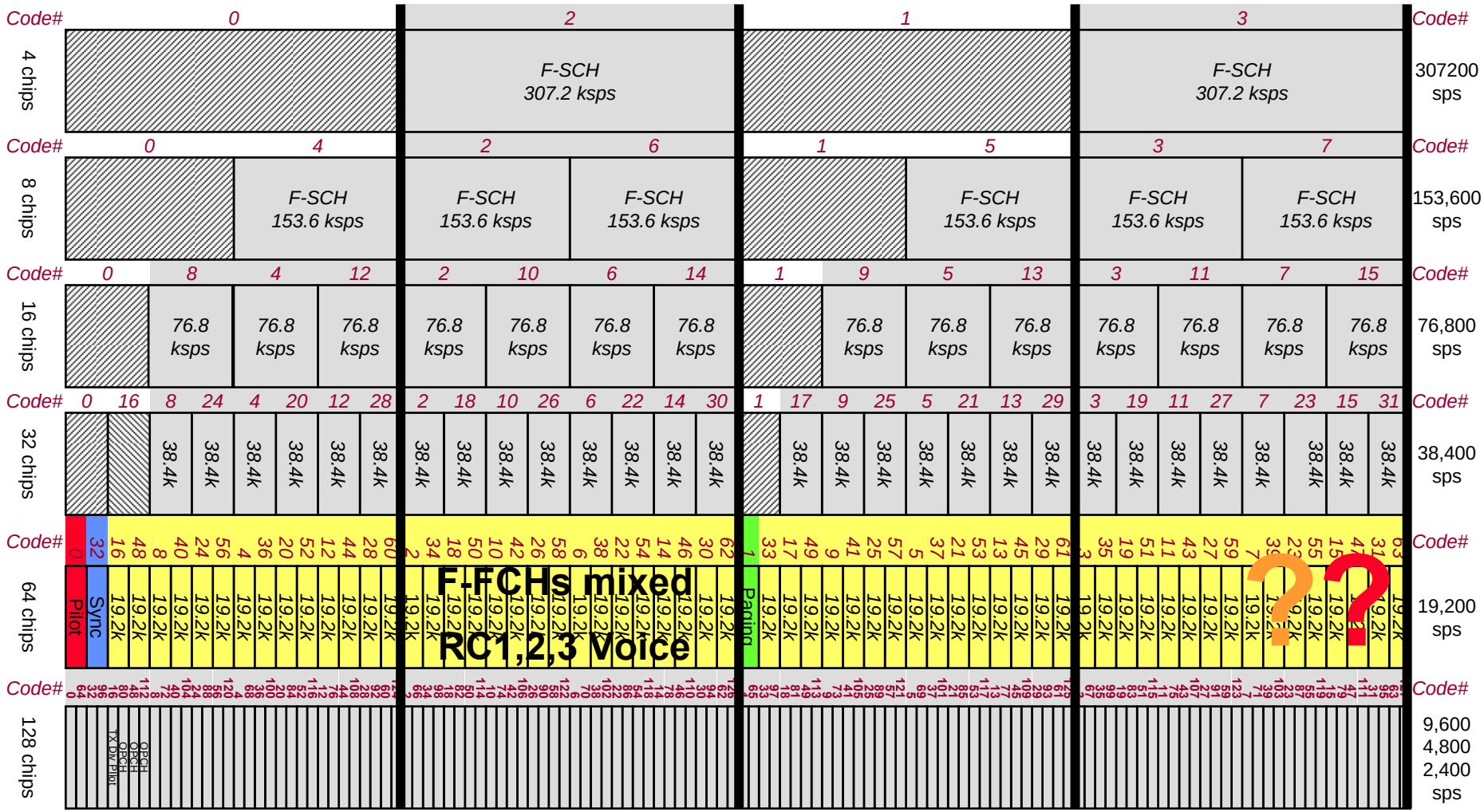


But if the users are highly mobile, forward power may exhaust at typically 30-40 users.
In fixed-wireless or "stadium" type applications, all walsh codes may be usable.



Mixed IS-95 / 1xRTT RC3 Voice Typical Usage:
Pilot, Paging Sync, up to 61 Voice Users

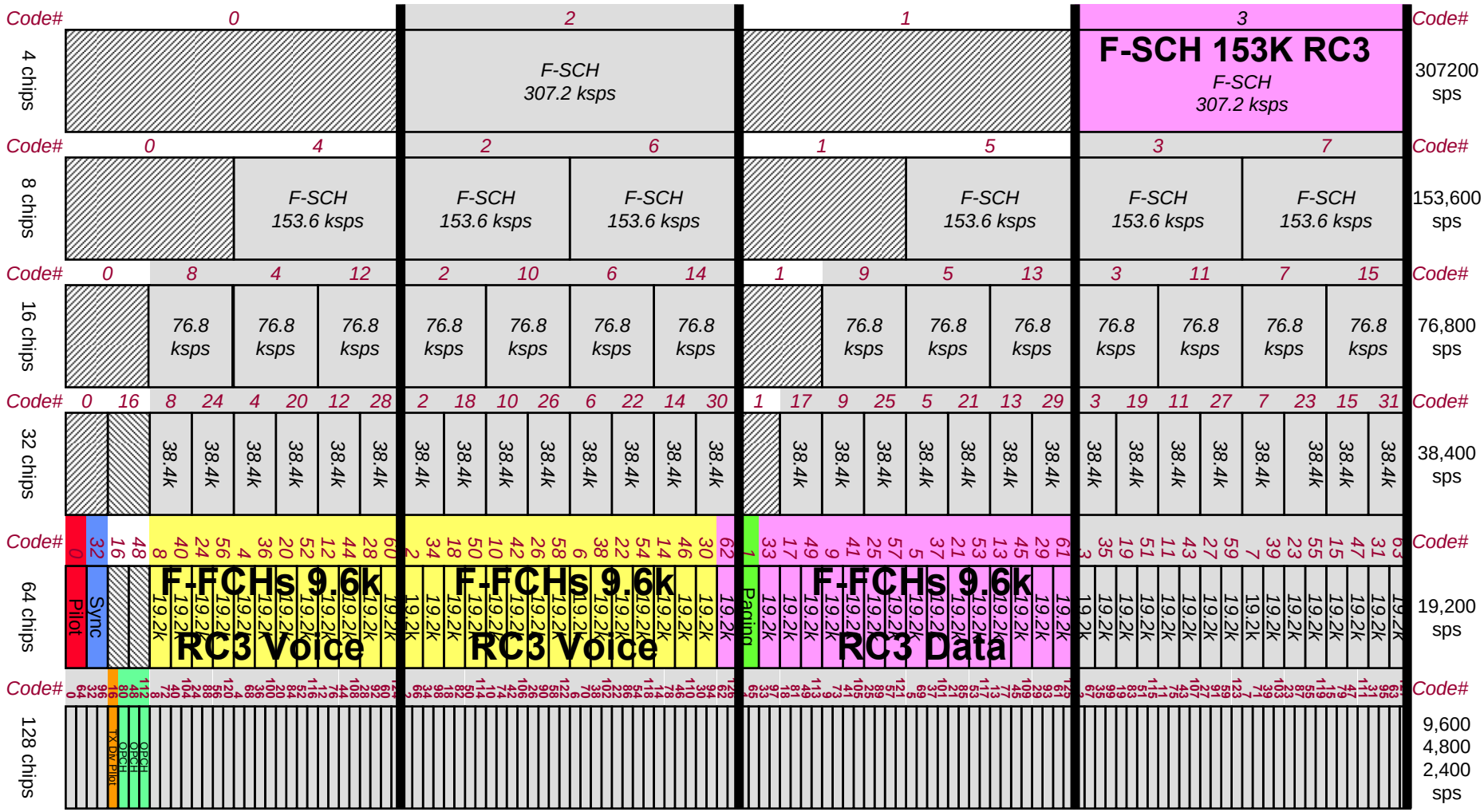
FCHs of 1xRTT RC3 users consume less power, so more total users are possible than in IS-95. The BTS will probably have enough forward power to carry calls on all 61 walsh codes!



A Possible 1xRTT RC3 BTS Dynamic State:

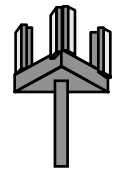
1 F-SCH, 27 Voice IS-95/1xRTT RC3 Users, 16 Active Data Users

The data users can rapidly share the one F-SCH for 153 kb/s peak, ~9Kb/s avg. user rates.
But so many active data users F-FCHs consume a lot of capacity, reduce number of voice users!

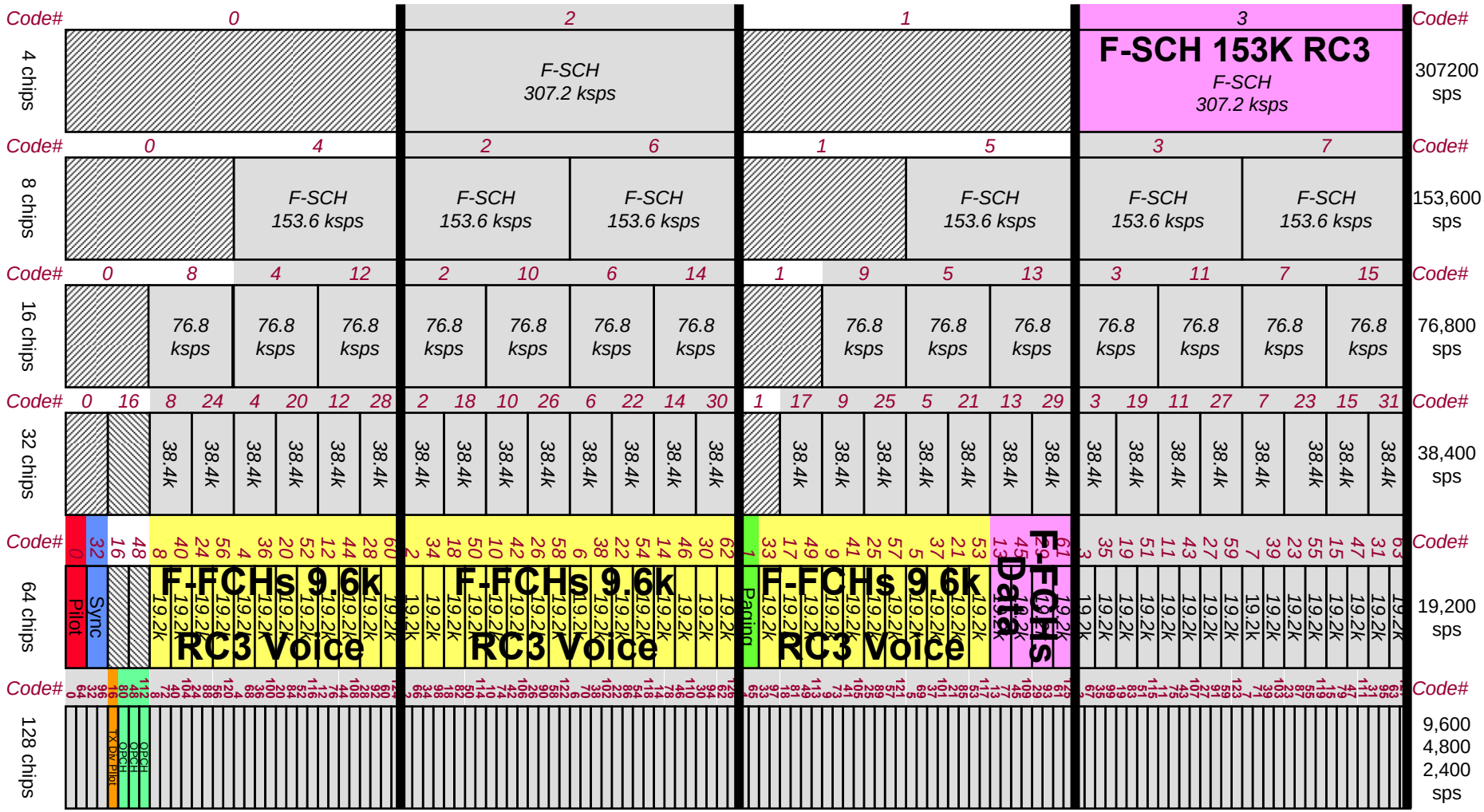


A Possible 1xRTT RC3 BTS Dynamic State:

1 F-SCH, 39 IS-95/1xRTT RC3 Voice Users, 4 Active+12 Dormant Data Users



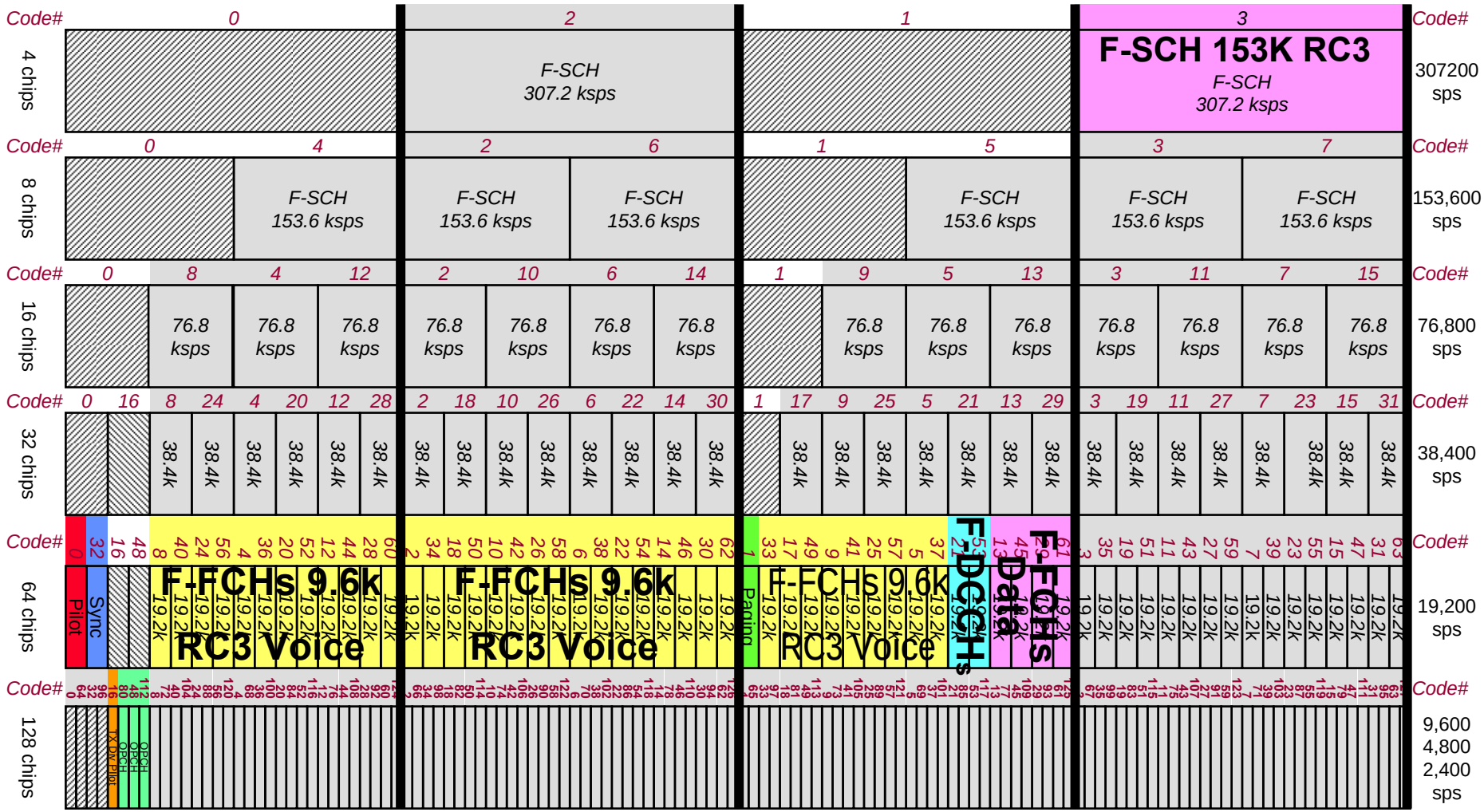
But it takes seconds to move various data users from Dormant to Active!
Data users will get 153 kb/s peak, ~9 kb/s average, but latency will be high.



Slightly Improved 1xRTT RC3 BTS Dynamic State:

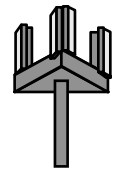
1 F-SCH, 37 IS-95/1xRTT RC3 Voice Users, 4 Active+12 Control-Hold Data Users

Instead of sending 16 data users to Dormant State, let them time-share 2 F-DCCH for Control Hold state. Data users will get 153 kb/s peak, ~9 kb/s average, good latency. Not yet available or implemented.

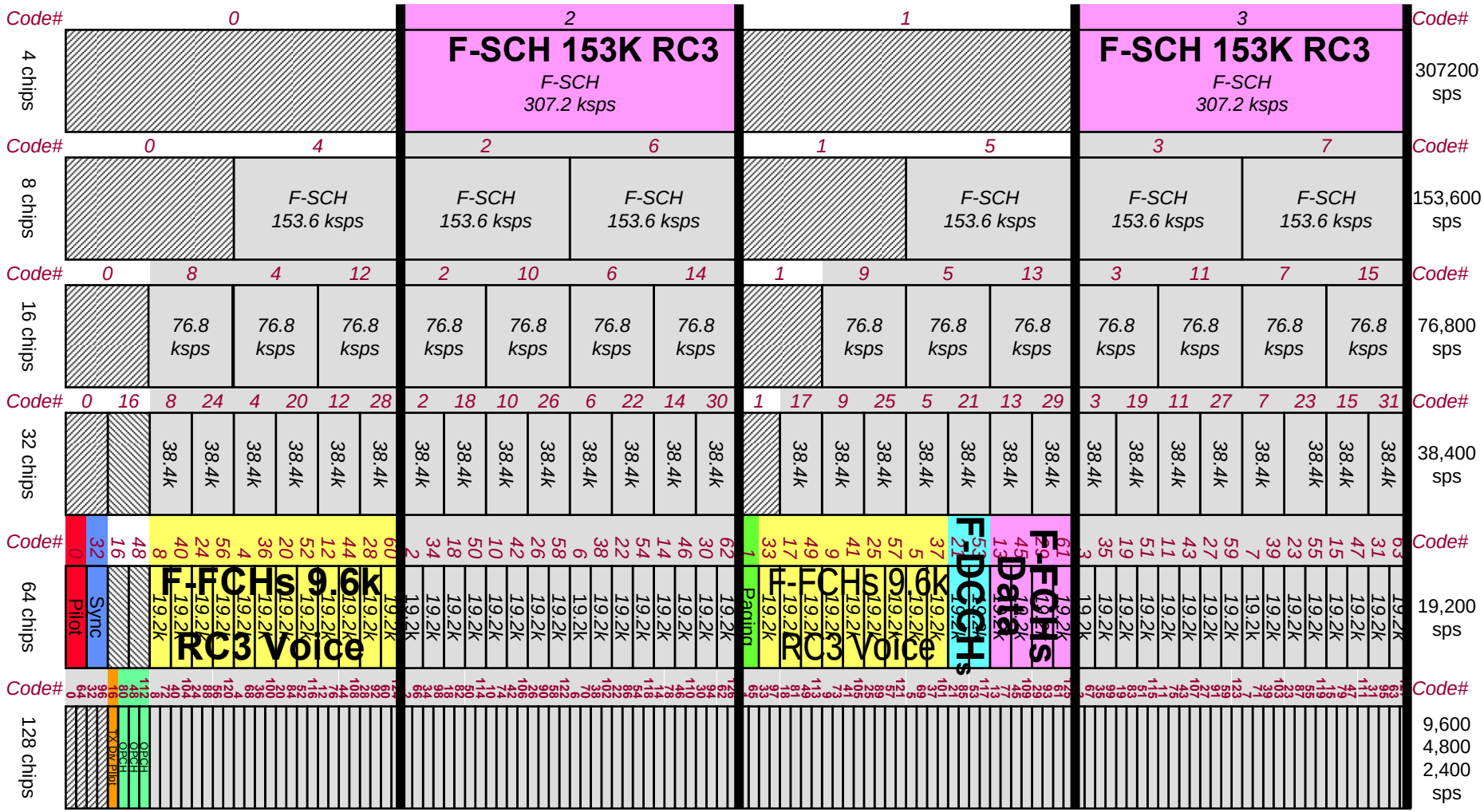


Heavy Data 1xRTT RC3 BTS Dynamic State:

2 F-SCH, 21 IS-95/1xRTT RC3 Voice Users, 4 Active+12 Control-Hold Data Users

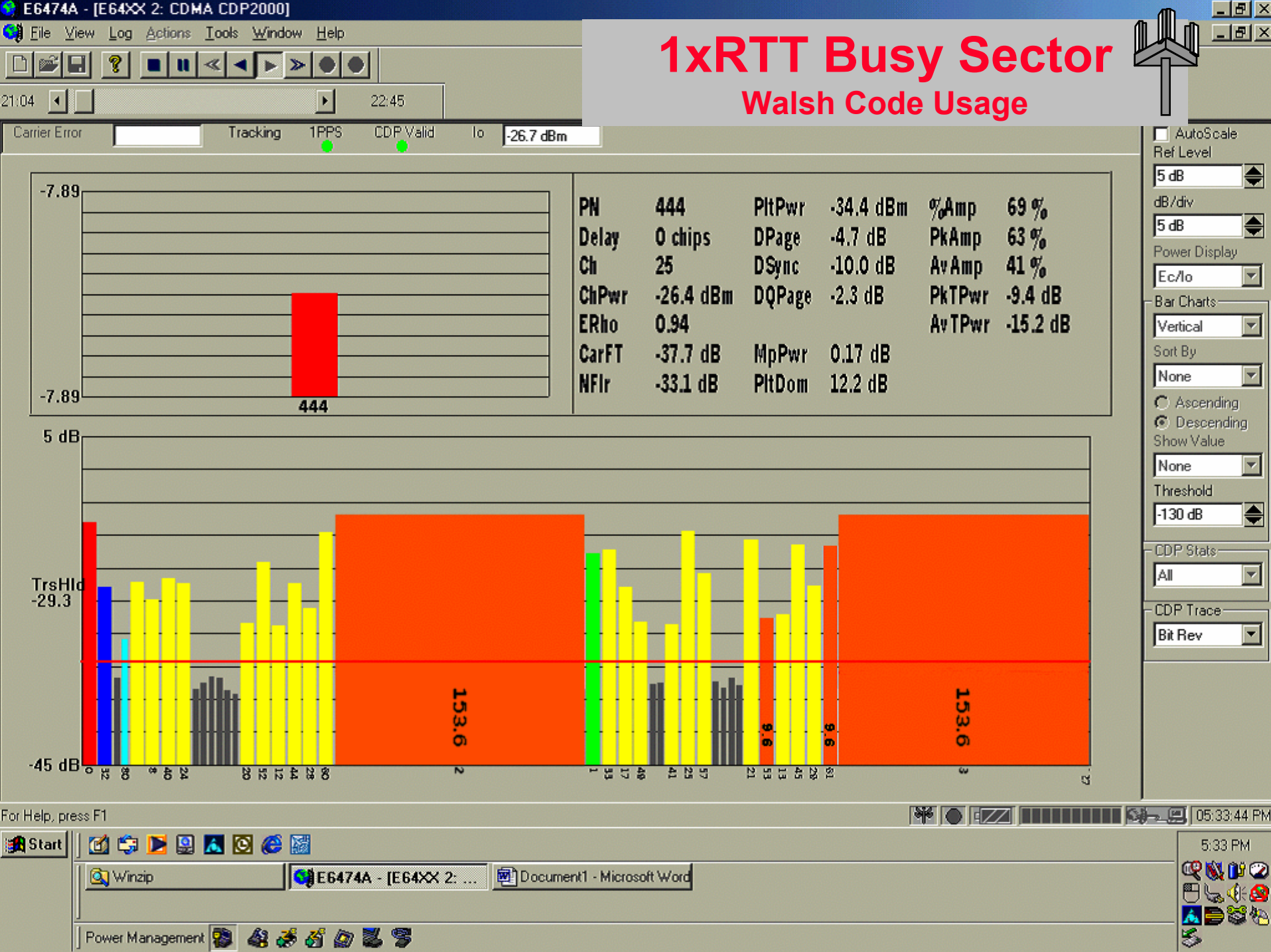


16 data users time-share 2 F-DCCH for Control Hold state. Data users get 38.4, 76.4, or 153.6 kb/s peak, ~19 kb/s average, good latency. But only 21 voice users!



1xRTT Busy Sector

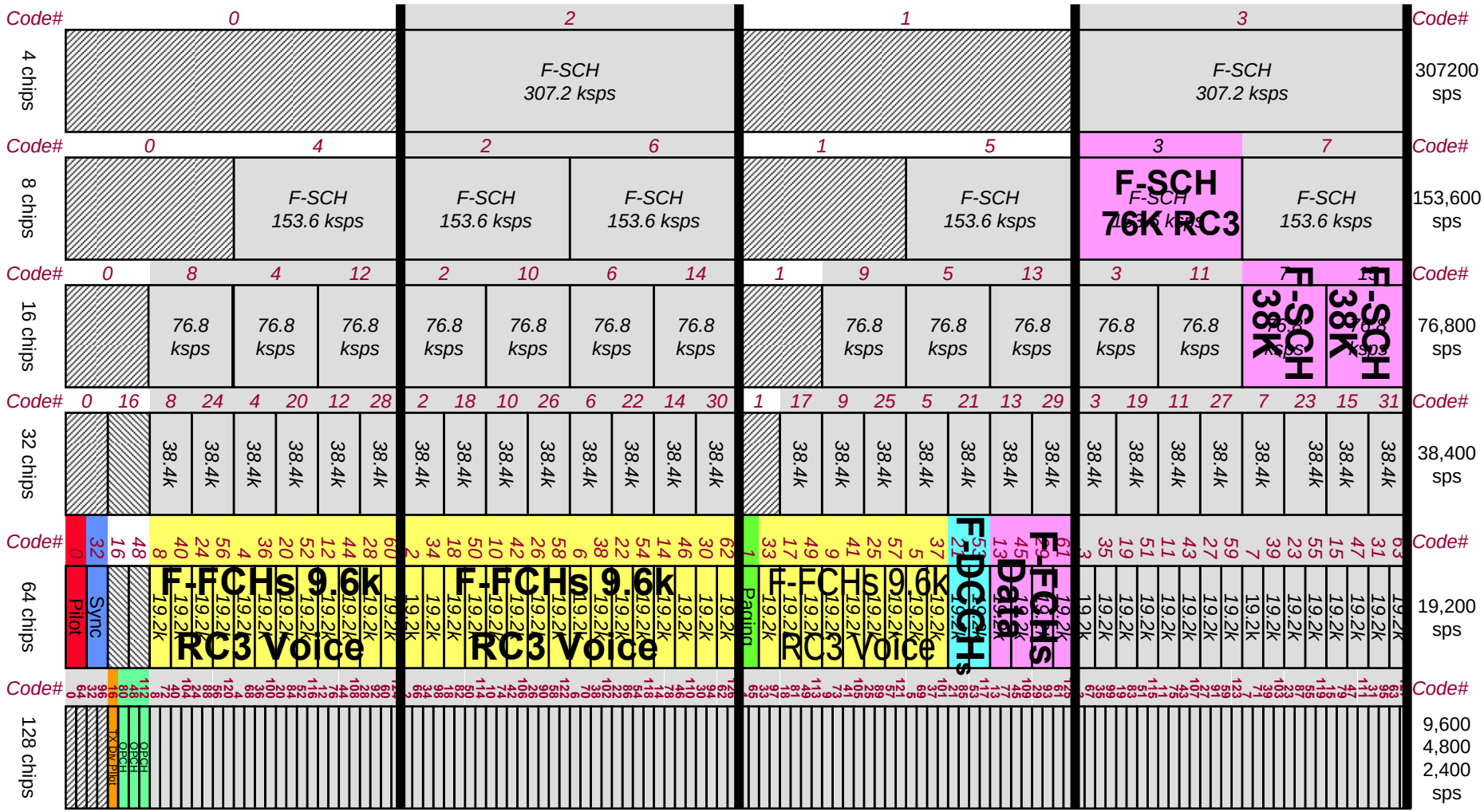
Walsh Code Usage



1xRTT RC3 BTS with Different User Data Rates:

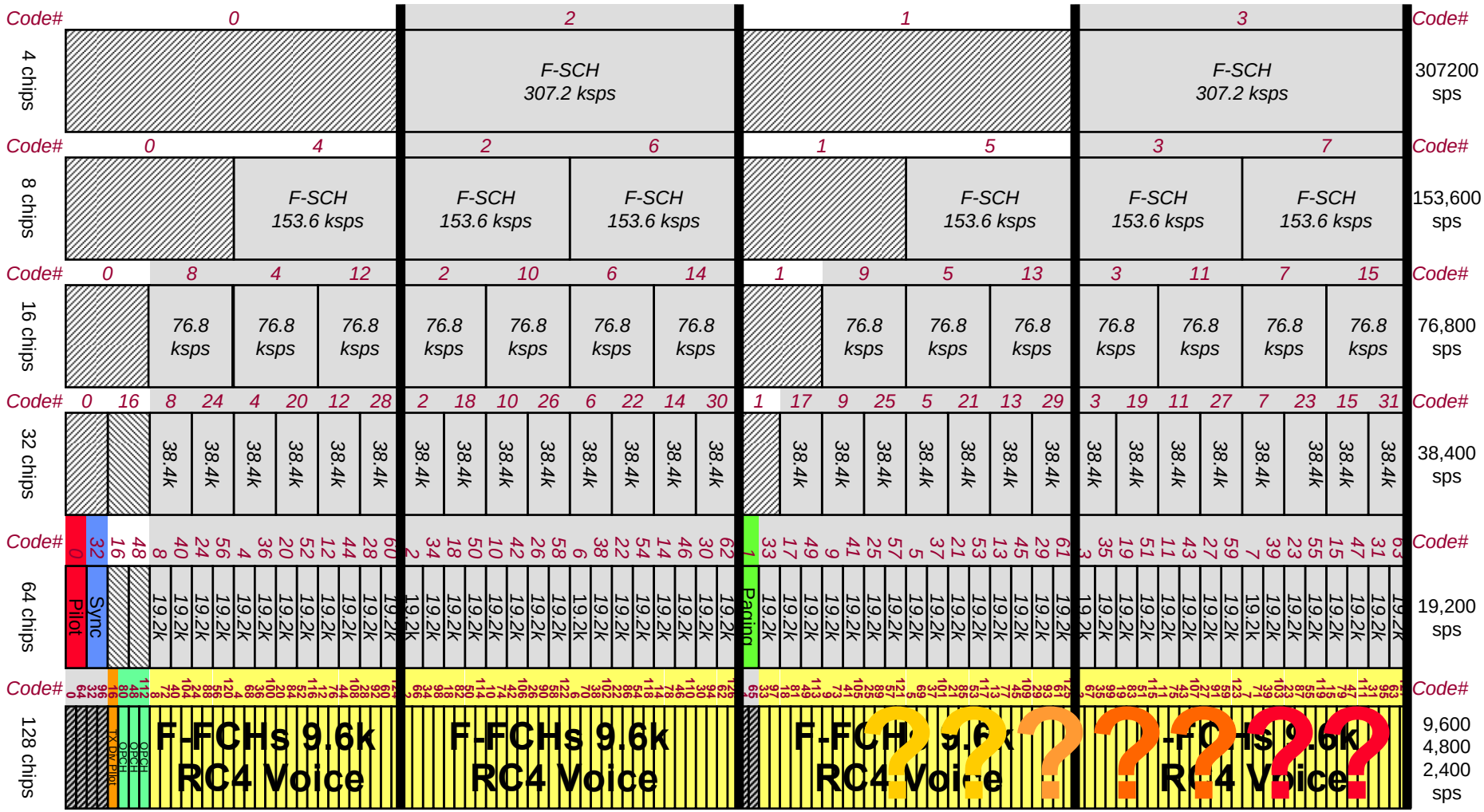
3 F-SCH, 37 IS-95/1xRTT RC3 Voice Users, 4 Active+12 Control-Hold RC3 Data Users

16 data users time-share 2 F-DCCH for Control Hold state.
Data users get 38.4, 76.4, or 153.6 kb/s peak, ~9 kb/s average, good latency.



1xRTT RC4 Voice Only:
Pilot, Paging Sync, up to 118 Voice Users

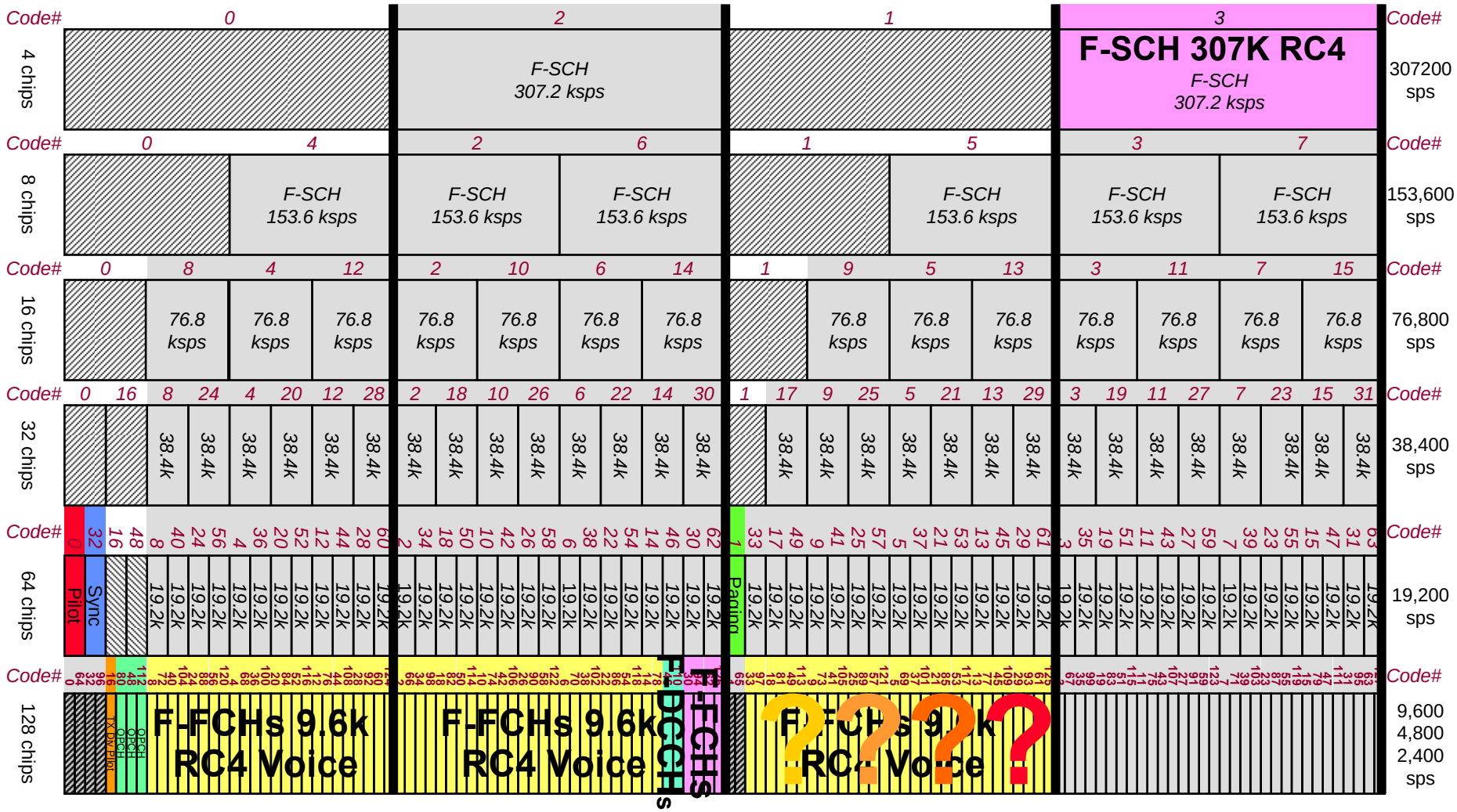
Wow! 118 users! But RC4 users F-FCHs consume as much power as old IS-95 calls.
BTS may run out of forward power before the all walsh codes are used.


Code# 0 2 1 3 Code#
4 chips
F-SCH 307.2 ksps
F-SCH 307.2 ksps
307200 sps
Code# 0 4 2 6 1 5 3 7 Code#
8 chips
F-SCH 153.6 ksps
153,600 sps
Code# 0 8 4 12 2 10 6 14 1 9 5 13 3 11 7 15 Code#
16 chips
76.8 ksps
76,800 sps
Code# 0 16 8 24 4 20 12 28 2 18 10 26 6 22 14 30 1 17 9 25 5 21 13 29 3 19 11 27 7 23 15 31 Code#
32 chips
38.4k
38,400 sps
Code# 0 32 16 48 8 40 24 56 4 36 20 52 12 44 28 60 2 34 18 50 10 42 26 58 6 38 22 54 14 46 30 62 1 33 17 49 9 41 25 57 5 37 21 53 13 45 29 61 3 35 19 51 11 43 27 59 7 39 23 55 15 47 31 63 Code#
64 chips
Pilot
Sync
Paging
19.2k
19,200 sps
Code# 0 64 32 96 16 80 48 112 8 72 40 104 24 88 56 120 4 68 36 100 20 84 52 116 12 76 44 108 28 92 60 124 2 66 34 98 18 82 50 114 10 74 42 106 26 90 58 122 6 70 38 102 22 86 54 118 14 78 46 110 30 94 62 126 1 65 33 97 17 81 49 113 9 73 41 105 25 89 57 121 5 69 37 101 21 85 53 117 13 77 45 109 29 93 61 125 3 67 35 99 19 83 51 115 11 75 43 107 27 91 59 123 7 71 39 103 23 87 55 119 15 79 47 111 31 95 63 127 Code#
128 chips
F-FCHs 9.6k RC4 Voice
F-FCHs 9.6k RC4 Voice
F-FCHs 9.6k RC4 Voice
??
??
??

1xRTT RC4 Voice and Data:

1 F-SCH, 80 1xRTT RC4 Voice Users, 4 Active+12 Control-Hold RC4 Data Users

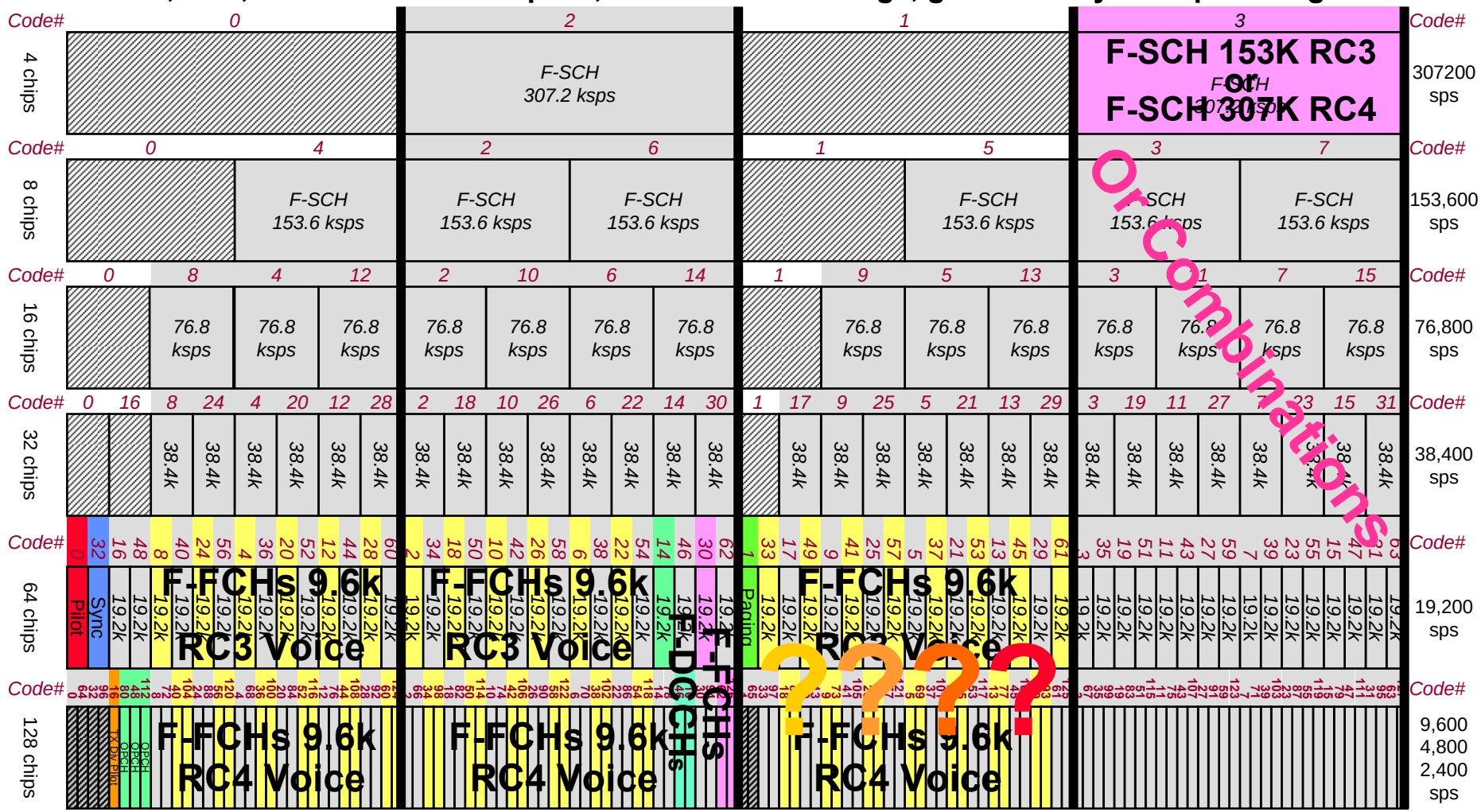
16 data users time-share 2 F-DCCH for Control Hold state. Data users will get 38.4, 76.4, 153.6 or 307.2 kb/s peak, ~19 kb/s average, good latency. But fwd power may exhaust!



Mature 1xRTT Mixed-Mode Voice and Data:

1 RC3/RC4 Shared F-SCH, 20 RC3 Voice Users, 38 RC4 Voice Users, 4 Active+12 Control-Hold RC3 and RC4 Data Users

16 data users time-share 2 F-DCCH for Control Hold state. Data users will get 38.4, 76.4, 153.6 or 307.2 kb/s peak, ~9 or 19 kb/s average, good latency. Fwd power tight!



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

- 1xRTT has 128 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)

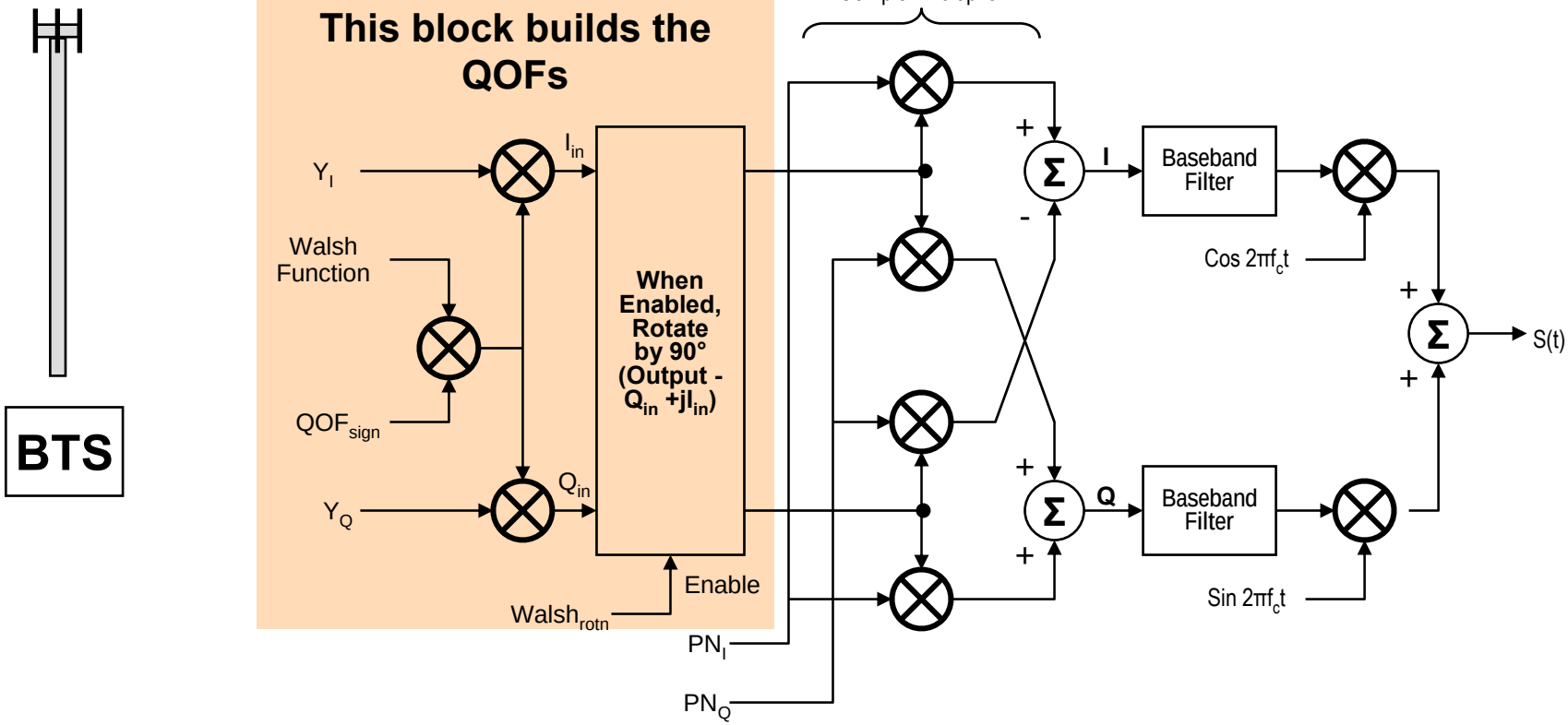
Table 3.1.3.1.12-1. Maximum Walsh Function Length for Code Channels on the Forward CDMA Channel Except the Auxiliary Pilot Channel and Auxiliary Transmit Diversity Pilot Channel

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



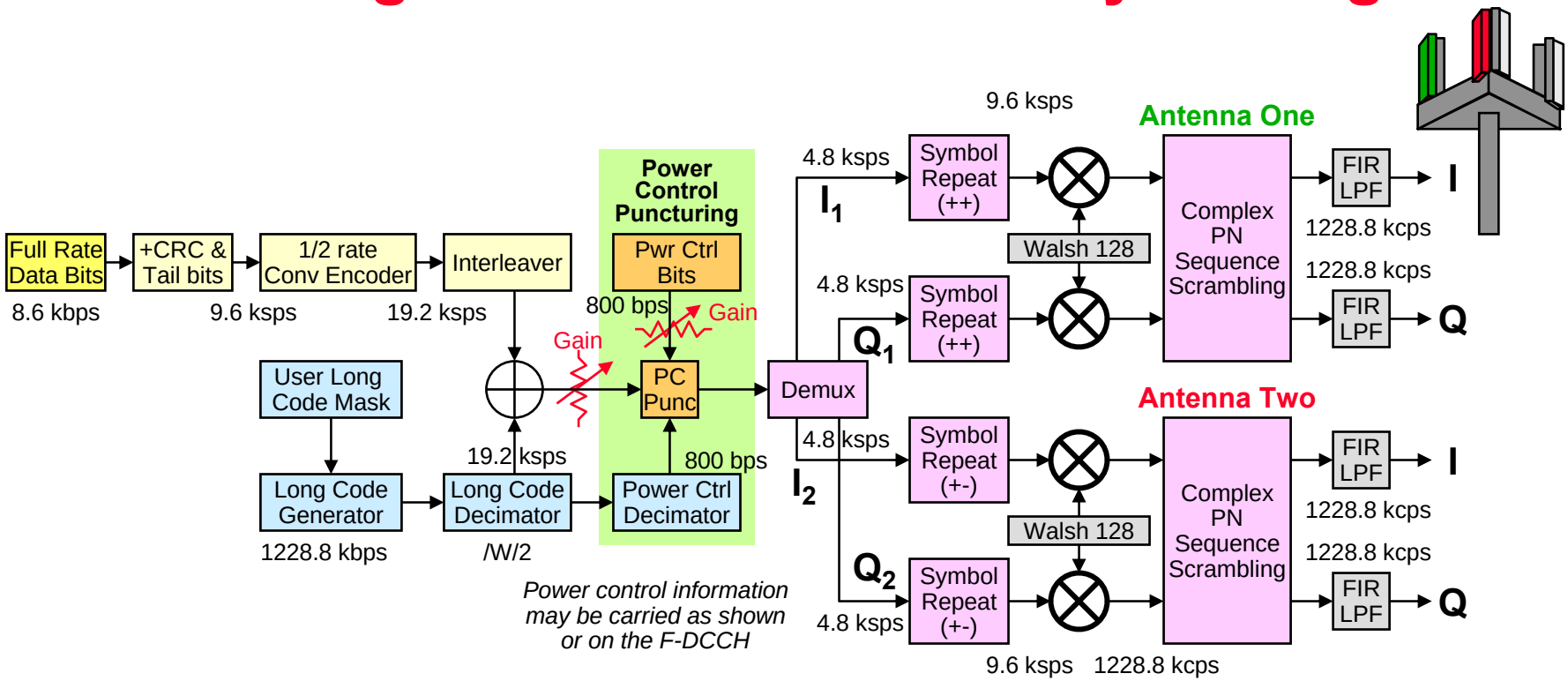
Walsh function = ±1 (mapping: '0'⇒+1, '1' ⇒-1)
QOF_{sign}= ±1 sign multiplier QOF mask (mapping: '0'⇒+1, '1' ⇒-1)
$Walsh_{rot}$ = '0' or '1' 90°-rotation-enable Walsh function
$Walsh_{rot}$ = '0' means no rotation
$Walsh_{rot}$ = '1' means rotate by 90°
The null QOF has QOF_{sign} = +1 and $Walsh_{rot}$ = '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

Forward Orthogonal Transmit Diversity (OTD)

SR1 Forward Orthogonal Transmit Diversity

- Forward link receive space diversity is not possible on phones due to space limitations
- Forward Orthogonal Transmit Diversity (OTD) divides the transmitted symbol stream into two streams before Walsh spreading
- Each signal is then transmitted by a separate antenna at the BTS
- OTD is not presently available in voice networks and phones, but will be offered in 1xEV-DO networks and future voice networks for fixed-wireless applications

SR1, RC4
Orthogonal Transmit Diversity Coding

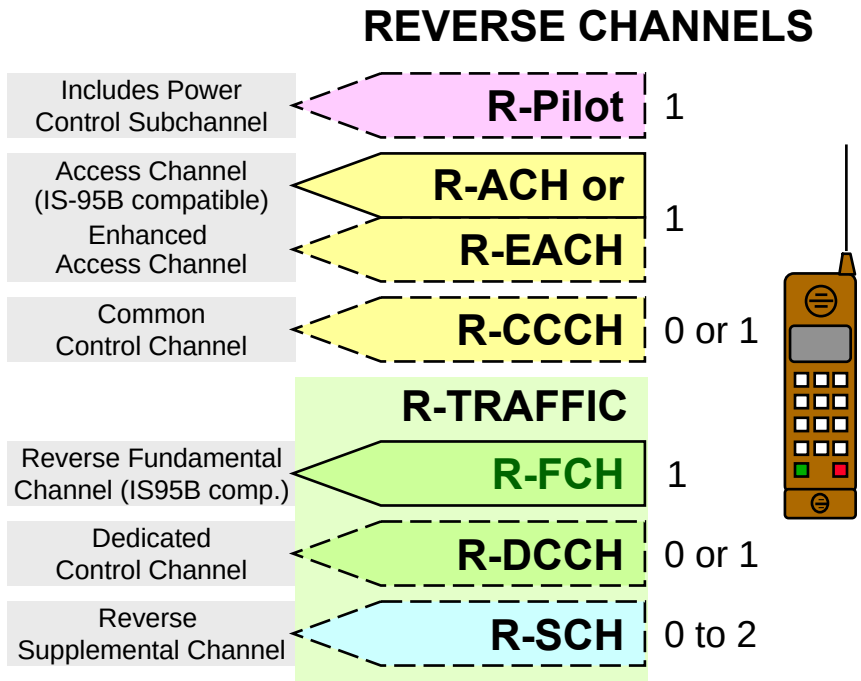


- The DEMUX splits the data into four streams at 1/4 the input rate
- Symbol repetition doubles the symbol rates of each channel
- The channels are then spread by a 128-bit Walsh code
- The resulting signal appears to have been spread by a 256-bit Walsh code
- Each carrier is transmitted on a different spatially-separated BTS antenna

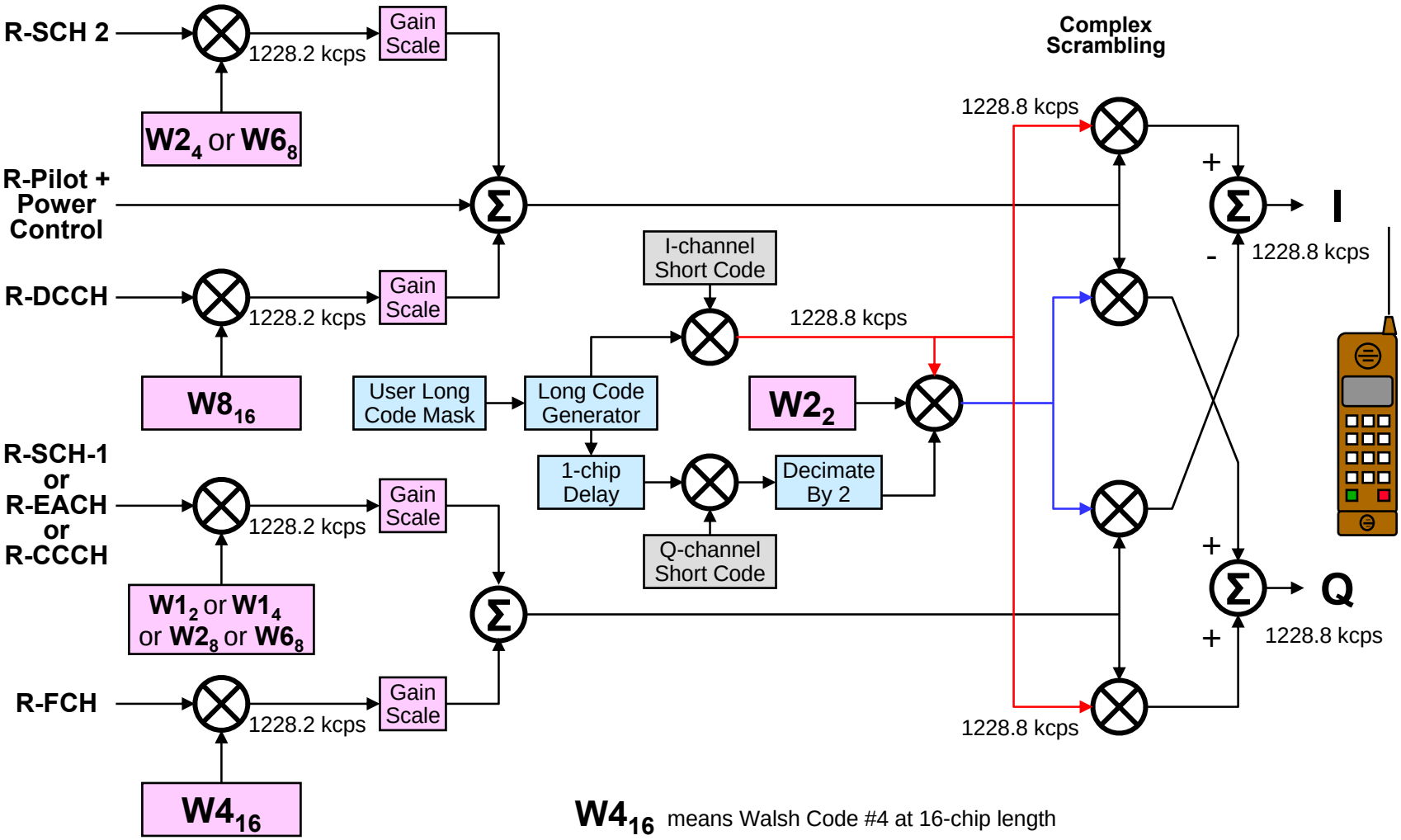
1xRTT Reverse Channels

CDMA2000 SR1 CDMA Reverse Channels

- IS-95 mobiles never transmit more than one kind of channel at a time
- A 1xRTT mobile can transmit up to five different channels simultaneously, all within its own signal using one long code offset
- An IS-95 mobile transmits the content of its single channel in the form of a string of walsh codes which are symbols of the information being sent
- A 1xRTT mobile uses steady walsh codes as individual channels of information, the same way a base station does on the forward link

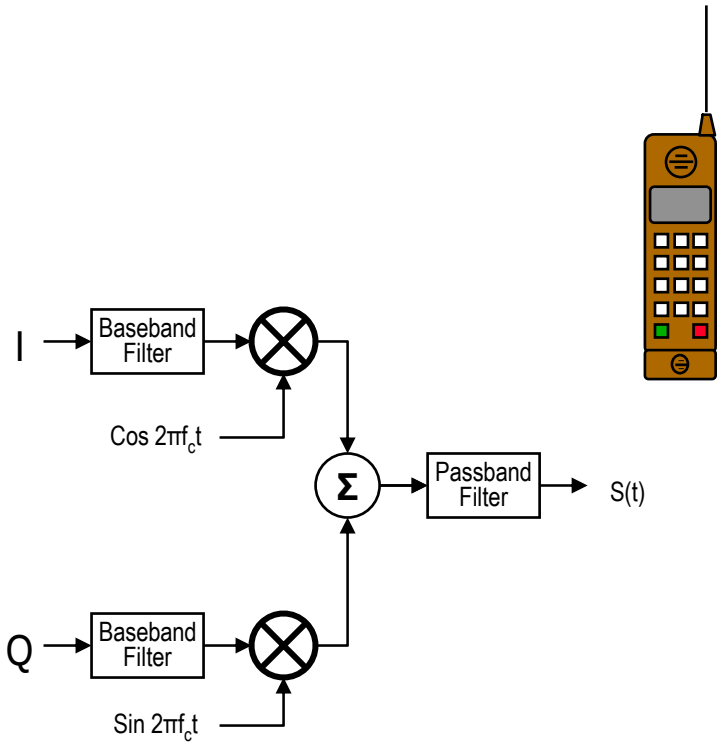


How a 1xRTT Mobile Builds Its Signal

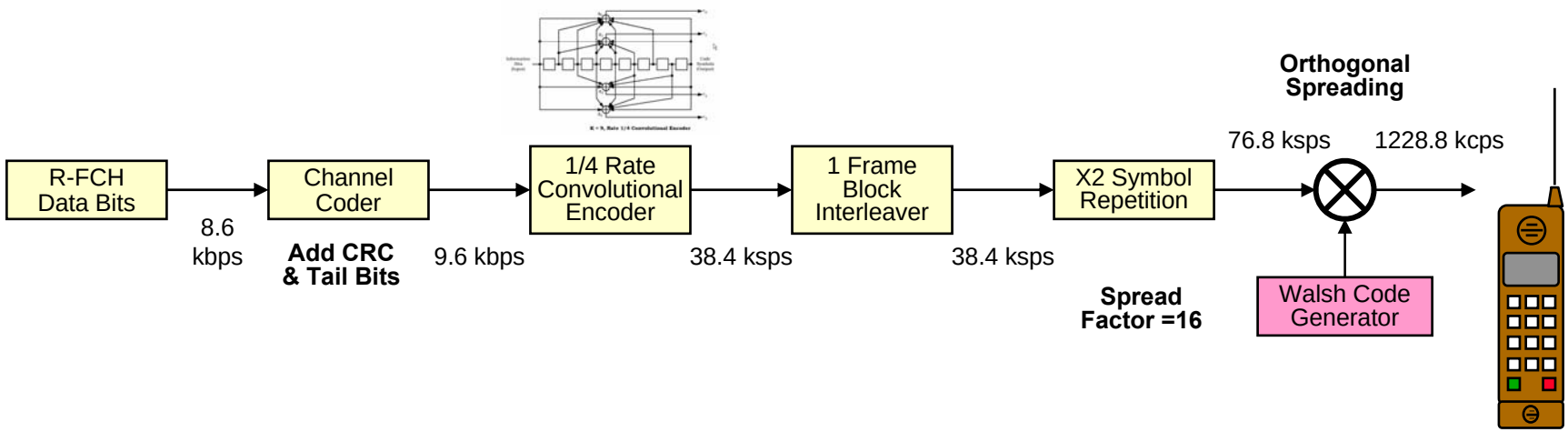


Reverse Link Modulation

- After construction of the composite baseband signal including all the active reverse channels, the I and Q signals are now ready for modulation
- Modulation is performed in the same was as IS-95
- Notice that although I and Q carry independent contents, all the reverse channels are complex-spread and occupy both I and Q due to the complex scrambling shown on the preceding page



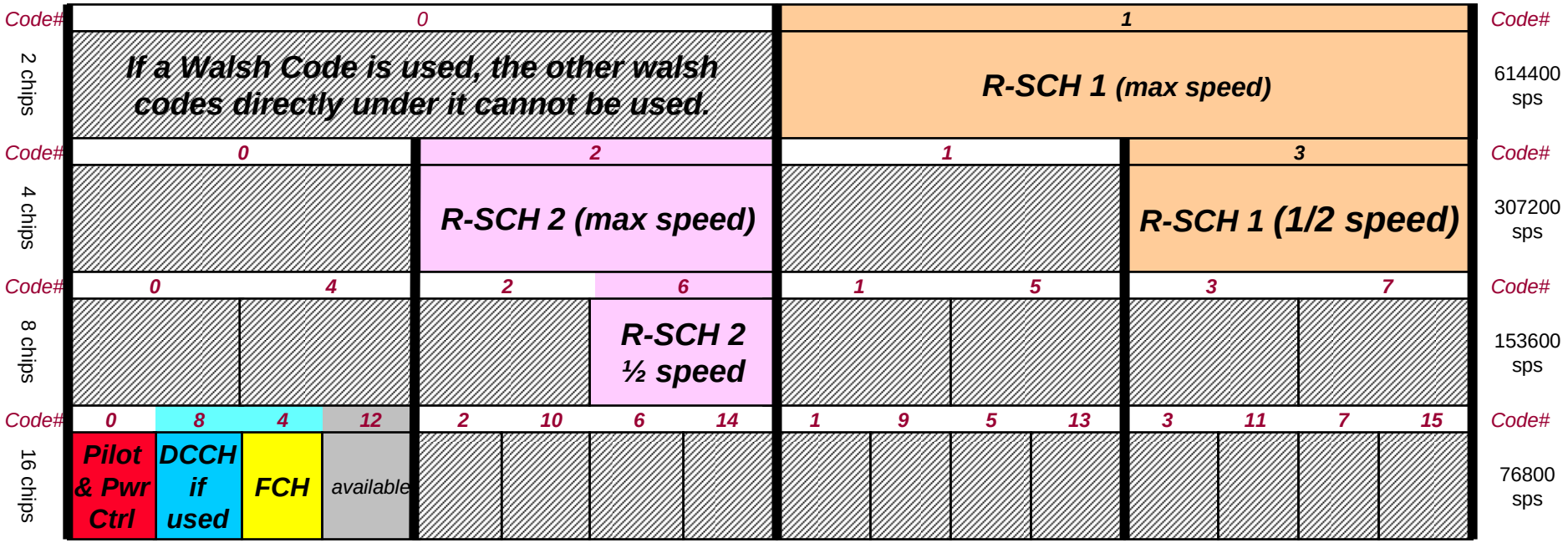
SR1 RC3 R-FCH Generation & Coding



- This is the fundamental channel for SR1 RC3, with frames 20 ms long when it is carrying voice information
- CRC and tail bits are added
- The data is passed through a R1/4 convolutional encoder, providing very powerful protection against bit errors
- The resulting symbols are block-interleaved against bursty fades
- Symbol repetition then brings the rate from 38.4 ksps to 76.8 ksps
- Each of the phone's reverse channels has a different walsh code; the R-FCH always uses Walsh code #4 at 16-chip length

Walsh Codes as Transmitted by 1xRTT Mobiles





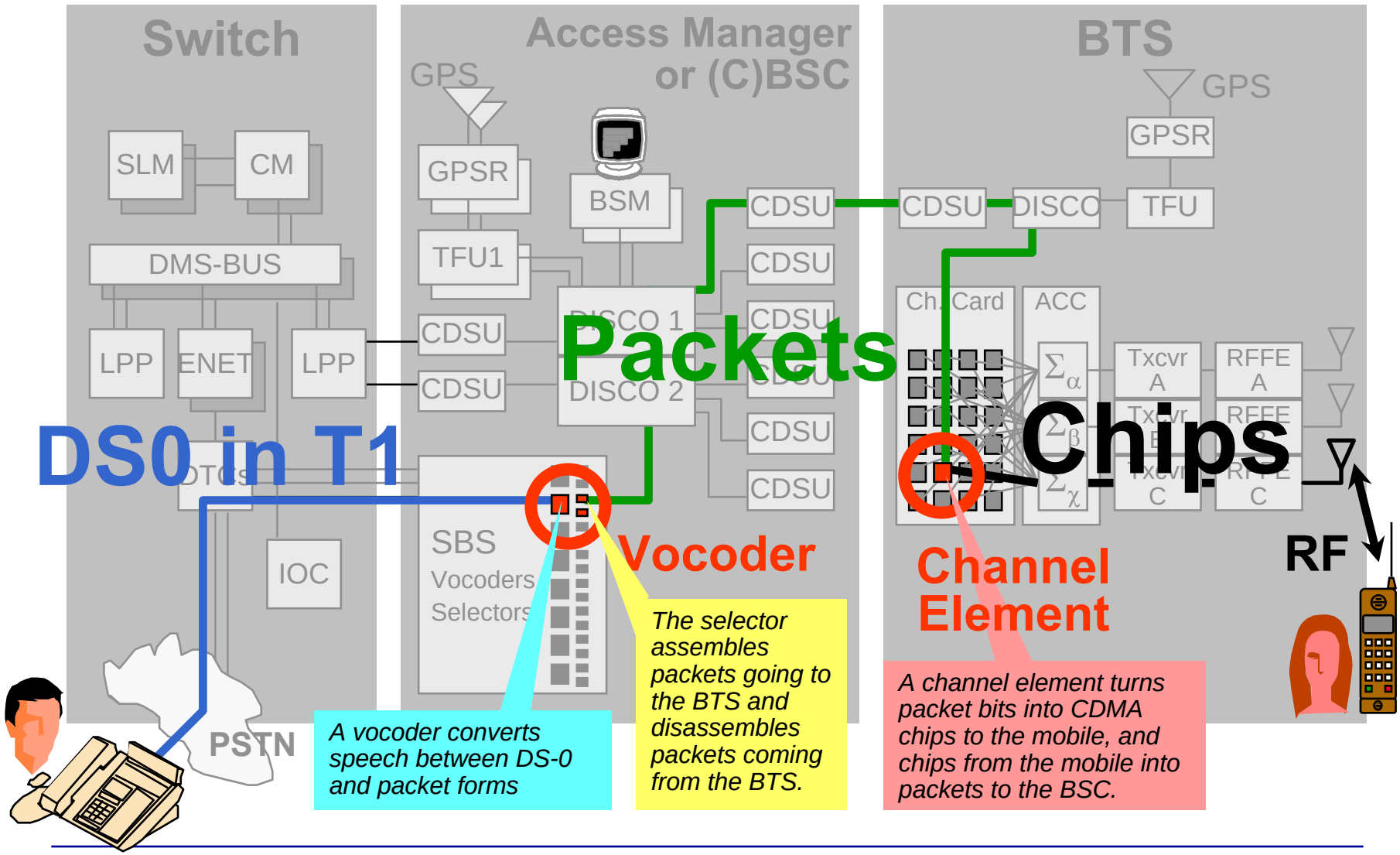
- A 1xRTT mobile may transmit several channels at the same time – for example, R-FCH and Pilot and R-SCH.
  - the mobile uses steady walsh codes as channels much like a BTS
- All mobiles use the same Walsh codes for the same functions
- notice the two possible speeds of R-SCH 1 and R-SCH 2

The Data Side of 3G Networks

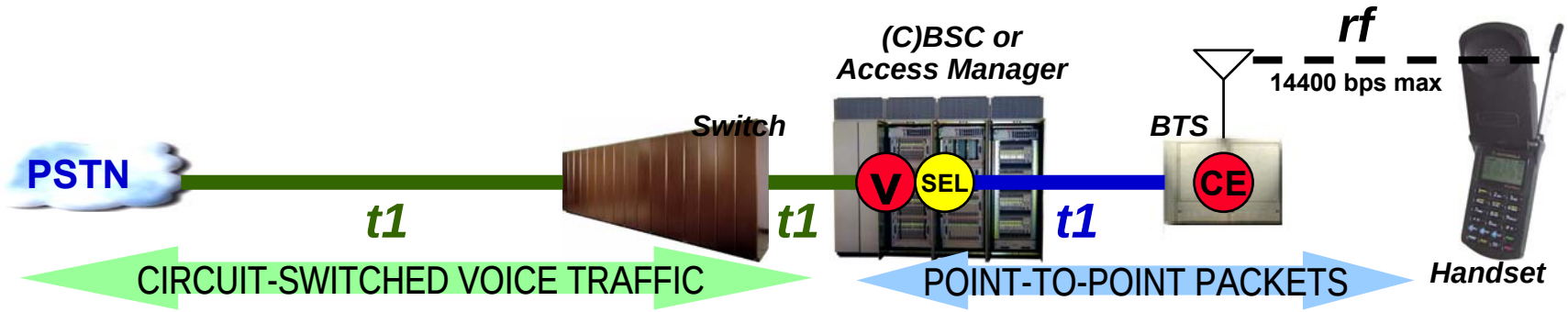
Network-Side Improvements in CDMA2000

- We've just seen how new CDMA2000 RF improvements create a whole new type of channel which can carry fast data
  - The RF link is no longer the bottleneck for mobile data!
- Many wireless operators' business plans expect data usage to rapidly expand, reaching bit volumes roughly equal to voice calls within just a year or so after CDMA2000 commercial launch
  - And voice traffic is still growing in the meanwhile!
- All this new fast data has to go through some kind of equipment
  - The traditional voice circuit-switched plant can't handle it
    - It handles only circuit-switched 64 kb/s DS-0s, which would be a big bottleneck for high speed data
  - A whole new back-side packet data network is needed to bypass mobile data around the switch, into internet or VPNs
- Fortunately, existing LAN-style data technologies are up to the job, and much more hardware-efficient than traditional switching

A 2G IS-95 CDMA Network

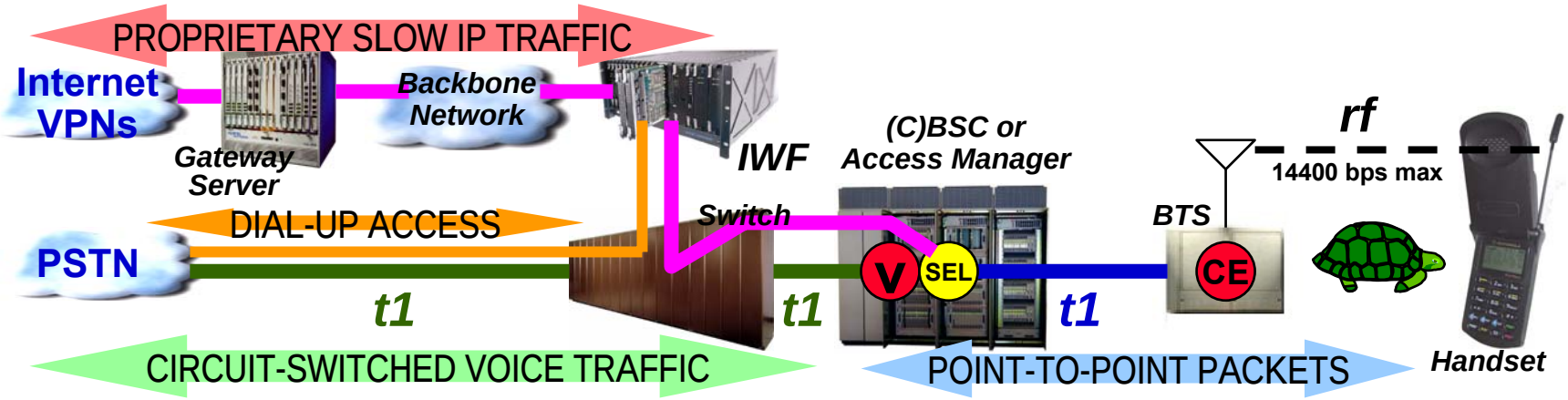


A 2G IS-95 CDMA Voice Network



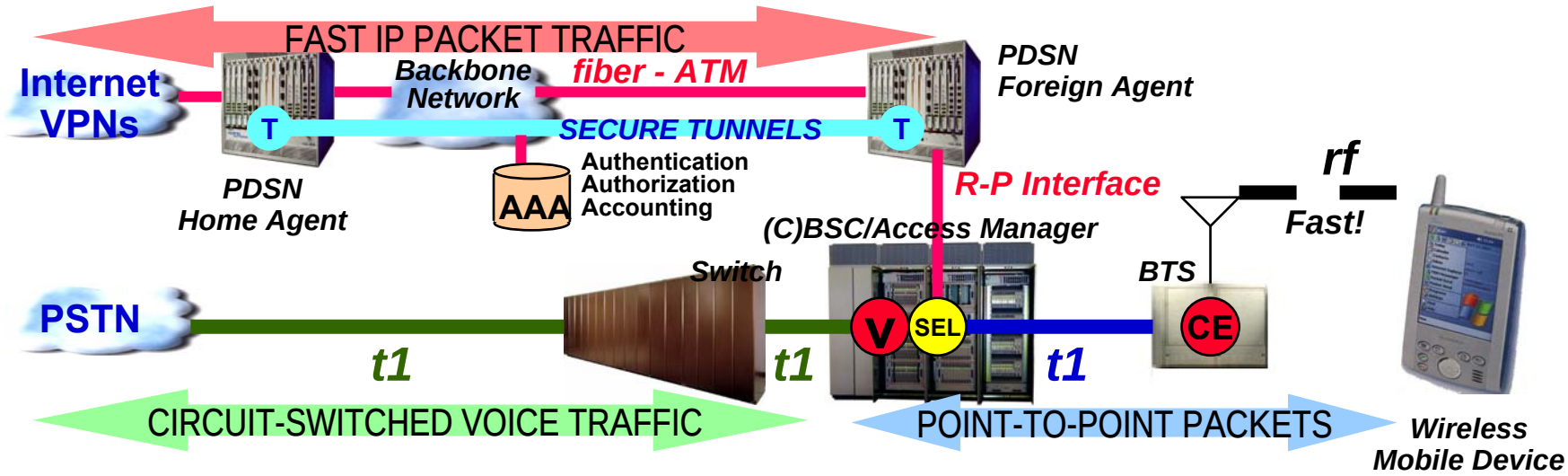
- 2nd Generation CDMA Networks were designed primarily to handle voice
- The CDMA voice conversation's 20-ms frames are carried as packets between mobile and the Selector
  - The selector assembles frames being sent to the mobile and disassembles frames coming from the mobile
  - Frame contents normally include voice and occasional signaling; may also include data if additional equipment is included (not shown)
- The vocoders in the BSC and the mobile convert the packet stream into continuous DS-0 audio for the end-users
  - The MSC makes a circuit-switched connection for call

2G IS-95 CDMA Network with 2G Slow Data Using the Interworking Function (IWF)



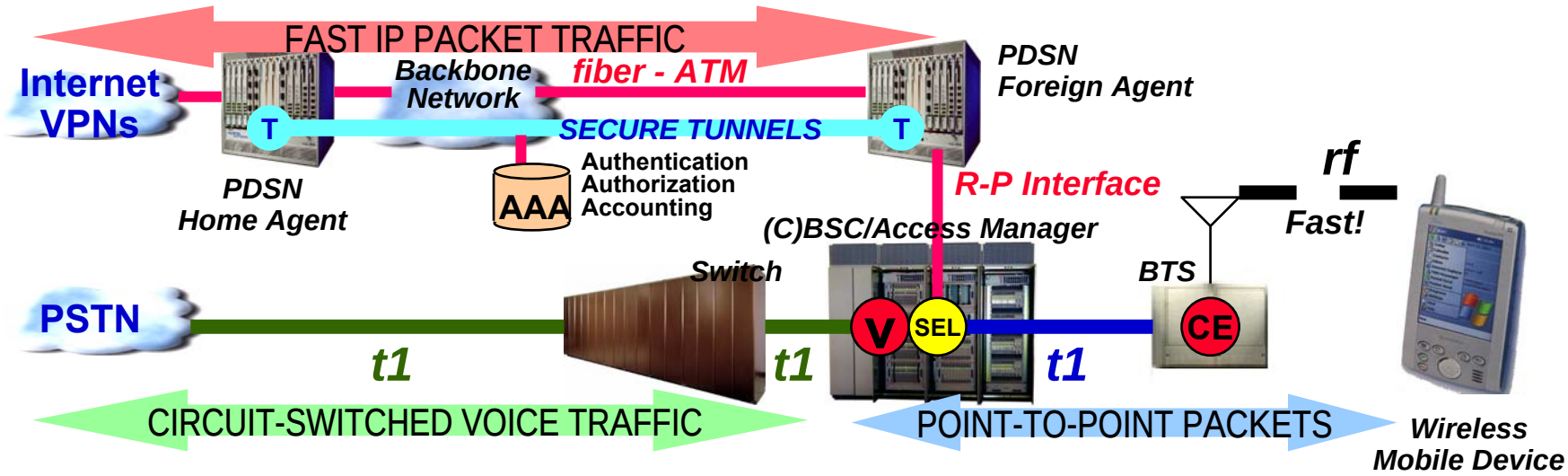
- Additional hardware is needed to carry data on a 2G network
- Data to/from the user connects near the selector in the BSC
  - Passed through the switch as 56kb/s data links in 64kb/s DS-0s
- Data connection to outside world handled by IWF Interworking Function
  - Includes modems to convert data stream into DS-0 for dial-up uses
  - Can contain data routers to access IP or PPP networks
  - May include capability for FAX and other communications modes

A 3G 1xRTT CDMA Network with Fast Data



- For full-featured data access over a 3G network, a true IP connection must be established to outside Packet Data Networks
- This requires a Packet Data Serving Node
  - ISP and operator-provided services are provided by external Home Network and Home Agent servers
  - Authentication, Authorization, and Accounting provided by external server
- The IWF (not shown above) is still maintained to allow old mobiles to use dial-up and WAP/wireless web keypad access

3G 1xRTT CDMA Network Element Descriptions



AAA - Authentication, Authorization, and Accounting - *may include both home and broker-provided functions*

BSC - Base Station Controller: *vocoders and packet router*

BTS - Base Transceiver Station
radio equipment

HA - Home Agent, **HN** - Home Network
IP access for Mobile IP on home and roaming networks

IWF - Interworking Function
provides necessary protocol conversions

MSC - Mobile Switching Center
voice/circuit-switched network hub

PDN - Packet Data Network
private, public, internet packet networks

PDSN - Packet Data Serving Node
routes user data packets to/from destinations

PSTN - Public Switched Telephone Network

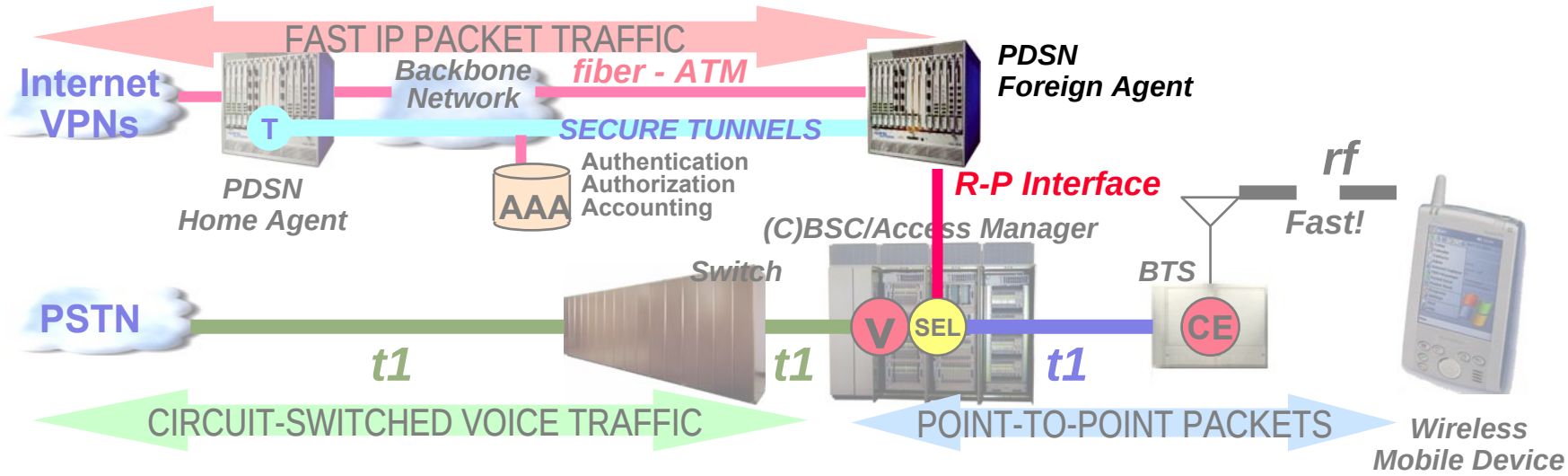
VLR - Visitor Location Register

HLR - Home Location Register

Authentication, Authorization & Accounting

- In a voice network, the central HLR is the master customer database and each switch's VLR is the local database of active users
- In a 1xRTT data network, these functions are provided by the AAA server
- the AAA server provides Authentication, Authorization, and Accounting functions for packet calls in a 1xRTT network
- AAA Server Functions:
  - Authentication
    - PPP authentication (PAP and CHAP)
    - Mobile IP authentication (User ID and password)
  - Authorization
    - Service profile for mobile, like an HLR stores users' voice profiles
    - Security key distribution
  - Accounting
    - Interface with external billing server
    - Links to enterprise systems for provisioning, packet data billing
  - Address management

PDSN Packet Data Serving Node

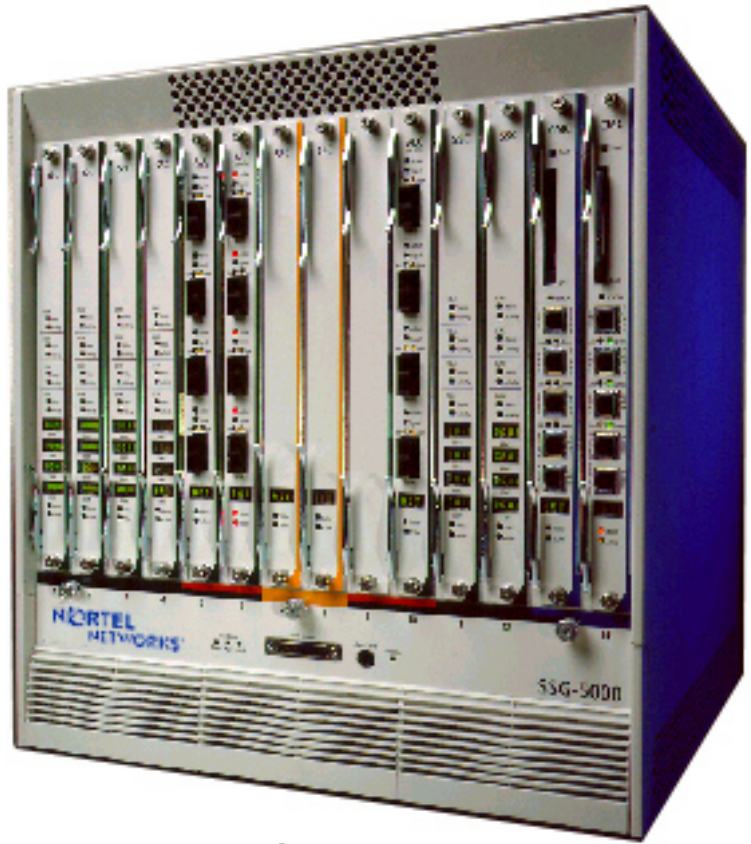


- The Packet Data Serving Node (PDSN) is a new network element to support packet data services
  - The PDSN is the heart of the Packet Data Network
  - The interface between the 1xRTT radio network and the PDSN is called the R-P interface
- Many network manufacturers offer competing PDSN solutions:

Nortel and Lucent PDSNs



LUCENT/SPRINGTIDE PDSN



NORTEL SHASTA PDSN

Ericsson, Motorola and 3COM PDSNs



ERICSSON
RXI 820 PDSN



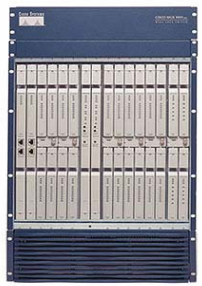
MOTOROLA PDSN
CISCO 7500 ROUTER



3COM PDSN



ERICSSON
AXC 706 PDSN



MOTOROLA Access Node
CISCO CATALYST 6509



3COM DISTRIBUTED
HOME AGENT

What the PDSN Does

- PDSN functions:
  - Provides logical links to the radio network (RN) across the radio-packet (R-P) interface
  - Routes packets to/from external packet data networks
    - Supports Simple IP and Mobile IP protocols
    - Uses a layer-2 tunneling protocol (L2TP) over a private IP network to implement packet transfer between the BSC and the public packet data network
  - Sets up, manages, and terminates PPP sessions for mobile users
  - Supports standard Internet routing protocols: maintains routing tables and performs route discovery
  - Provides Foreign Agent functionality supporting the Mobile IP protocol
  - Initiates Authentication, Authorization, and Accounting (AAA) for the mobile station client to the AAA server
  - Receives service parameters for the mobile client from the AAA server
  - Collects usage data for accounting to be relayed to the AAA
  - Allows data users to roam seamlessly across the provider's network while appearing to the PDN as if they were at a fixed network address

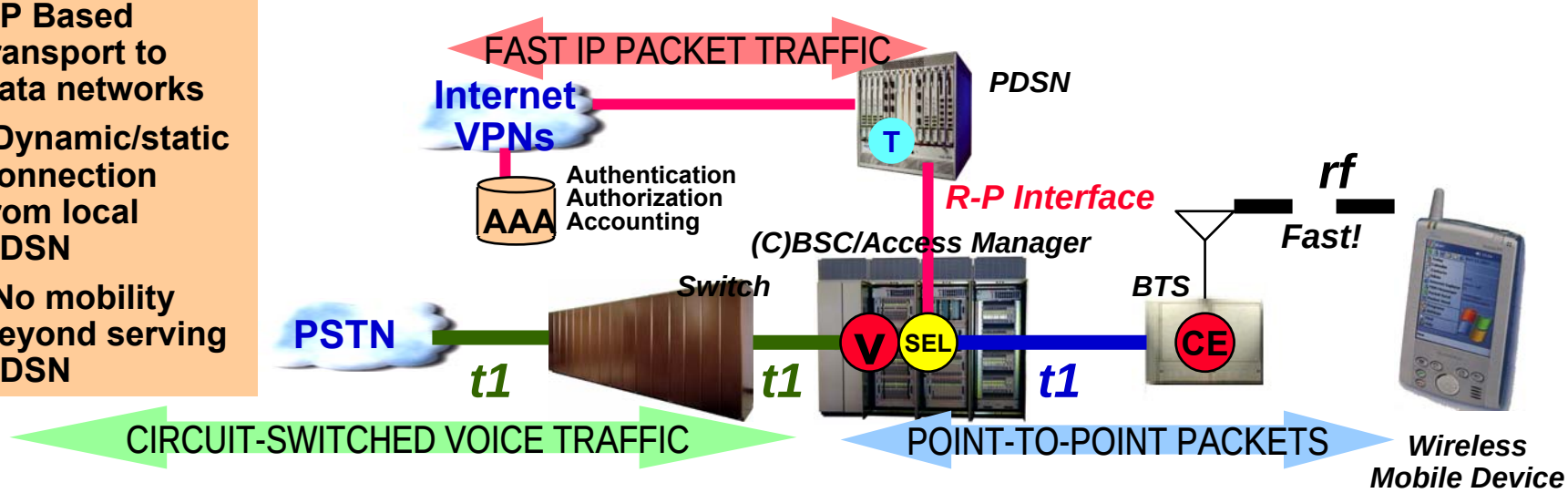
3G-1x Mobility Modes

- Simple IP Service
  - Dynamically Assigned IP Addresses
  - CHAP Authentication
  - Local Mobility (dynamic IP address valid within PDSN coverage area)
  - Uses Standard (MS-Windows) dial-up protocols in mobile / laptop
  - Optional Private Network Access via L2TP
- Mobile IP Service
  - Static (public or private) or Dynamically Assigned IP Addresses
  - MIP / AAA Authentication
  - Full Mobility Without Application Impact (even across MSCs)
  - Private Network Access via Corporate HAs
  - Secure Reverse Tunnels between FA and HA

Simple IP Network Architecture

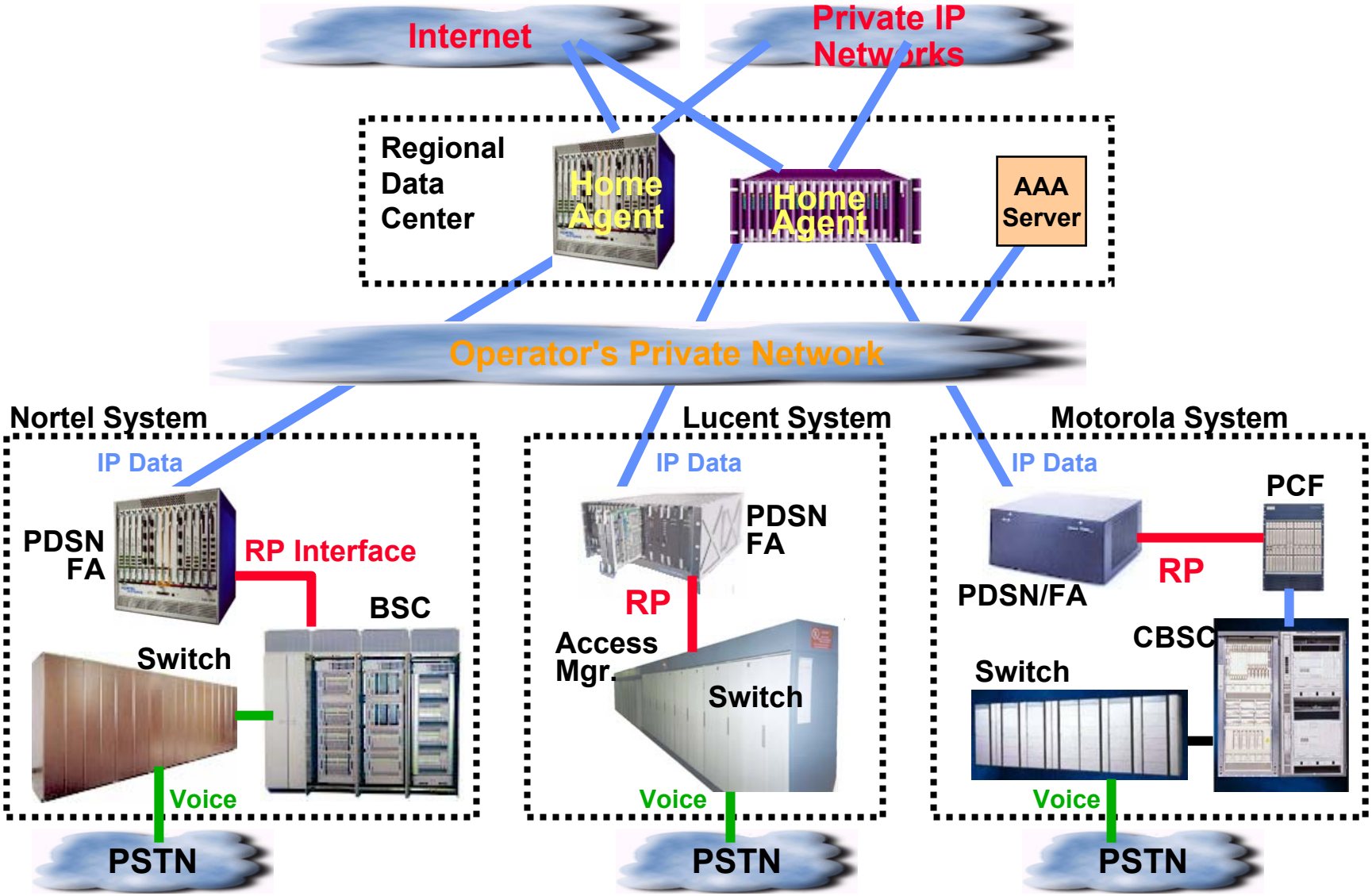
Simple IP

- **IP Based transport to data networks**
- **Dynamic/static connection from local PDSN**
- **No mobility beyond serving PDSN**



- In a Simple IP network, the mobile is able to connect to the external packet networks directly through the PDSN attached to the local BSC
- The IP address for the internet connection is assigned by the local PDSN from the pool of addresses available to it
- If the mobile moves into a different network, the data session ends
  - The mobile can establish an entirely new connection through the new network, if desired

Mobile IP in a Multi-Market Network



Mobile IP

- Subscriber's IP routing service is provided by a public IP network
- Mobile station is assigned a static IP address belonging to its Home Agent
- Mobile can maintain the static IP address even for handoff between radio networks connected to separate PDSNs!
- Mobile IP capabilities will be especially important for mobiles on system boundaries
  - Without Mobile IP roaming capability, data service for border-area mobiles will be erratic

MOBILE IP
IMPLICATIONS

•Handoffs possible between PDSNs
•Mobile can roam in the public IP network
•Mobile termination is possible while Mobile is in dormant or active mode

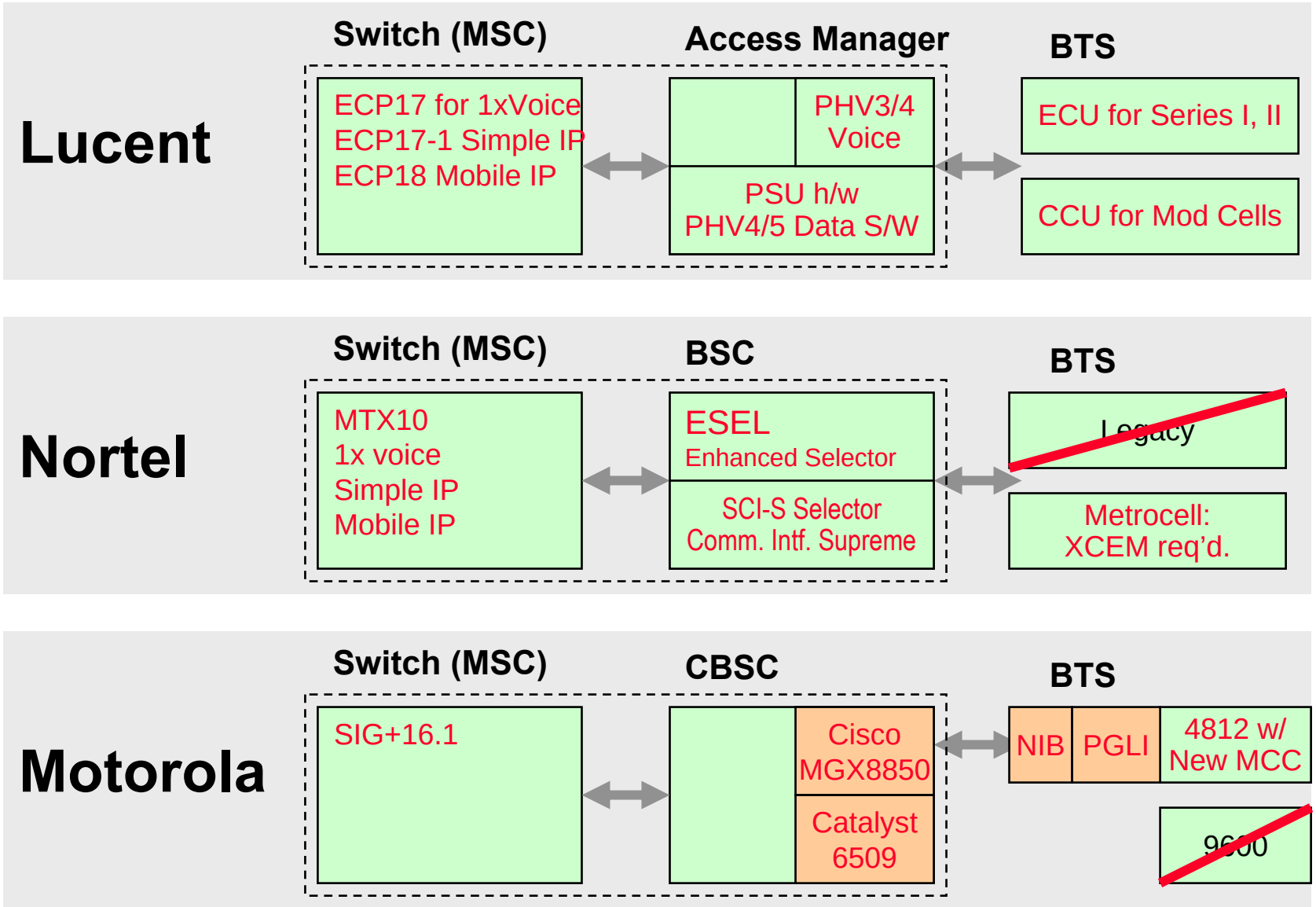
How the PDSN HA and FA Forward Your Packets

Mobile IP is a packet-forwarding arrangement that allows the mobile user to send and receive packets just as if they were physically present at their home agent location.



Upgrading an IS-95 Network to 1xRTT Operation

Network Upgrades Required for 1xRTT

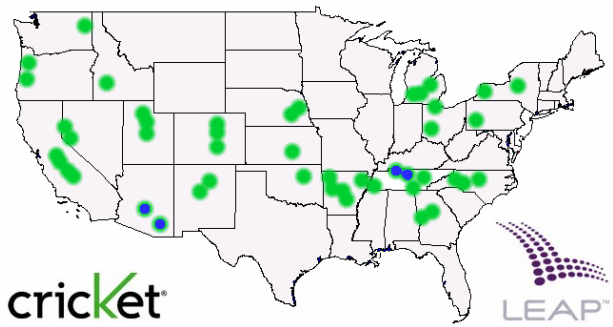


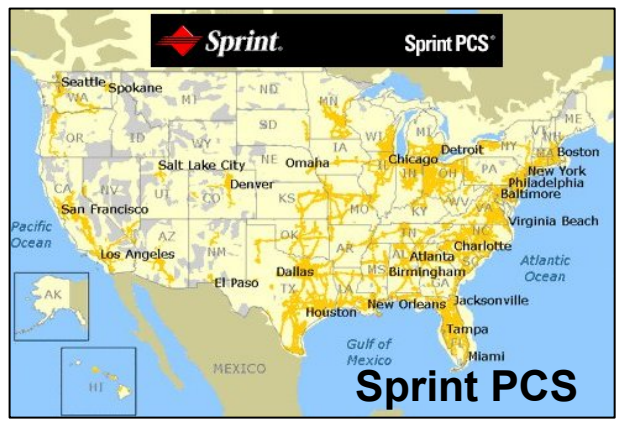
How 1xRTT Deployment Began, 1x Terminals Survey

CDMA2000 1xRTT Deployment

- 1xRTT has finally launched in US markets in 2002
- Verizon was first to market, launching 1xRTT in seven regions in 1Q2002
  - IS-95 and 1xRTT RC3 voice services
  - 1xRTT RC3 data: “Express Network”
  - Verizon Lucent and Nortel markets have launched; Motorola markets will follow around year-end 2002
- Leap Wireless “Cricket” deployed RC3 in selected markets 1Q2002
  - motivated solely by voice capacity gains, not planning to offer data
- Sprint PCS launched 1xRTT ***nationwide*** in August 2002
  - IS-95 and 1xRTT RC3 voice services
  - 1xRTT data services
  - “Picture phone” devices expected by year-end 2002







Some of the First 1xRTT Terminals

1xRTT PCMCIA CARDS





1x PHONES: VOICE & DATA



1x CF CARDS



Available now!

1x INTEGRATED PHONES-PDAS

POCKET-PC PDAs
using PCMCIA 1x CARDS



Audiovox Thera
Toshiba 2032

Pocket PC2002



Palm OS

Handspring Treo



SCH-I330

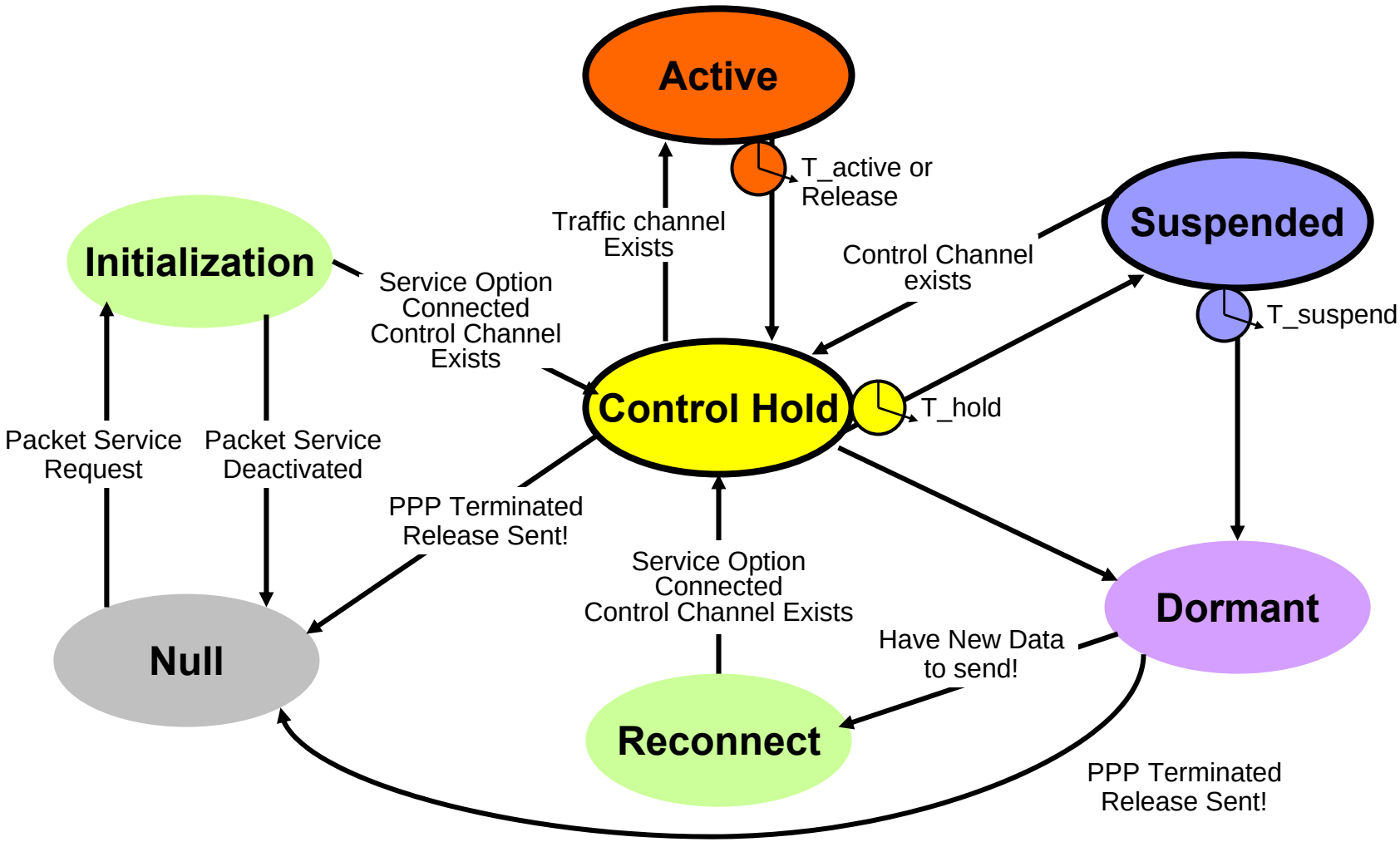


QCP 7135



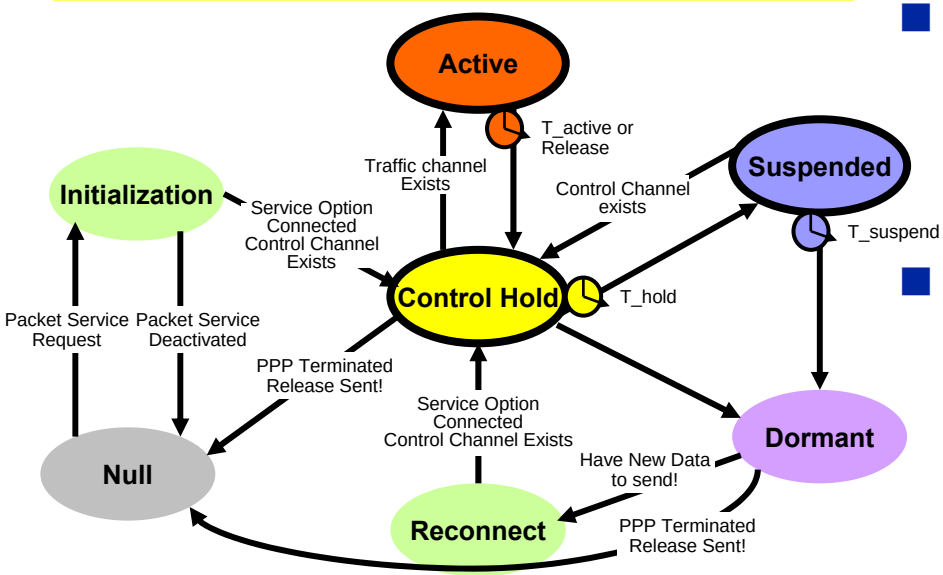
CDMA2000
Call Processing States

States and Transitions In the Data Service



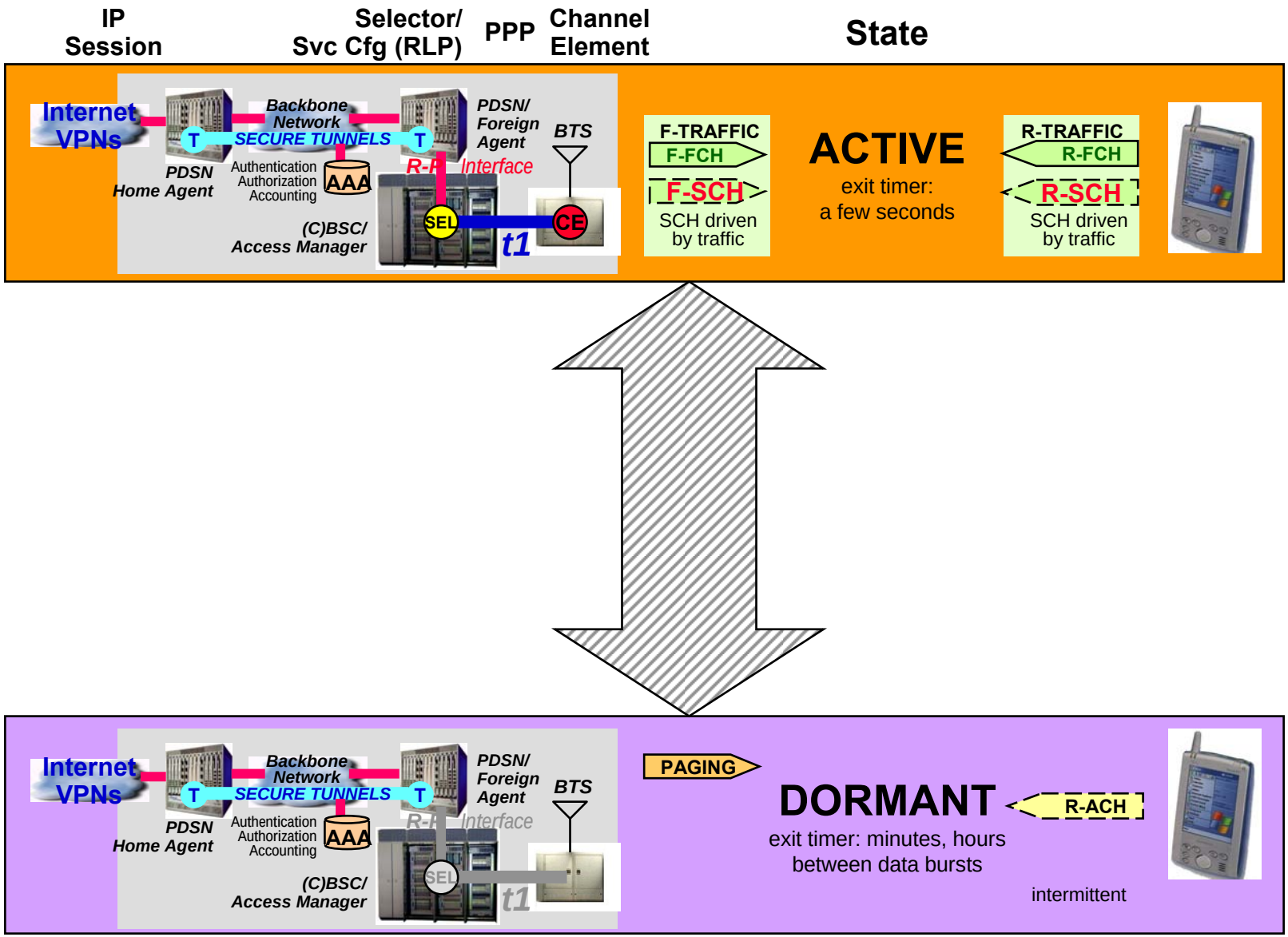
System MAC/LAC Parameters

•How is data flow managed?
•Can I keep my FCH all the time?
•Will my connection drop in a fade?
•When is an SCH turned on for me?
•How long will my SCH burst last?
•What is the data rate of my SCH?
•If I can't get a full-rate SCH, can I at least get a lower-rate SCH?
•Which kinds of traffic have priority?
•Do some users have higher priority?

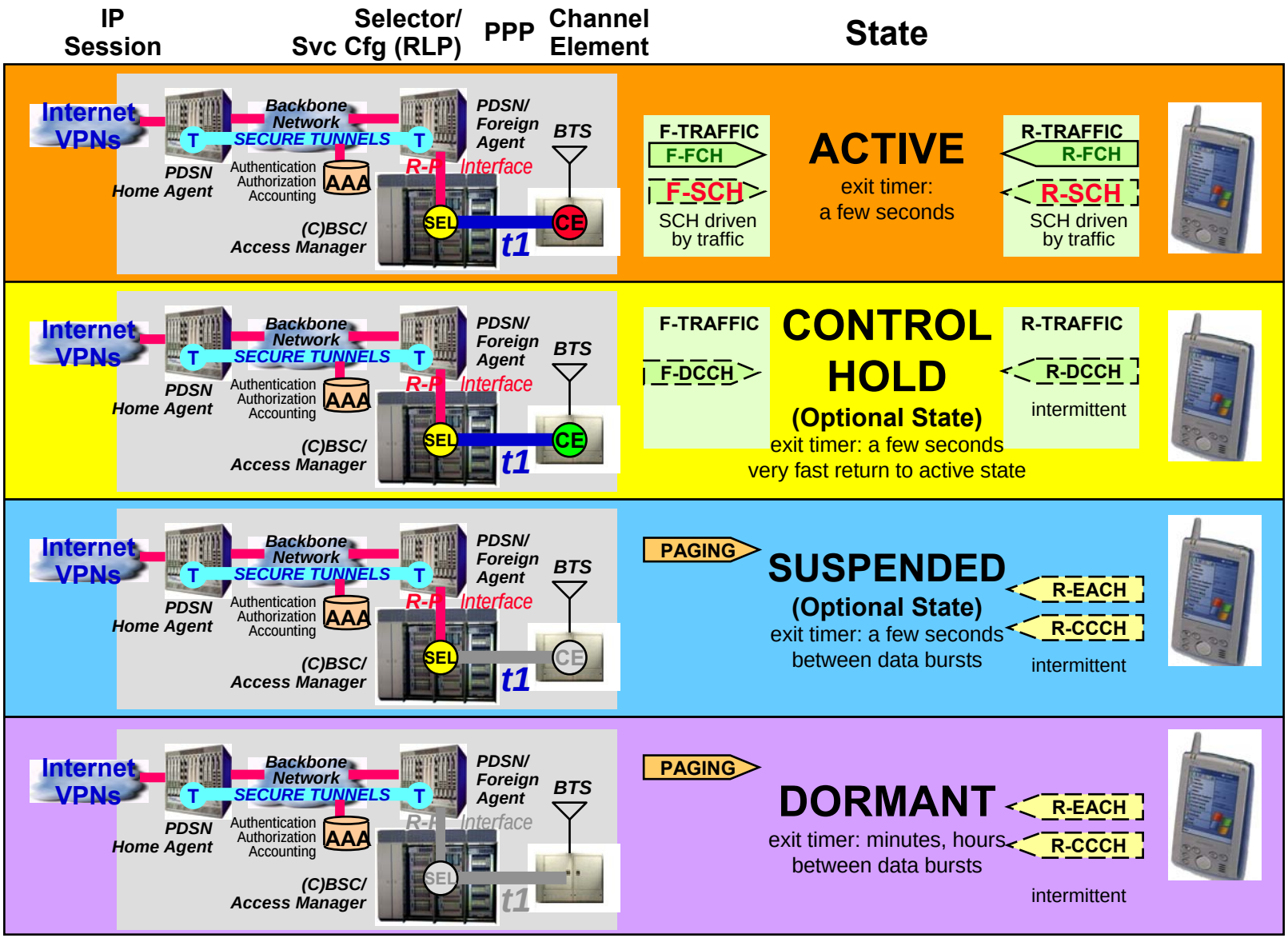


- The answers to all these questions are determined by MAC & LAC layer processes and parameters
- Each network manufacturer implements some subset of the MAC/LAC states and parameters specified in the IS-2000 standard
- Each manufacturer has its own unique parameter set to control state transitions
- Most networks begin operation using manufacturer-recommended defaults
  - as networks and applications mature, parameters will be fully optimized
- A basic knowledge of the manufacturers proprietary parameters gives very useful insights into configuration and performance issues

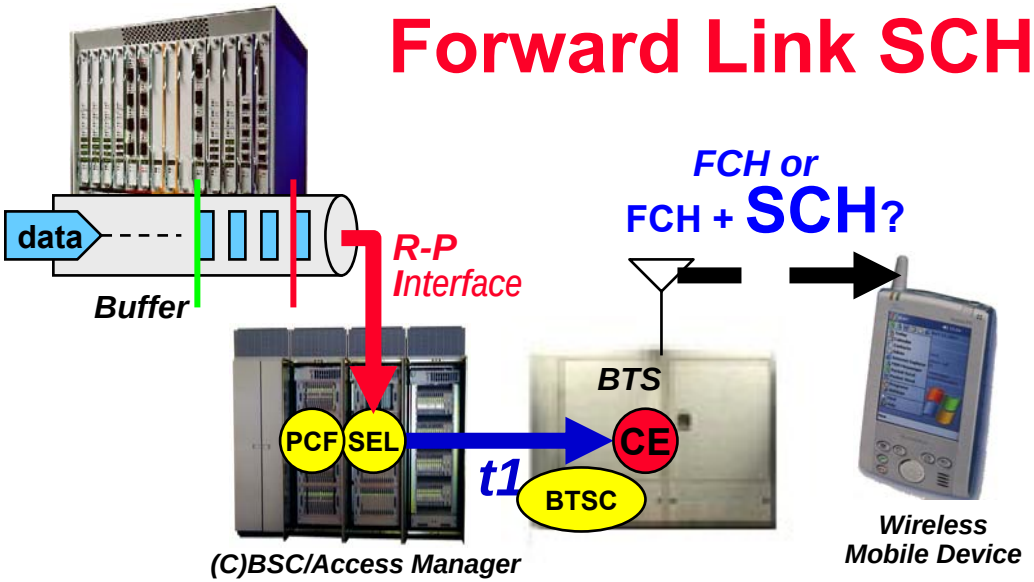
MAC States in 1xRTT Phase I

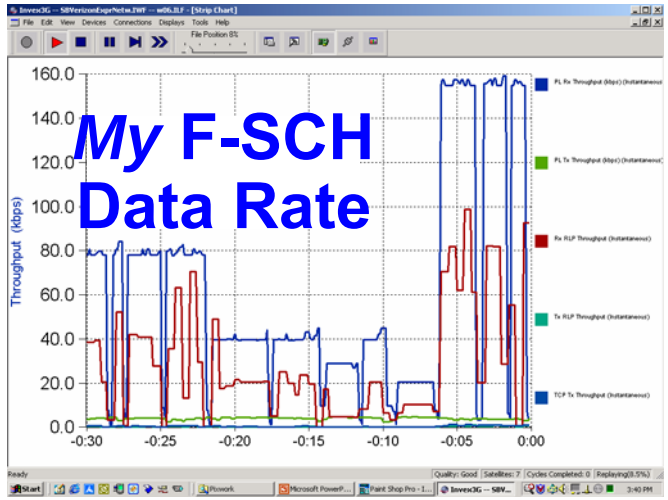


MAC States in 1xRTT Phase II



Forward Link SCH Scheduling

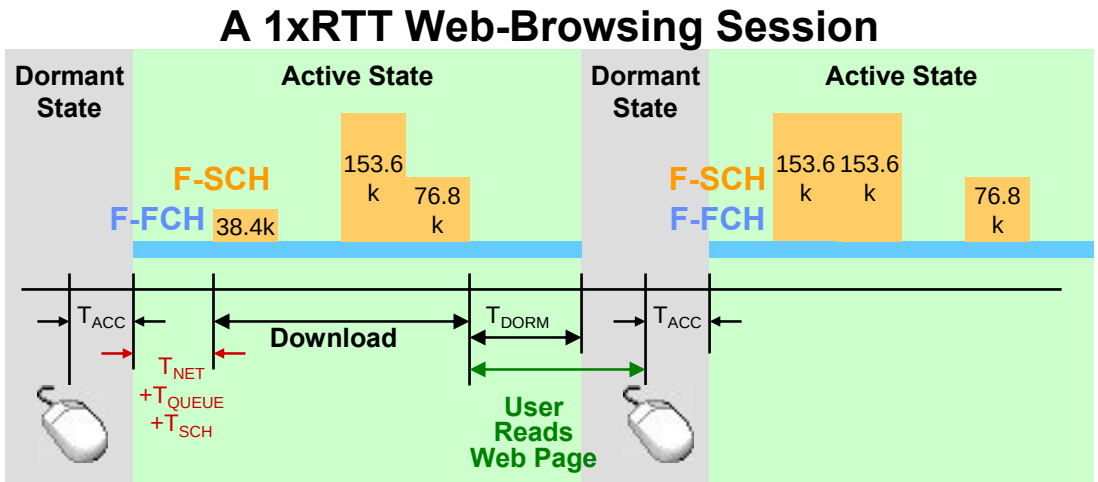




- The main bottleneck is the forward link itself: restricted by available transmitter power and walsh codes
- Each connected data User has a buffer in the PDSN/PCF complex
  - When waiting data in the buffer exceeds a threshold, the PDSN/PCF asks the BTS for an F-SCH. Its data rate is limited by:
    - Available BTS forward TX power; available walsh codes; competition from other users who also need F-SCHs; and mobile capability
  - When the buffer is nearly empty, the SCH ends; FCH alone
  - Occupancy timers and other dynamic or hard-coded triggers may apply
  - QOS (Quality of Service) rules also may be implemented, giving preference to some users and some types of traffic

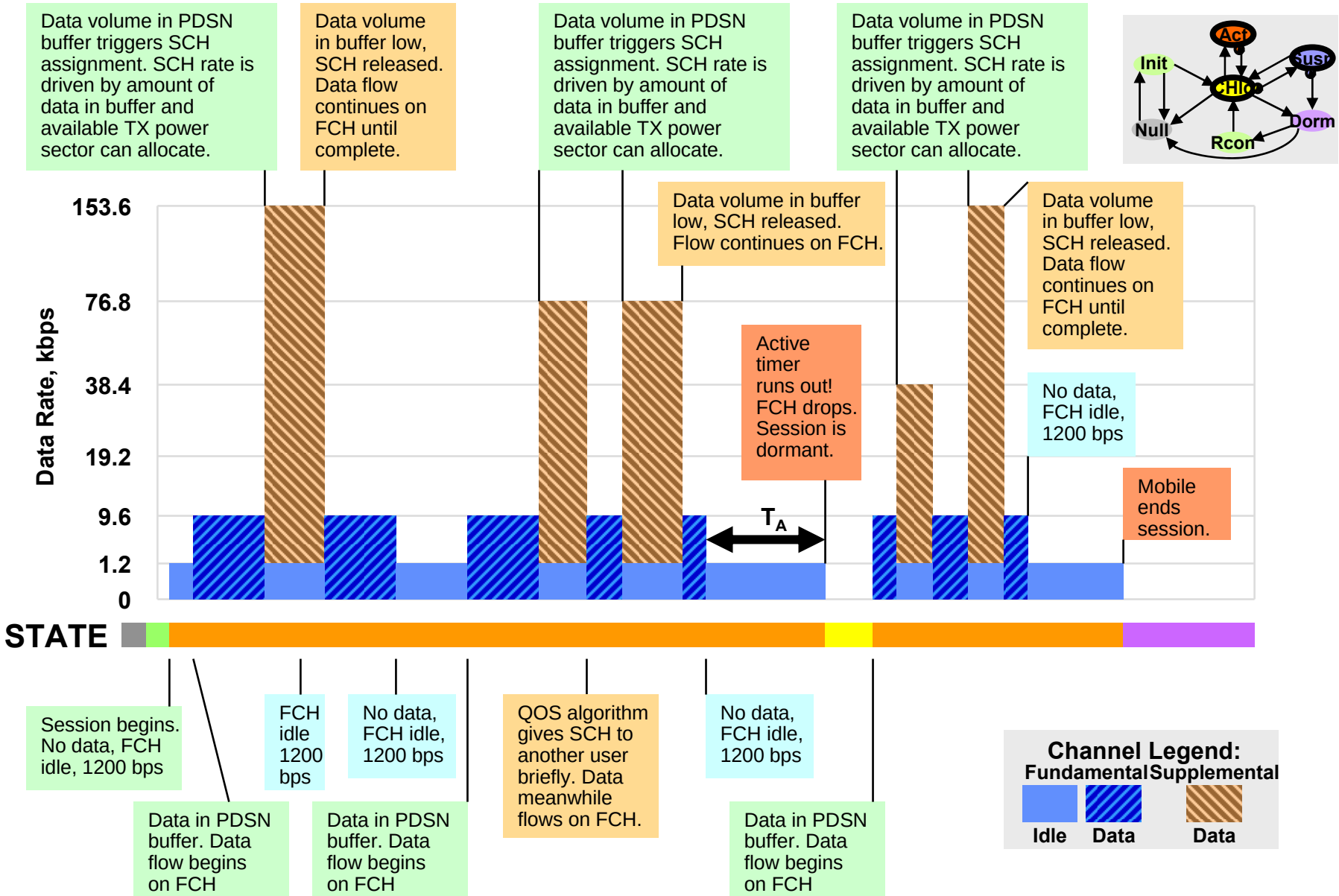
Active State: Managing F-FCHs, F-SCHs

- Every time a call enters the active state, an F-FCH is set up
  - at new call setup
  - at return from dormant to active state



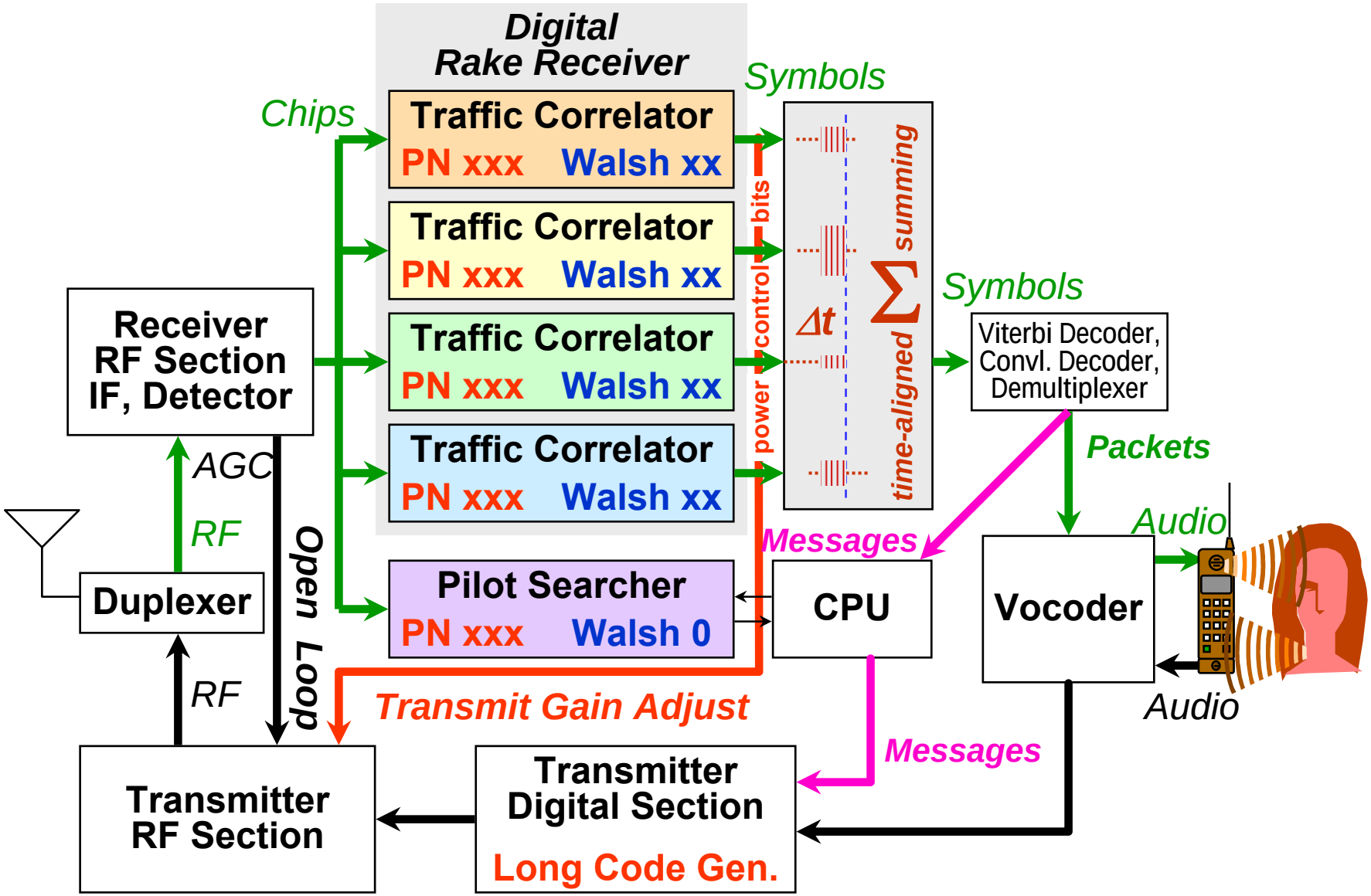
- Messages are exchanged on access and paging channels to setup F-FCH
- FCH setup only occurs if necessary resources are available
  - Walsh Codes, Forward Power, Reverse Power, backhaul, hardware
- If a new F-FCH is blocked because an existing F-SCH is tying up resources, the existing F-SCH is released early to free-up resources
- Networks today give same priority to new F-FCHs -- voice or data
- When data packet is finished, Active-to-Dormant timer begins
  - at end of timer, F-FCH is extinquished and link enters dormant state
  - but packet session is still maintained!

Forward Link Events in a Typical User Session



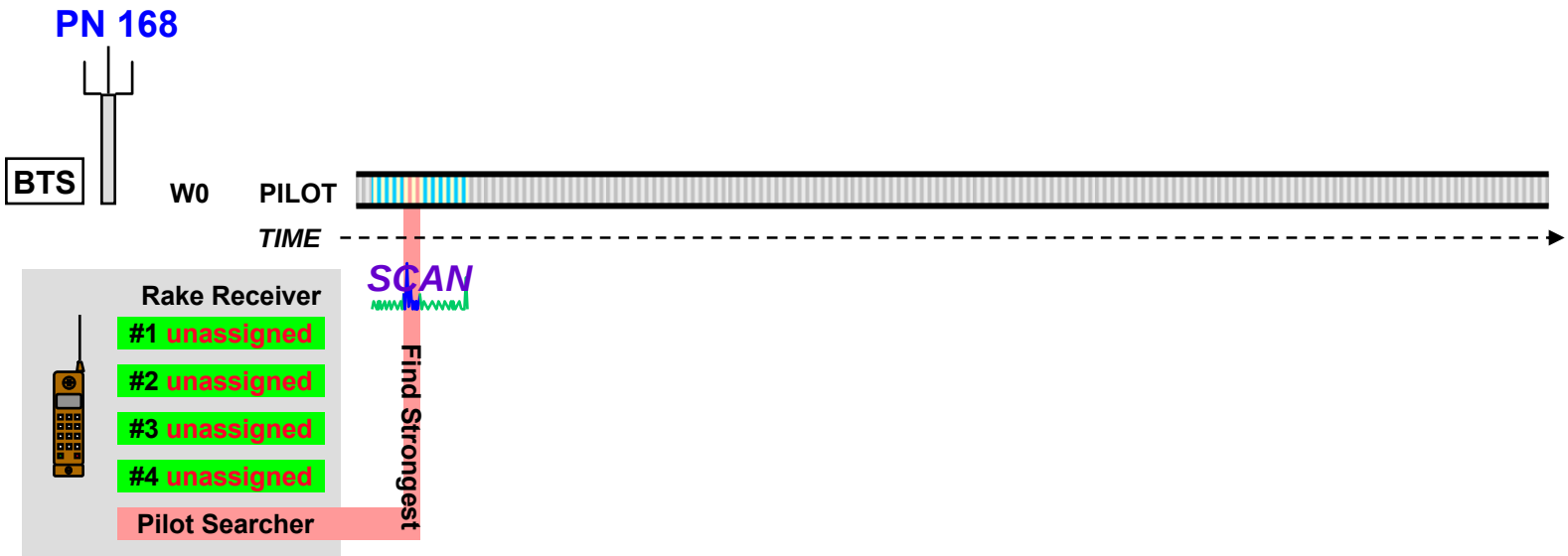
A Streamlined Visual Tour Of CDMA Call Processing

What's In a Handset? How does it work?

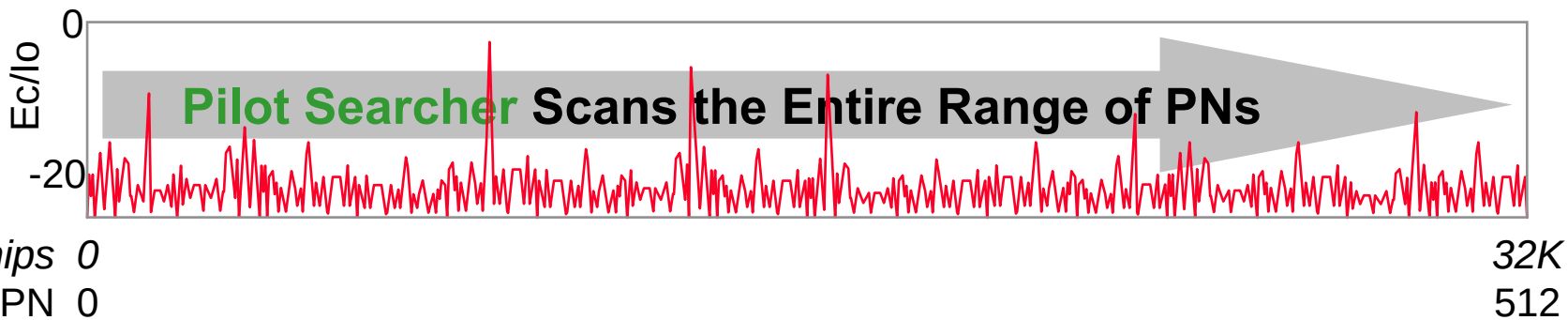


Finding the System and Starting Operation

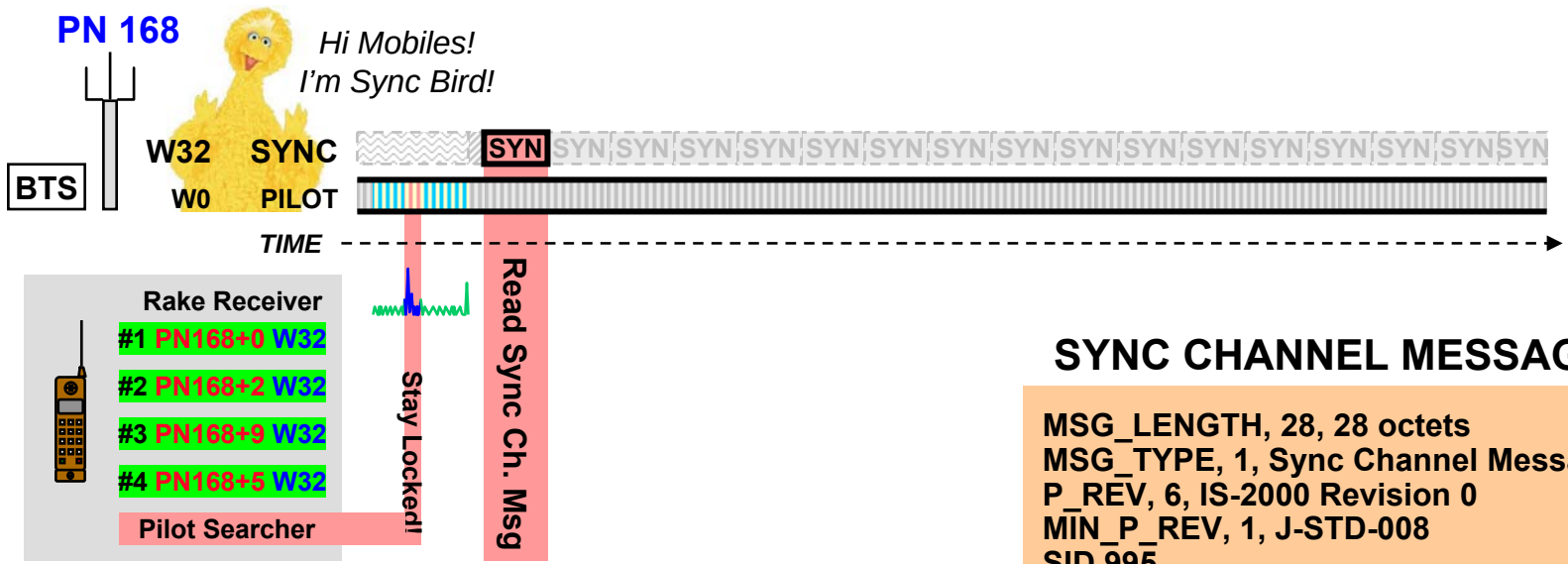
1. Find the Strongest Pilot!



- The pilot searcher of the phone spends about 3.4 seconds measuring every possible PN delay, in miniscule 1/8 chip delay steps, to see how much energy is being received from every nearby sector
- The sector with the strongest pilot is chosen



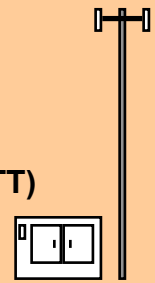
2. Read the Sync Channel Message



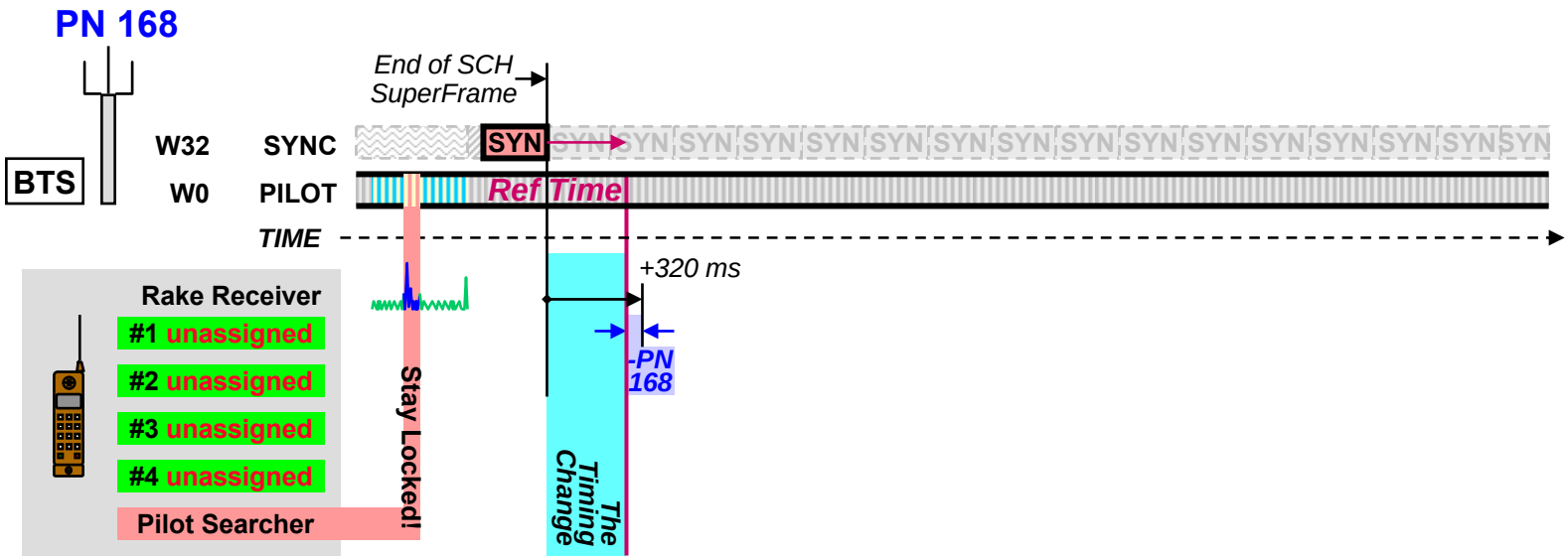
- Great! We found a signal. Now we know:
  - The strongest pilot available
  - The exact timing of this pilot
- We do NOT yet know
  - This pilot's PN offset
  - 20 msec frame timing of channels
  - Long Code State
- The SYNC channel is a special channel timed exactly in step with the short PN sequence
  - It tells us all these unknown quantities

SYNC CHANNEL MESSAGE

MSG_LENGTH, 28, 28 octets
MSG_TYPE, 1, Sync Channel Message
P_REV, 6, IS-2000 Revision 0
MIN_P_REV, 1, J-STD-008
SID 995,
NID 3,
PILOT_PN 240
LC_STATE, 0x00 25 93 12 7C FA,
SYS_TIME, 0x02 20 34 B7 53,
10/23/2001 11:02:54
LP_SEC, 13,
LTM_OFF, 54, -660 minutes
DAYLT, 1, Yes
PRAT, 1, 4800 bps
CDMA_FREQ, 274 (IS-95)
EXT_CDMA_FREQ, 274 (1xRTT)
SR1_BCCH_SUPPORTED, 0
SR3_INCL, 0, No
RESERVED, 0,



3. The Timing Shift: Adjust Phone Internal Clocks



- This timeline shows each step as the mobile acquires the system
- First search all PNs to find the strongest pilot
- Read the Sync Channel Message to learn times and LC state
  - The times and state refer to a future moment 320 ms after the end of the Sync Channel superframe, minus the BTS PN offset. This waiting period is called the Timing Change.

4. Is This the Right System to Use? Scan the PRL for Anything Better

ROAMING LIST

Roaming List Type:	**IS-683A**
Preferred Only:	**FALSE**
Default Roaming Indicator:	**0**
Preferred List ID:	**10018**

- It's not enough just to find a CDMA signal
  - We want the CDMA signal of our own system or a favorite roaming partner
- Phones look in the PRL to see if there is a more preferred signal than whatever they find first
  - They check frequencies in the Acquisition Table until they find the best system, or look down the list level by level

SYSTEM TABLE

INDEX	SID	NID	NEG/ PREF	GEO	PRI	ACQ INDEX	ROAM IND
296	4144	65535	Pref	NEW	SAME	13	1
297	4812	65535	Pref	SAME	MORE	21	1
298	205	65535	Pref	SAME	SAME	4	0
299	208	65535	Pref	SAME	MORE	37	0
300	208	65535	Pref	SAME	SAME	4	0
301	342	65535	Pref	SAME	MORE	37	0
302	342	65535	Pref	SAME	SAME	4	0
303	478	65535	Pref	SAME	SAME	4	0
304	1008	65535	Pref	SAME	SAME	4	0
305	1010	65535	Pref	SAME	SAME	4	0
306	1008	65535	Pref	SAME	SAME	4	0
307	1315	65535	Pref	SAME	SAME	4	0
308	1385	65535	Pref	SAME	MORE	4	0
309	143	65535	Pref	SAME	MORE	37	0
310	143	65535	Pref	SAME	MORE	4	0
311	4103	65535	Pref	NEW	SAME	3	1
312	4157	65535	Pref	SAME	MORE	2	1
313	312	65535	Pref	SAME	SAME	4	0
314	444	65535	Pref	SAME	MORE	37	0
315	444	65535	Pref	SAME	SAME	4	0
316	1008	65535	Pref	SAME	SAME	4	0
317	1012	65535	Pref	SAME	SAME	4	0
318	1014	65535	Pref	SAME	SAME	4	0
319	1688	65535	Pref	SAME	MORE	4	0
320	113	65535	Pref	SAME	MORE	37	0
321	113	65535	Pref	SAME	SAME	4	0
322	179	65535	Pref	SAME	MORE	37	0
323	179	65535	Pref	SAME	SAME	4	0
324	465	65535	Pref	SAME	SAME	4	0
325	2119	65535	Pref	SAME	MORE	4	0
326	2094	65535	Pref	SAME	MORE	4	0
327	1005	65535	Pref	SAME	SAME	4	0
328	1013	65535	Pref	SAME	SAME	4	0

Climb a GEO GROUP

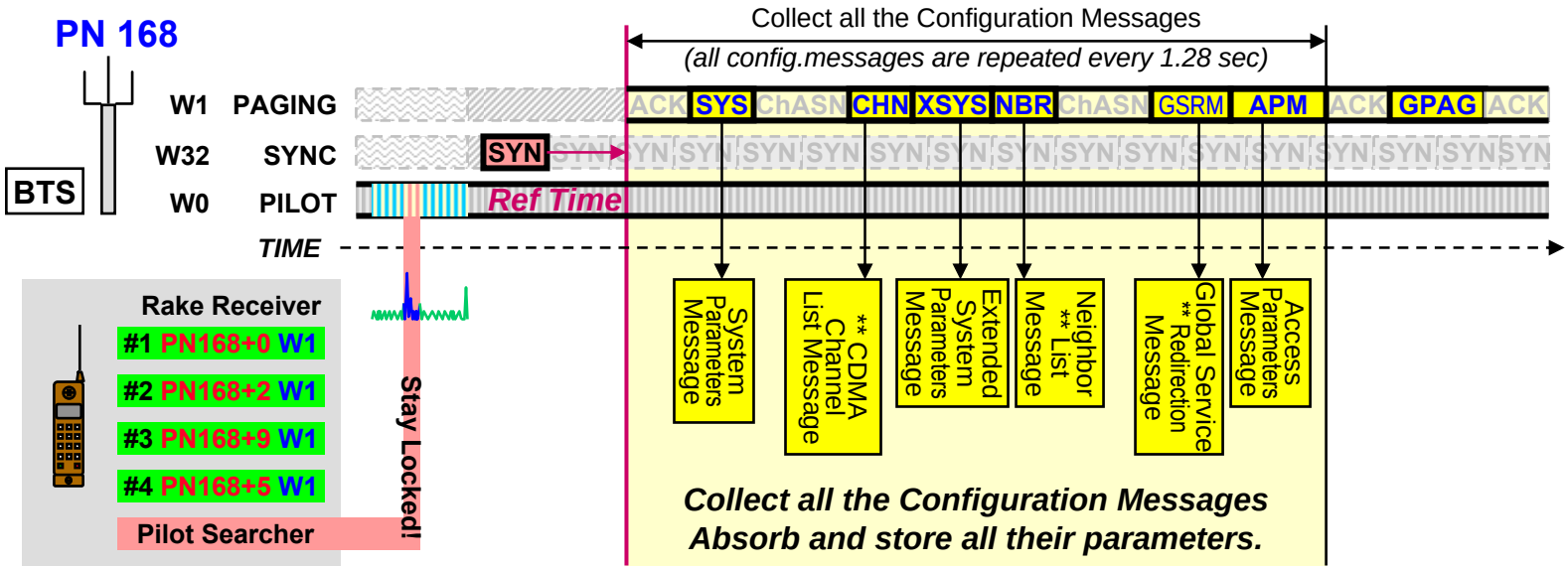
Climb a GEO GROUP

ACQUISITION TABLE

INDEX	ACQ TYPE	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9
0	6	500	425	825	575	850	325	625		
1	6	575	625	500	425					
2	6	50	100	75	475	825	850	175	250	
3	6	25	200	350	375	725	50	475	175	250
4	1	Both								
5	6	450	500	350	575	650				
6	6	675	500	600	575	475				
7	6	250	50	175						
8	6	550	375	425	625					
9	6	75	50	175	250					
10	6	200	250	175	50					
11	6	425	500	575	25	325	650			
12	6	500	575	475		675				
13	6	500	625	350	50	375	775	575	725	425
14	6	650	500	575	75	425	50	575		
15	6	25	50	375	350	250	175			
16	6	425	550	225	725	750	775			
17	6	200	50	175	375	250				
18	6	825	850	925						
19	6	350	325	375	675	25	1175	725	600	100
20	6	750	725	775						
21	6	325	725	350	750	375	775	425	575	625
22	6	1150	1175							
23	6	350	875	325	375	1175				
24	6	25	1175	825	200	75	175	250		
25	6	50	200	25	100	250	75			
26	6	500	1075	850	825					
27	1	A								
28	1	B								
29	5	A								
30	5	B								
31	5	C								
32	5	D								
33	5	E								
34	5	F								
35	4	A								
36	4	B								
37	4	Both								
38	6	350	825							
39	6	25	100							
40	6	675	600	750	850	1175	775			
41	6	850								
42	6	650								
43	6	450	475							
44	6	325	350	375	1025	1050	1075			
45	6	150	475	625	675					
46	6	1025	1050	1075						

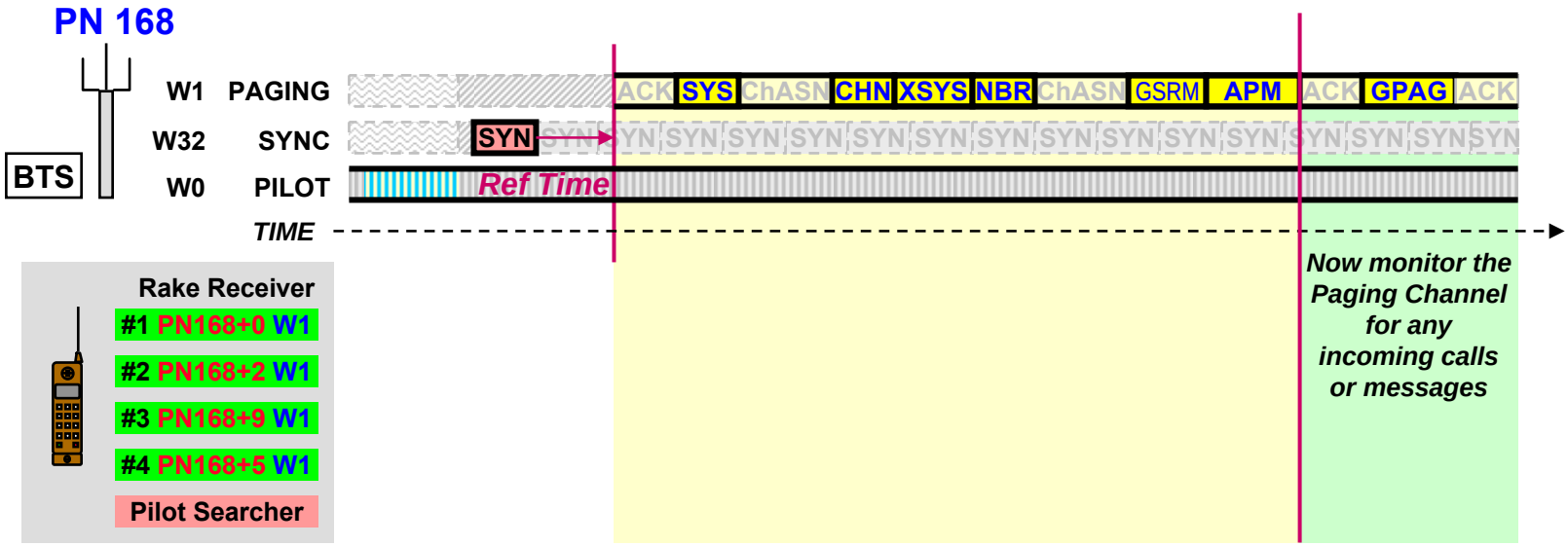
PRL: Preferred Roaming List
Programmed into each phone by the system operator; can be updated over the air.

5. Collect the Configuration Messages!



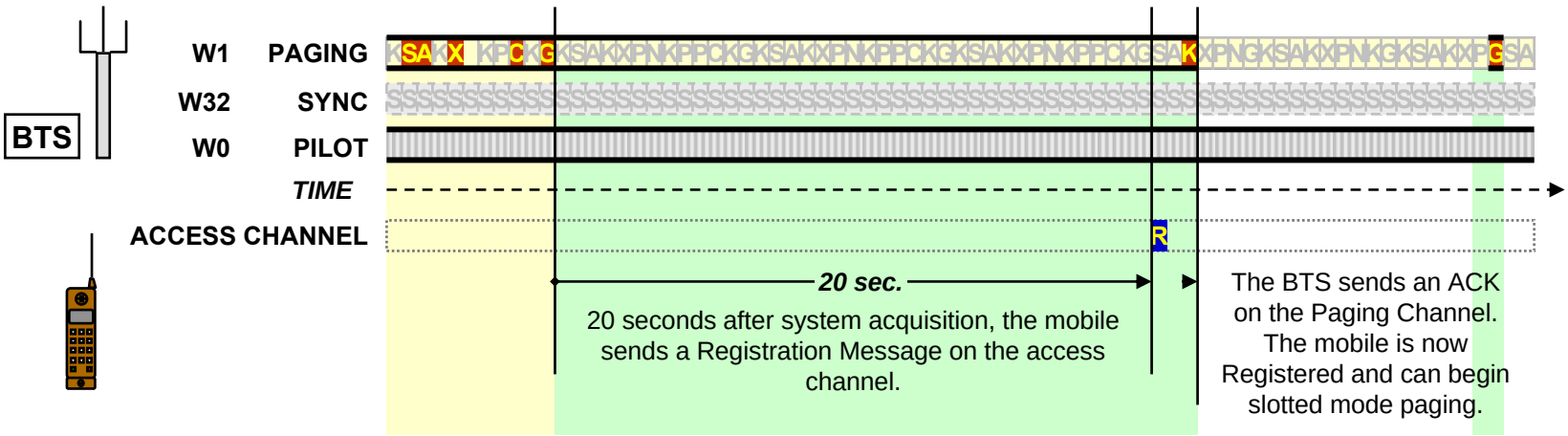
- The Configuration Messages tell the mobile everything it needs to know to successfully operate on the system
  - Access Parameters Message *(how to behave on the access channel)*
  - System Parameters Message *(registration, handoff, window settings)*
  - Extended System Parameters Message *(how to identify; packet details)*
  - Channel List Message *(list of all carrier frequencies on this sector)*
  - Neighbor List Message *(list of nearby sectors to watch out for)*
  - Global Service Redirection Message *("don't stay here - go over there")*

6. Welcome! Just Monitor the Paging Channel



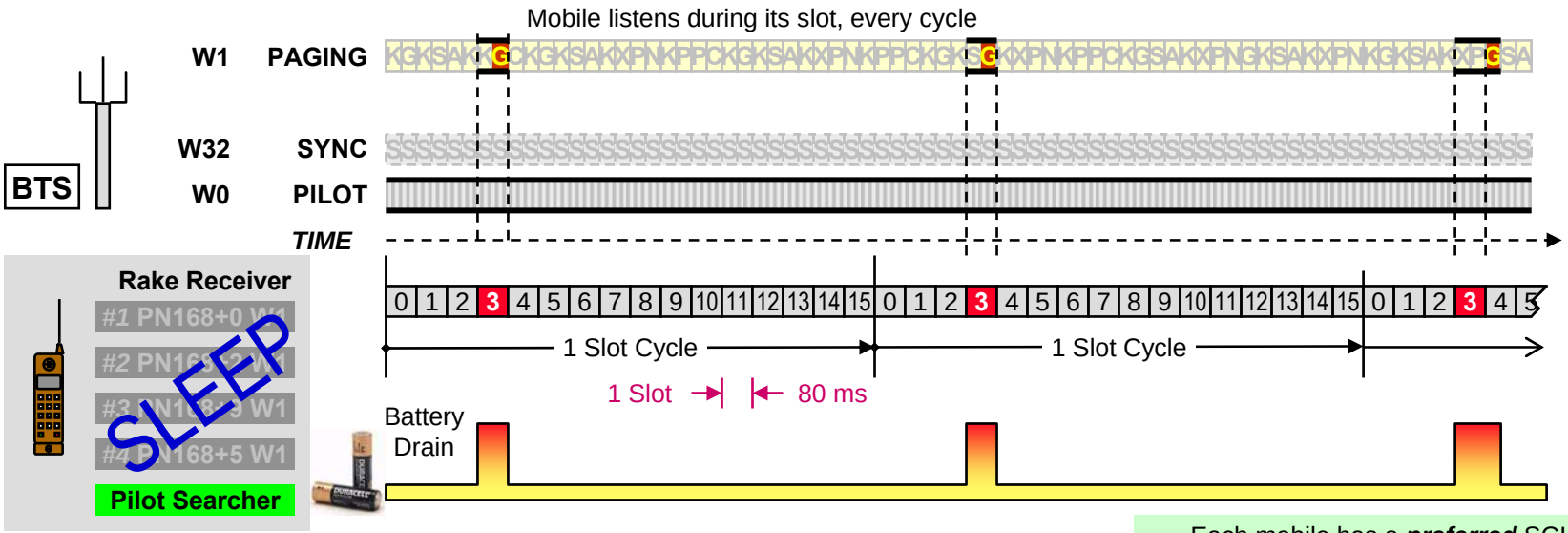
- Listen to see if you get any incoming calls or short messages!

Registration: Mobile, Sign In Please



- After acquiring the system, the mobile must register
  - This allows the current system to update the HLR with the mobile's location, so incoming calls can be delivered here
  - It also allows the mobile to tell the system if it wants to do slotted mode paging, and if so, what Slot Cycle Index.
- A "holdoff" timer delays initial registration 20 seconds after acquisition
  - This avoids needless registration by mobiles just being turned on to check who is the owner, or other short power-on/off uses
- Registration has many different controlling parameters, all declared by the system on the paging channel in the System Parameters Message

Stretch Your Battery! Use Slotted Mode Paging

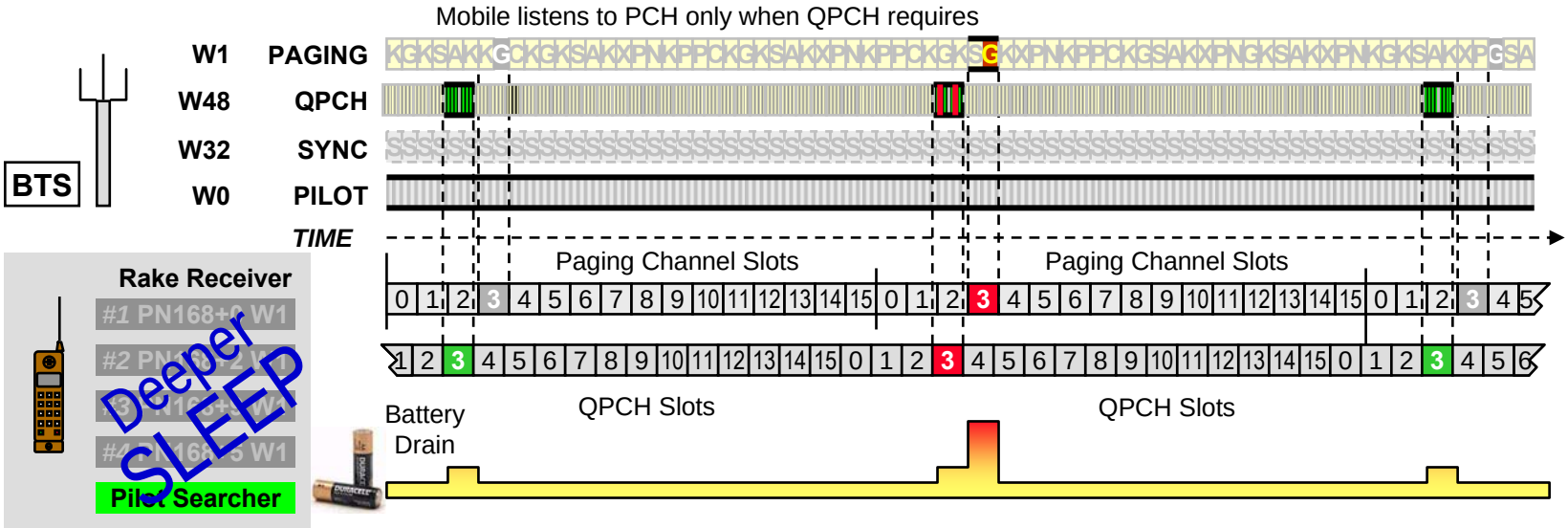


- Slotted Mode Paging is a battery-saving trick
  - After registering with the system, the mobile goes into sleep mode with low battery drain
  - It wakes on a schedule to listen for pages
- Page slots are 80 ms. Long
- Slot cycles can be set to many lengths
- Longer cycles give better battery life, but introduce longer possible delays in call delivery
- Each mobile uses Hashing with its IMSI and SCI to determine which slot it should always monitor

Each mobile has a ***preferred*** SCI programmed by the vendor. The system also declares a ***maximum*** slot cycle index, which mobiles may not exceed.

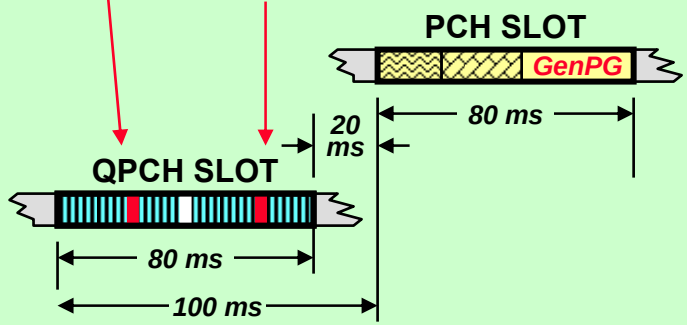
Slot Cycle Index (**SCI**)	Number Slots in Cycle	Length of Cycle, sec.
0	16	1.28 sec.
1	32	2.56 sec.
2	64	5.12 sec.
3	128	10.24 sec.
4	256	20.48 sec.
5	512	40.96 sec.
6	1024	81.92 sec.
7	2048	163.84 sec.

Even Better: CDMA2000 Slotted Mode Paging Using the Quick Paging Channel (QPCH)



- IS-95 mobiles must monitor their PCH slots during ***every*** slot cycle
  - Must wake up 1000's of times per hour and run high-drain message parsers, even if they are not paged
- The Quick Paging Channel (QPCH) is a simpler bitstream which notifies a 1xRTT mobile to monitor the PCH, only when a page is coming for its IMSI group
  - There are at least xx IMSI groups. A mobile knows its group by hashing.

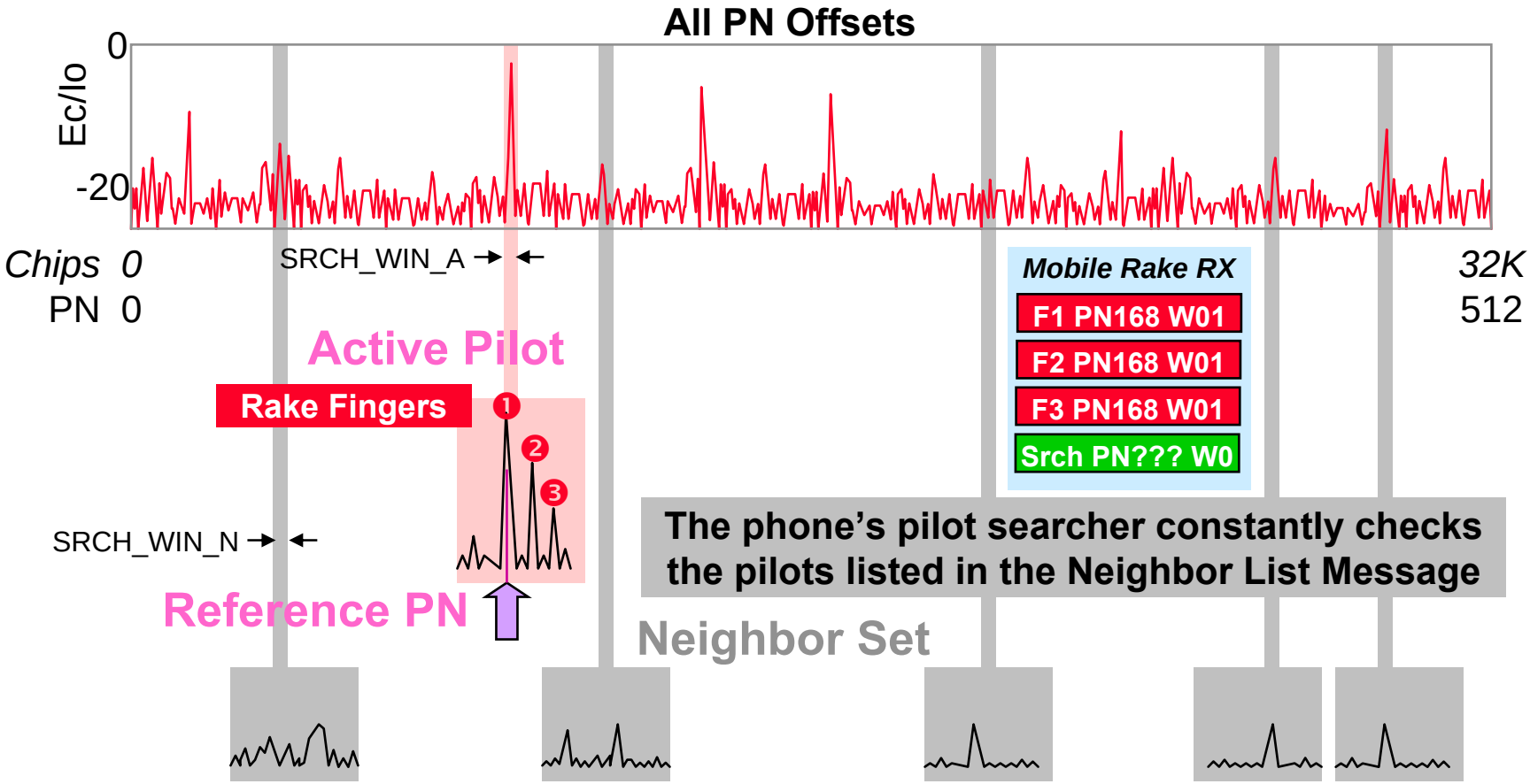
Mobile hashes using its IMSI to recognize which indicator bits it should monitor. If the bits are on, the mobile wakes up and listen to the next PCH slot – somebody watching those bits will be paged.



Idle Mode Handoff

- An idle mobile always uses the best available signal
  - In idle mode, it isn't possible to do soft handoff and listen to multiple sectors or base stations at the same time -- the paging channel information stream is different on each sector, not synchronous -- just like ABC, NBC, CBS, and CNN TV news programs aren't in word-sync for simultaneous viewing
  - Since a mobile can't combine signals, the mobile must switch quickly, always enjoying the best available signal
- The mobile's pilot searcher is constantly checking neighbor pilots
- A Mobile might change pilots for either of two reasons:
  - It notices another pilot at least 3 db stronger than the current active pilot, and it stays this good continuously for at least five seconds: mobile switches at end of the next superframe
  - Mobile loses the current paging channel. If another signal is better than the old active sector, change immediately to the new one.
- On the new paging channel, if the mobile learns that registration is required, it re-registers on the new sector

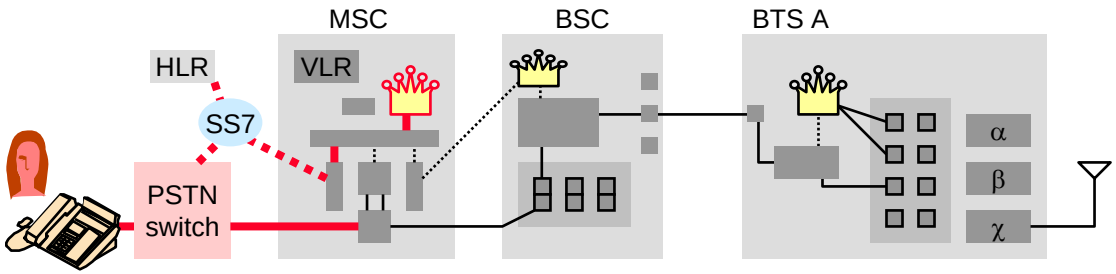
Idle Mode on the Paging Channel: Meet the Neighbors, track the Strongest Pilot



If the searcher ever notices a neighbor pilot substantially stronger than the current reference pilot, it becomes the new reference pilot and the phone switches over to its paging channel on the next superframe. This is called an *idle mode handoff*.

Receiving An *Incoming* Call

Incoming Call Termination – Voice





Rake Receiver

#1 PN168+0 W01

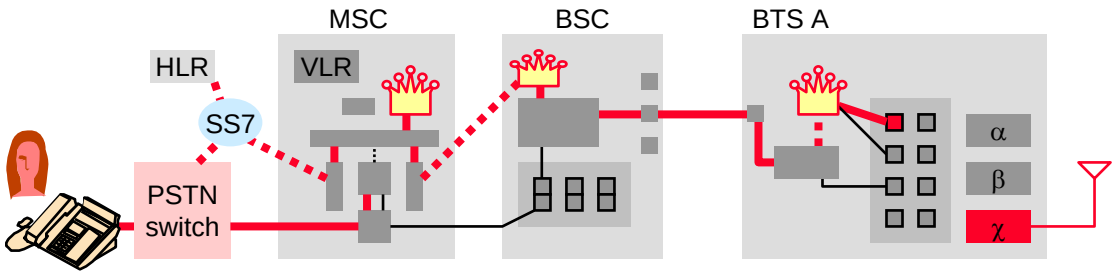
#2 PN168+2 W01

#3 PN168+9 W01

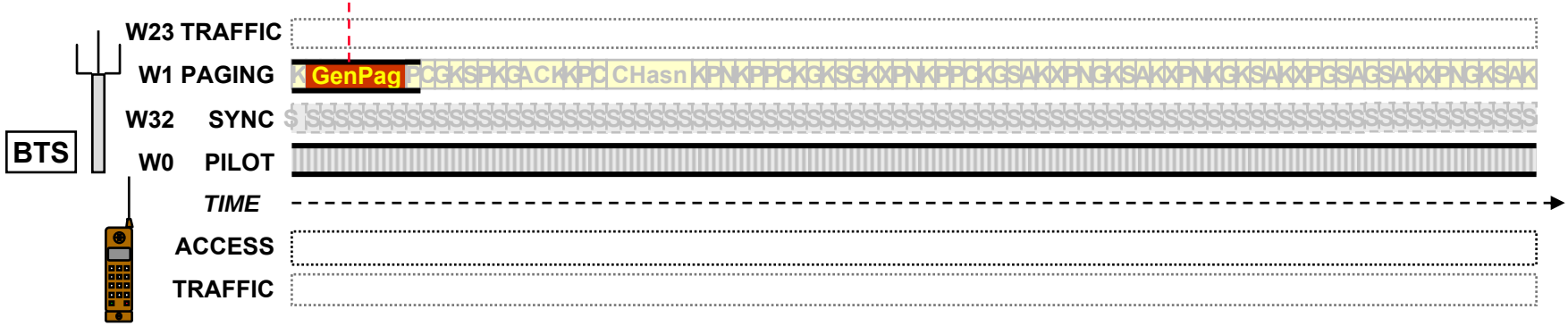
#4 PN168+5 W01

Pilot Searcher

Incoming Call Termination – Voice



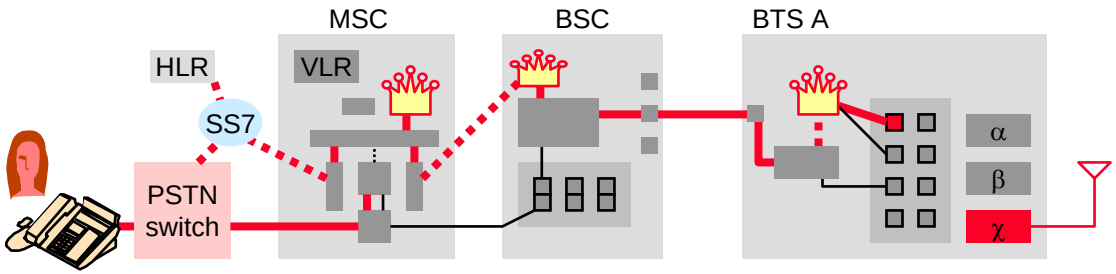
Scott's mobile, are you there? You have a call.



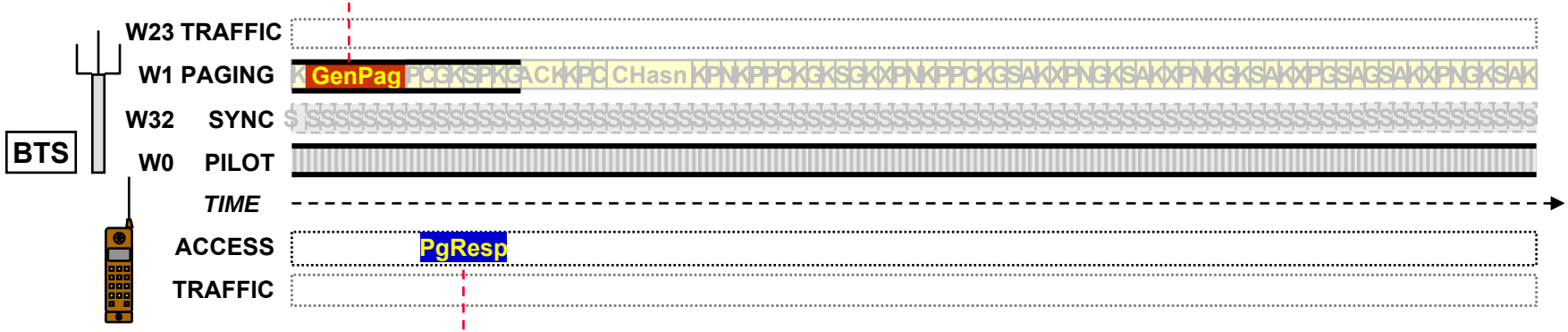
Rake Receiver

- #1 PN168+0 W01
- #2 PN168+2 W01
- #3 PN168+9 W01
- #4 PN168+5 W01
- Pilot Searcher

Incoming Call Termination – Voice



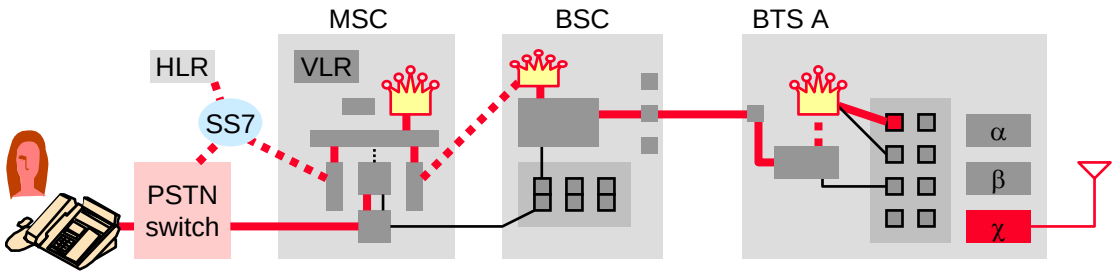
Scott's mobile, are you there? You have a call.

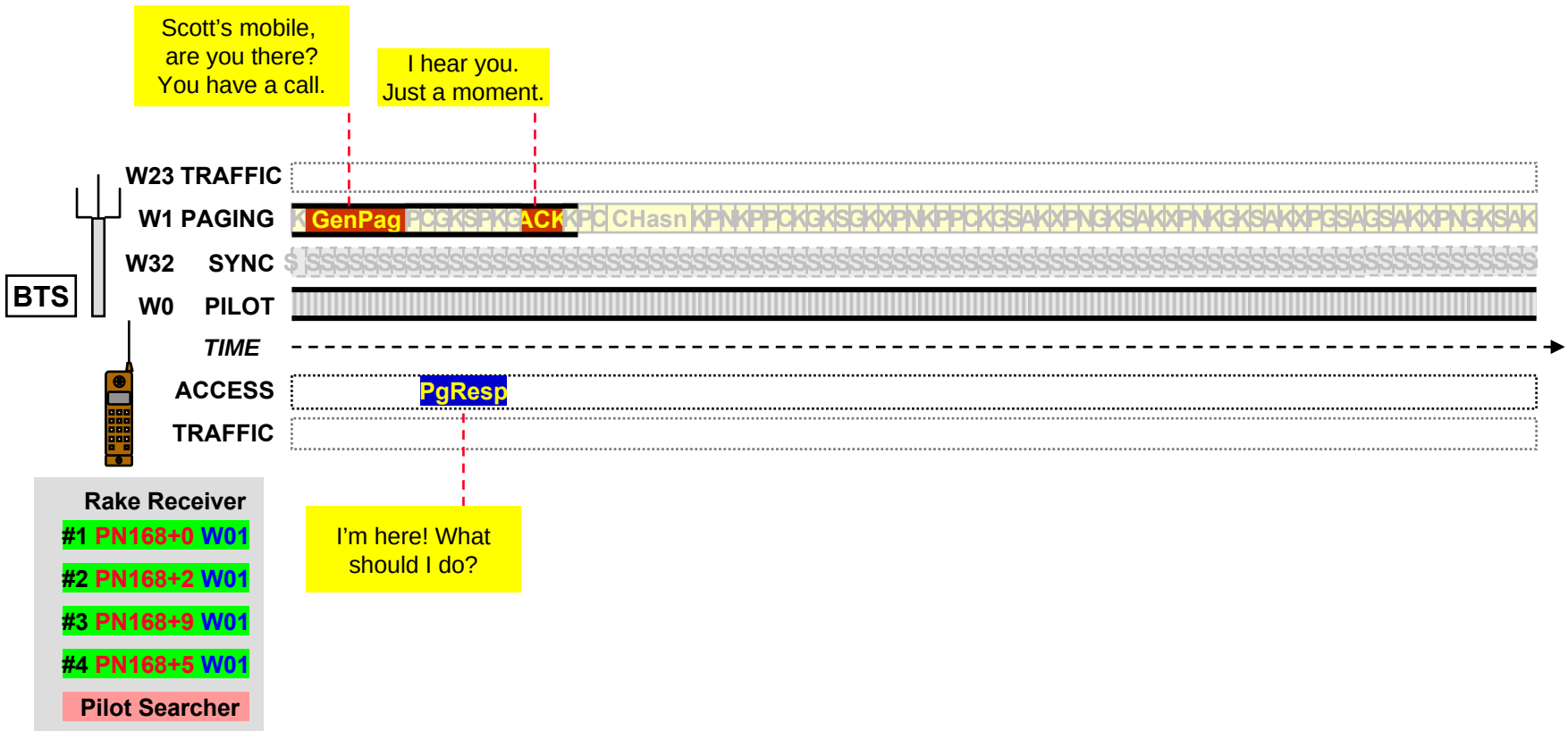


I'm here! What should I do?

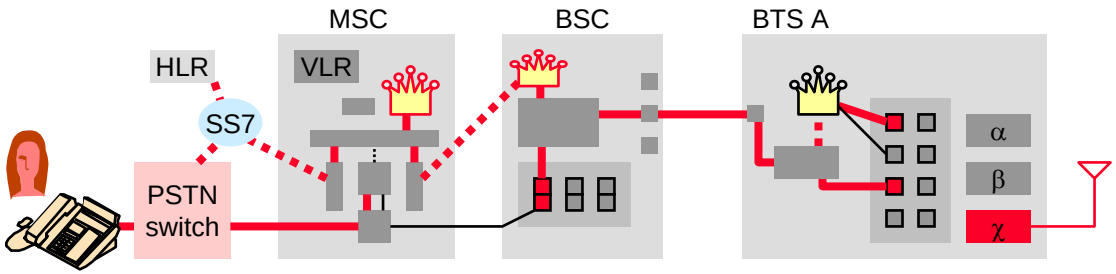
Rake Receiver
#1 PN168+0 W01
#2 PN168+2 W01
#3 PN168+9 W01
#4 PN168+5 W01
Pilot Searcher

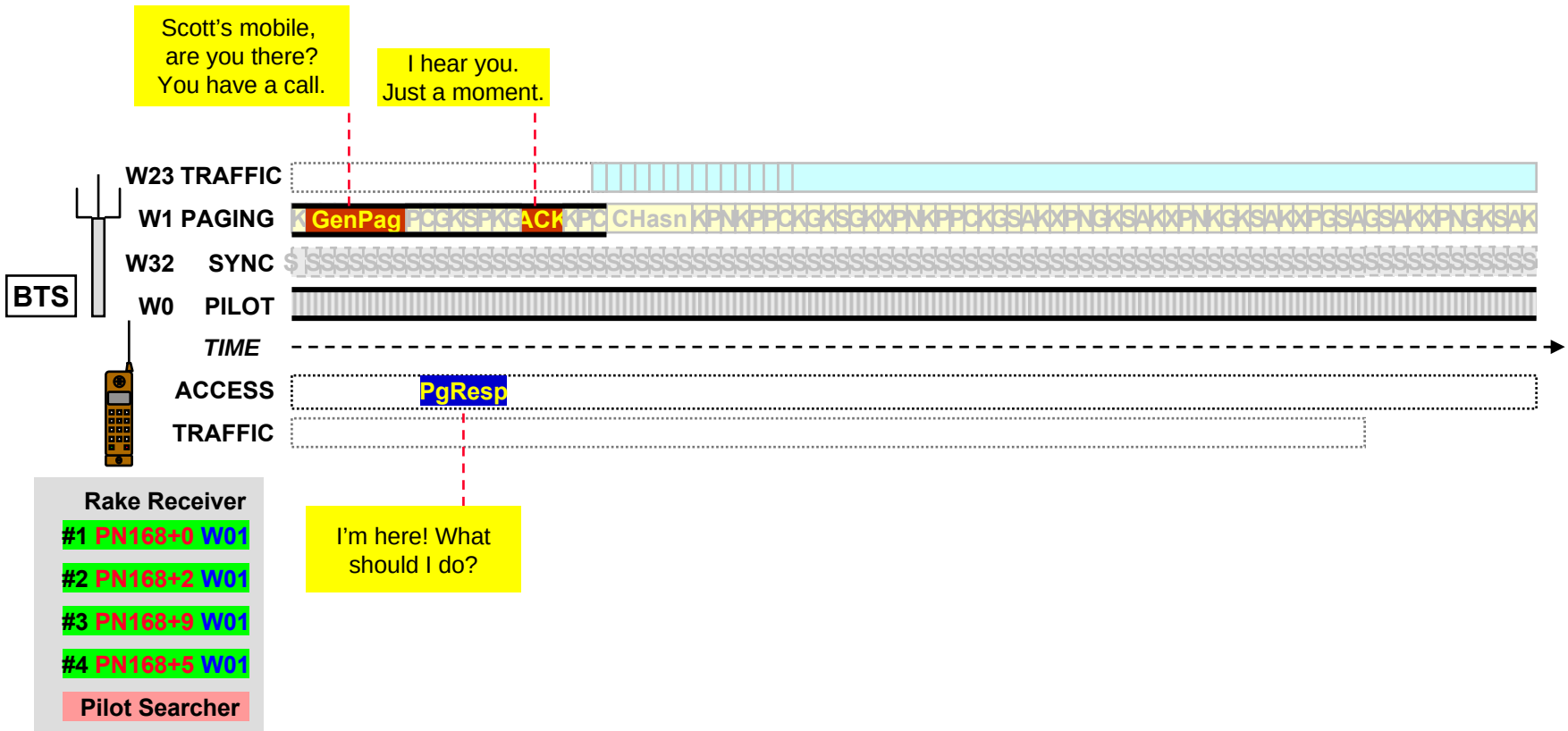
Incoming Call Termination – Voice



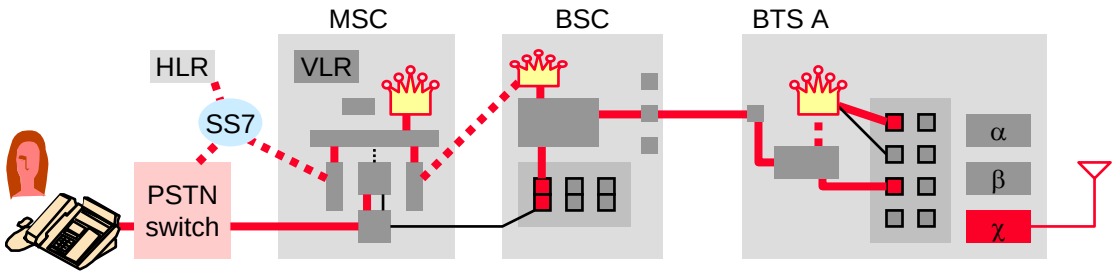


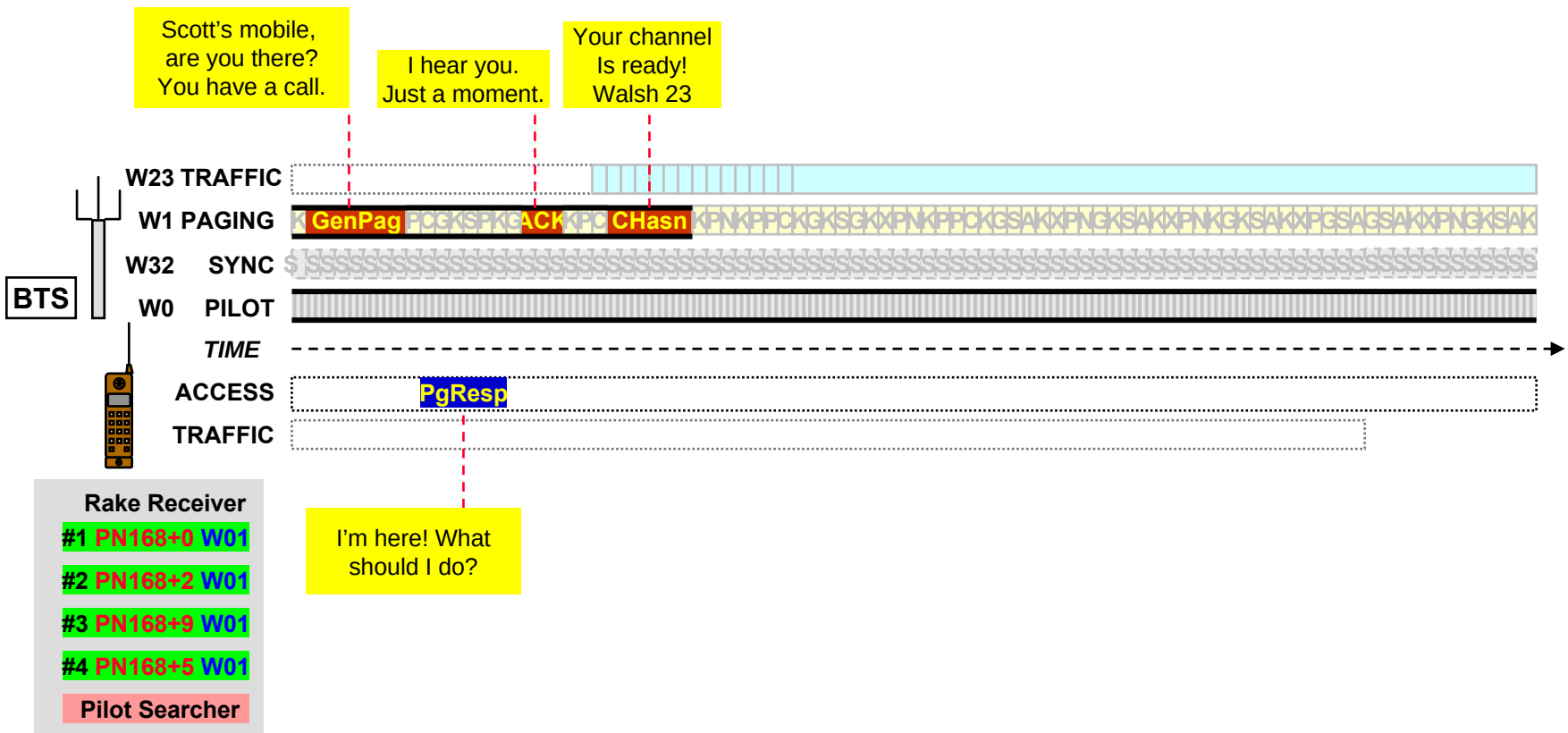
Incoming Call Termination – Voice



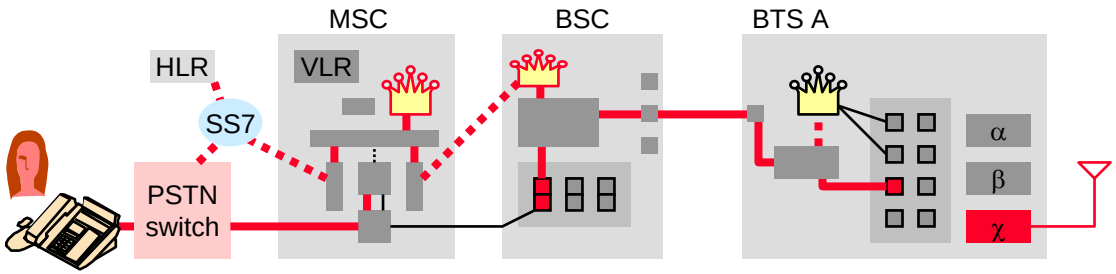


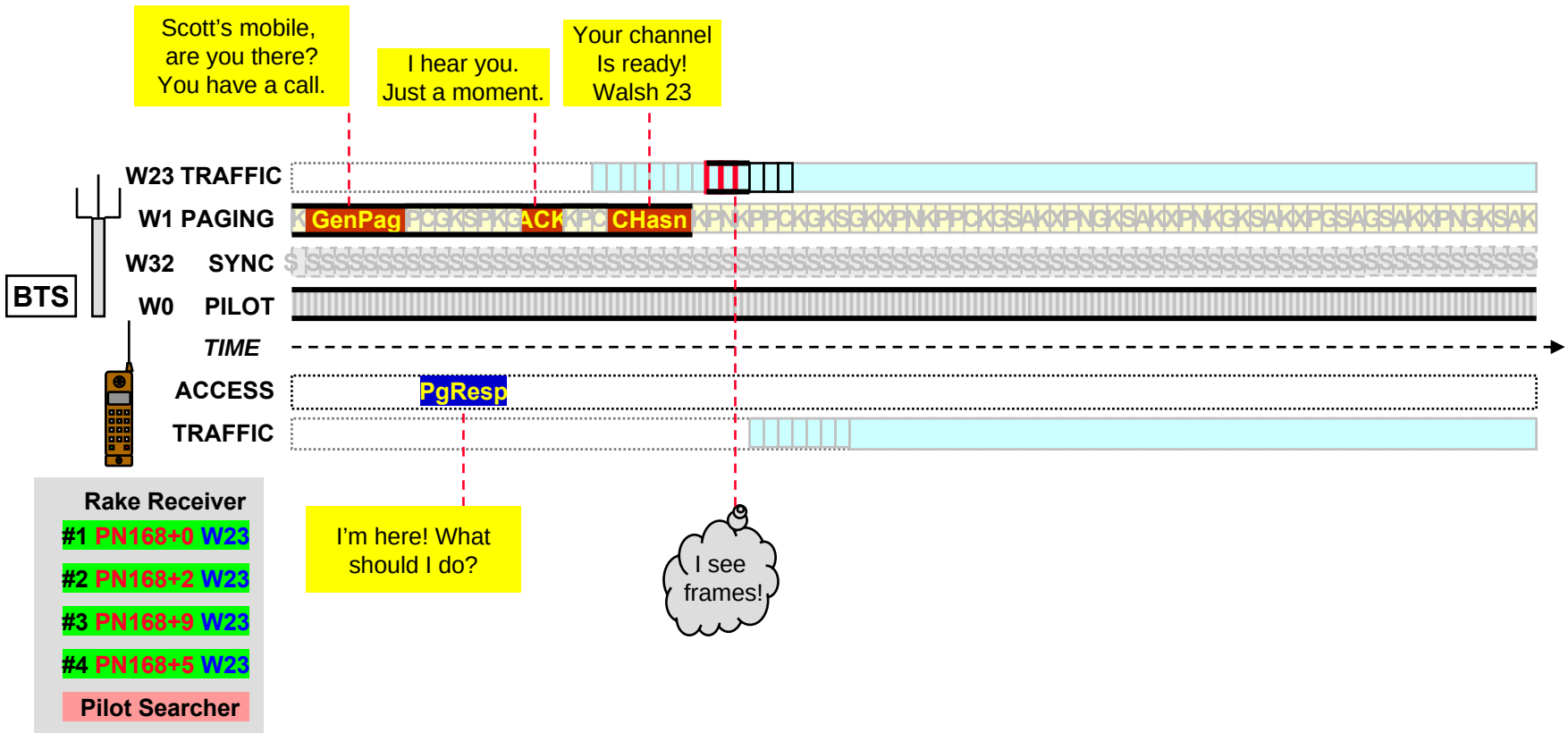
Incoming Call Termination – Voice



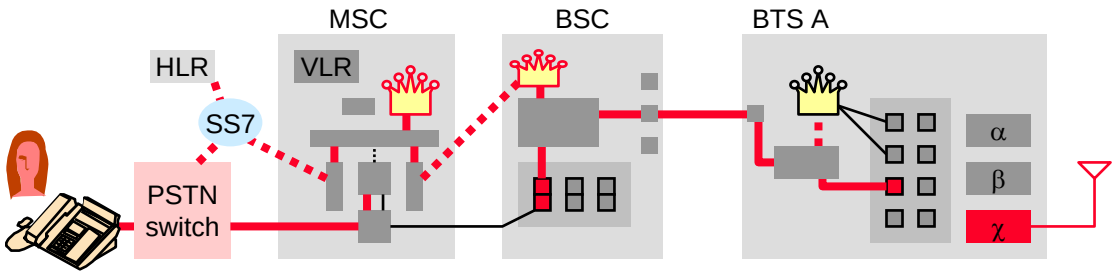


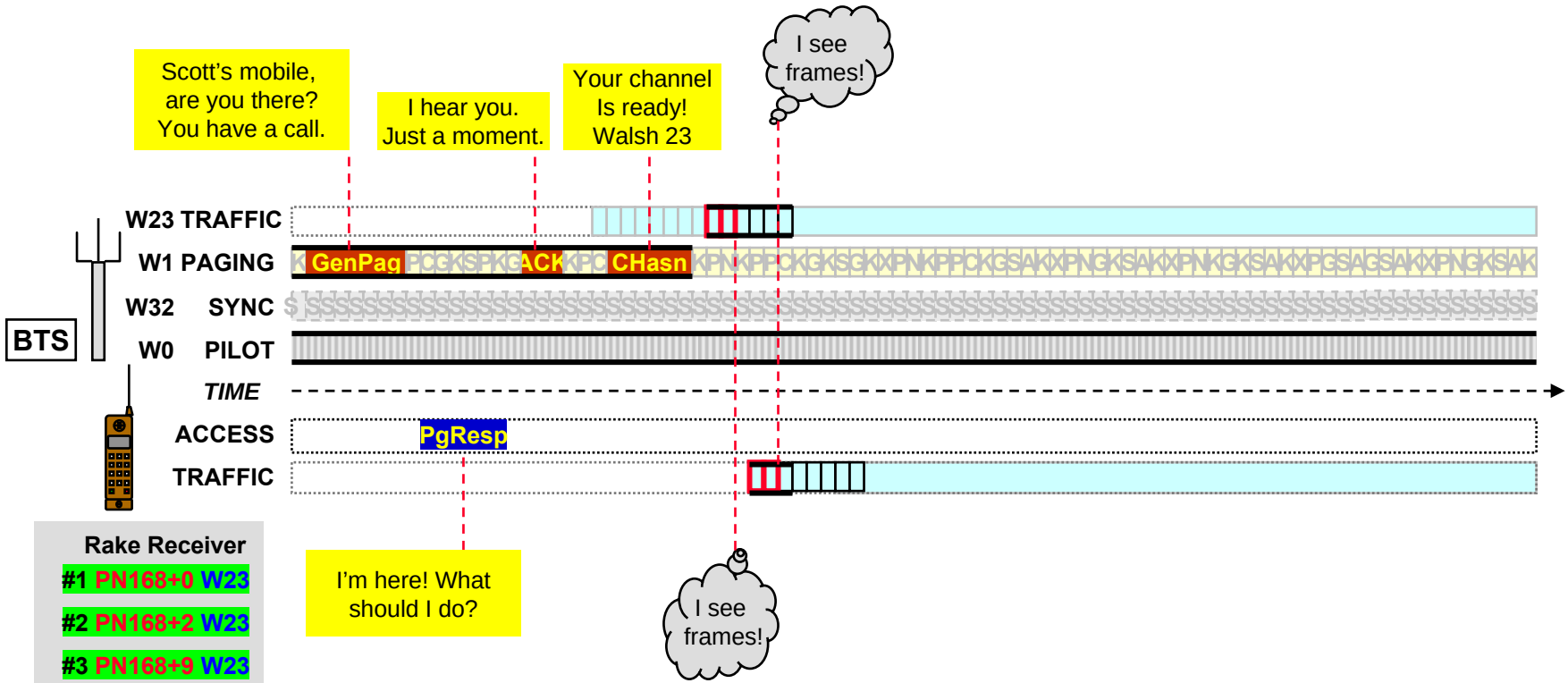
Incoming Call Termination – Voice



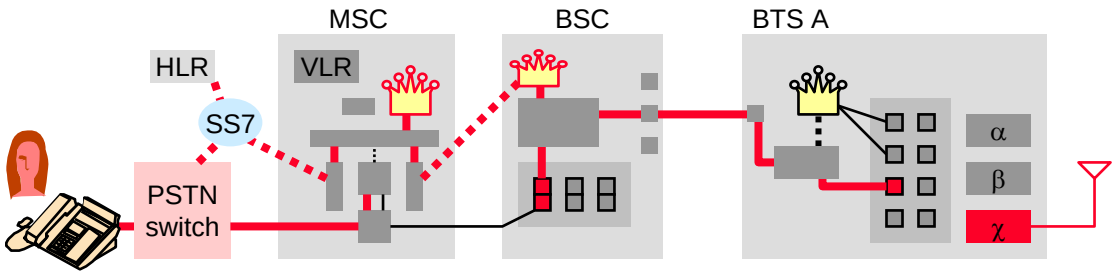


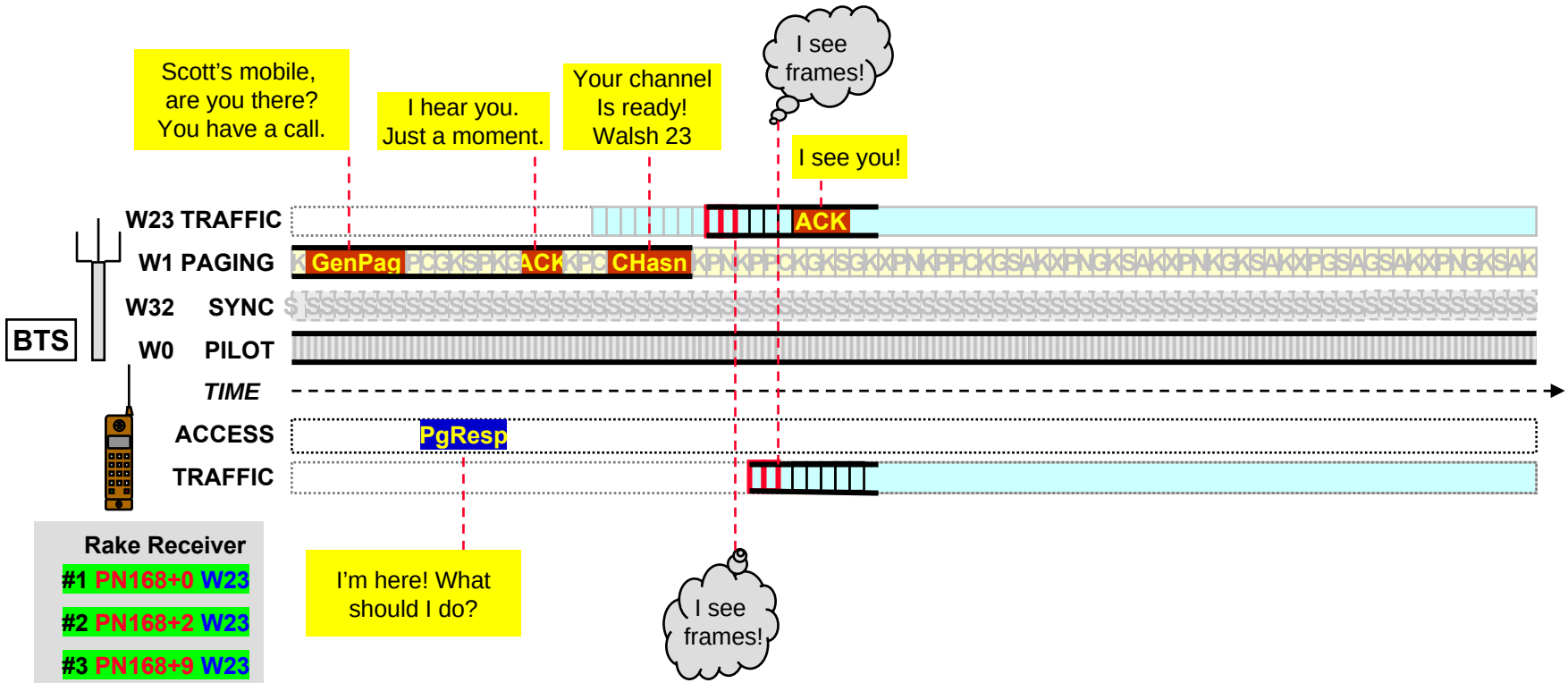
Incoming Call Termination – Voice



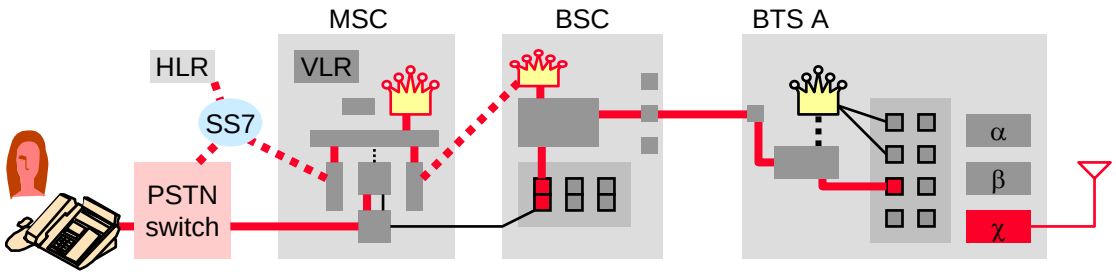


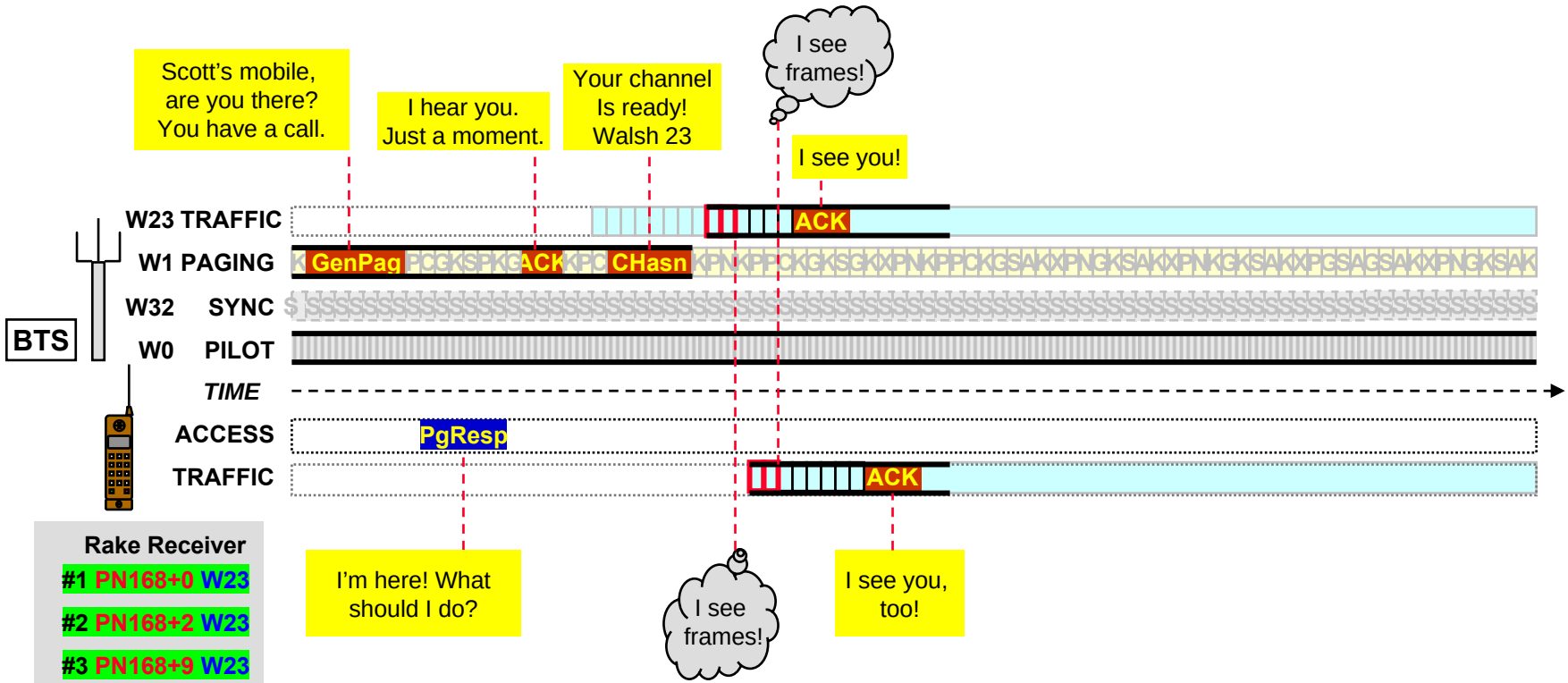
Incoming Call Termination – Voice



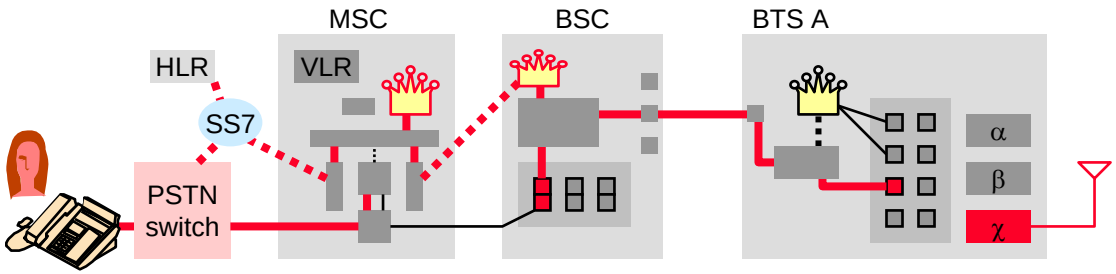


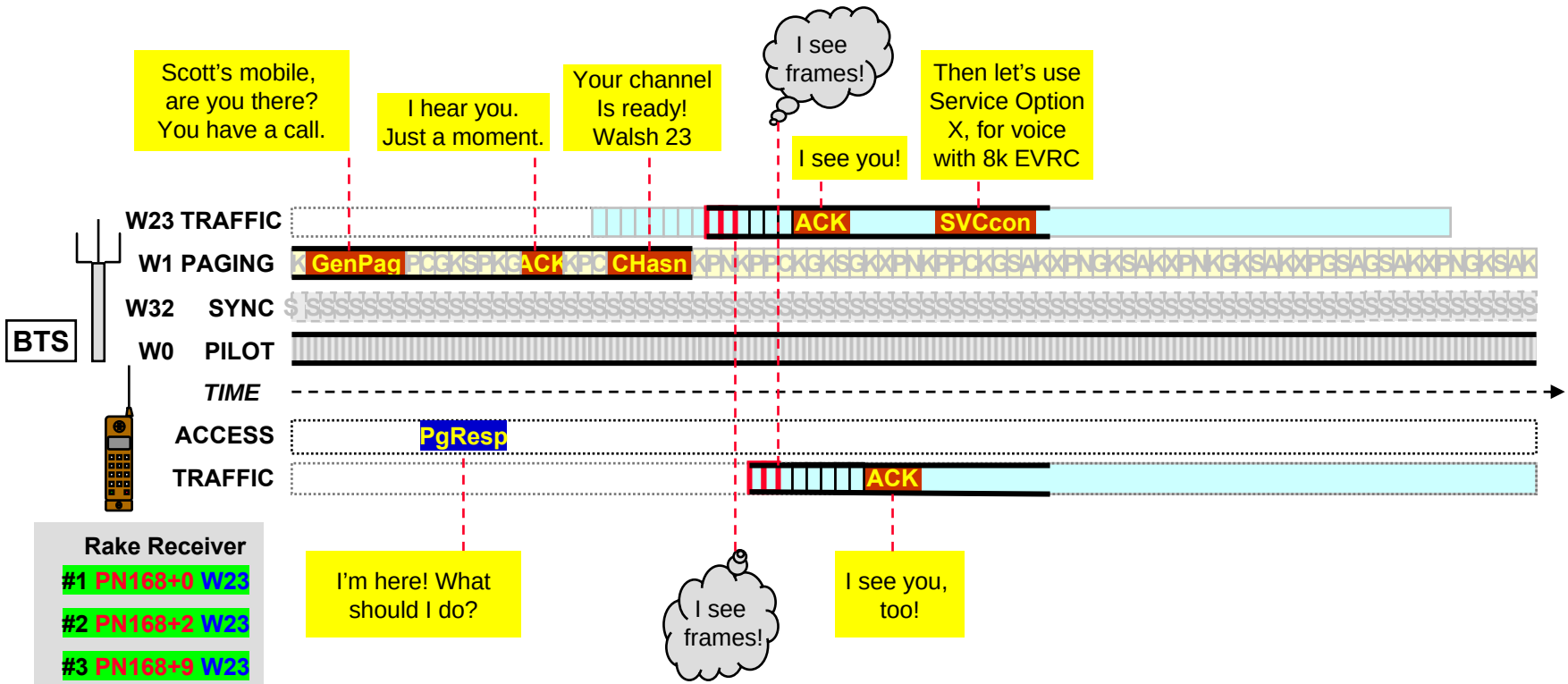
Incoming Call Termination – Voice



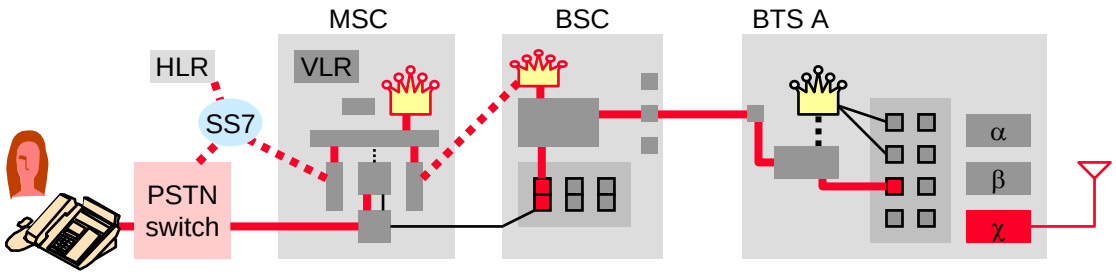


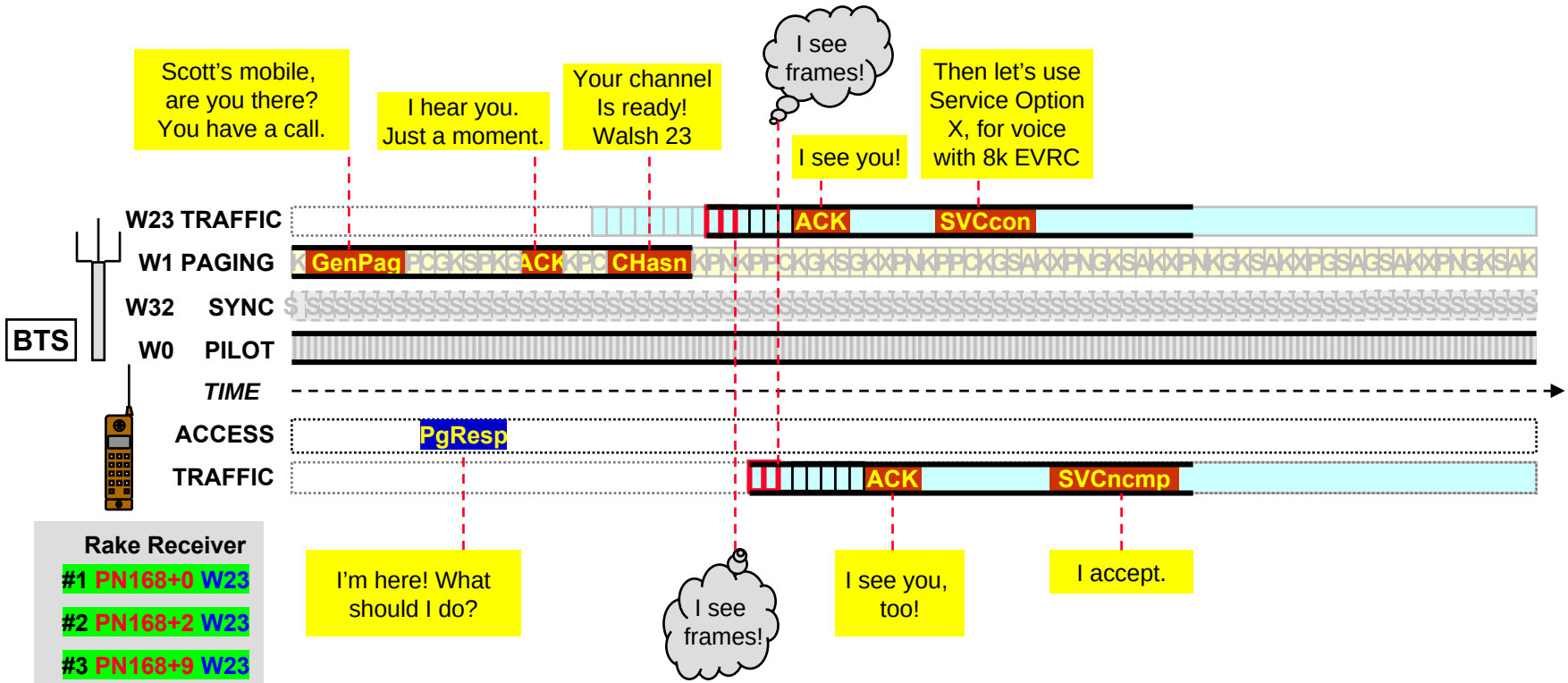
Incoming Call Termination – Voice



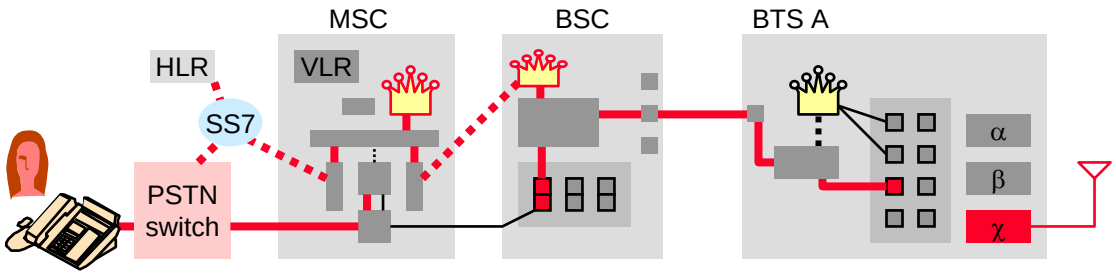


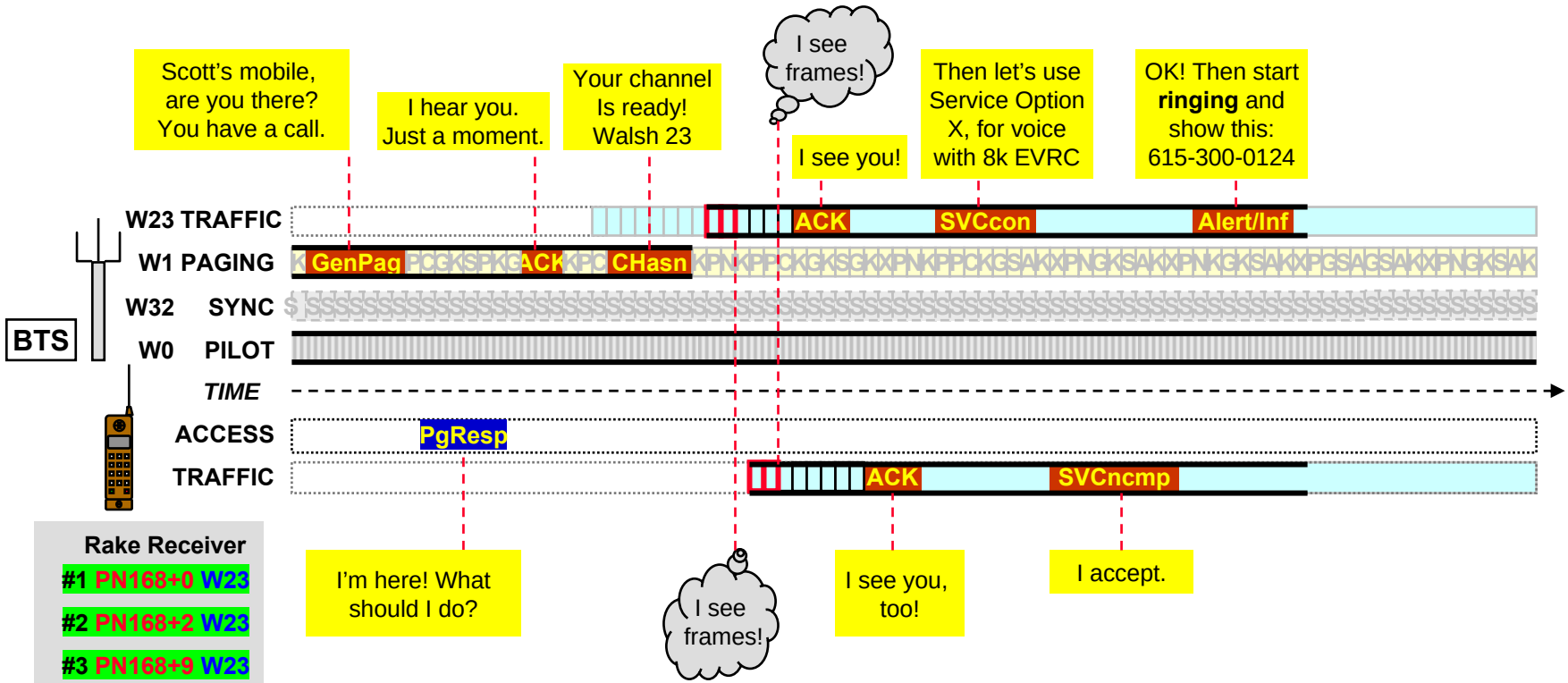
Incoming Call Termination – Voice



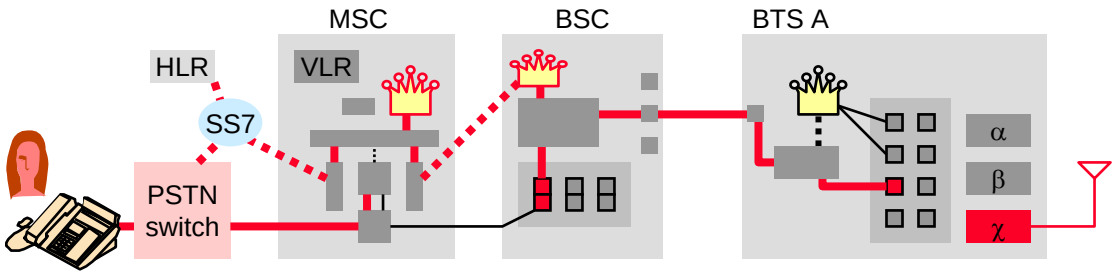


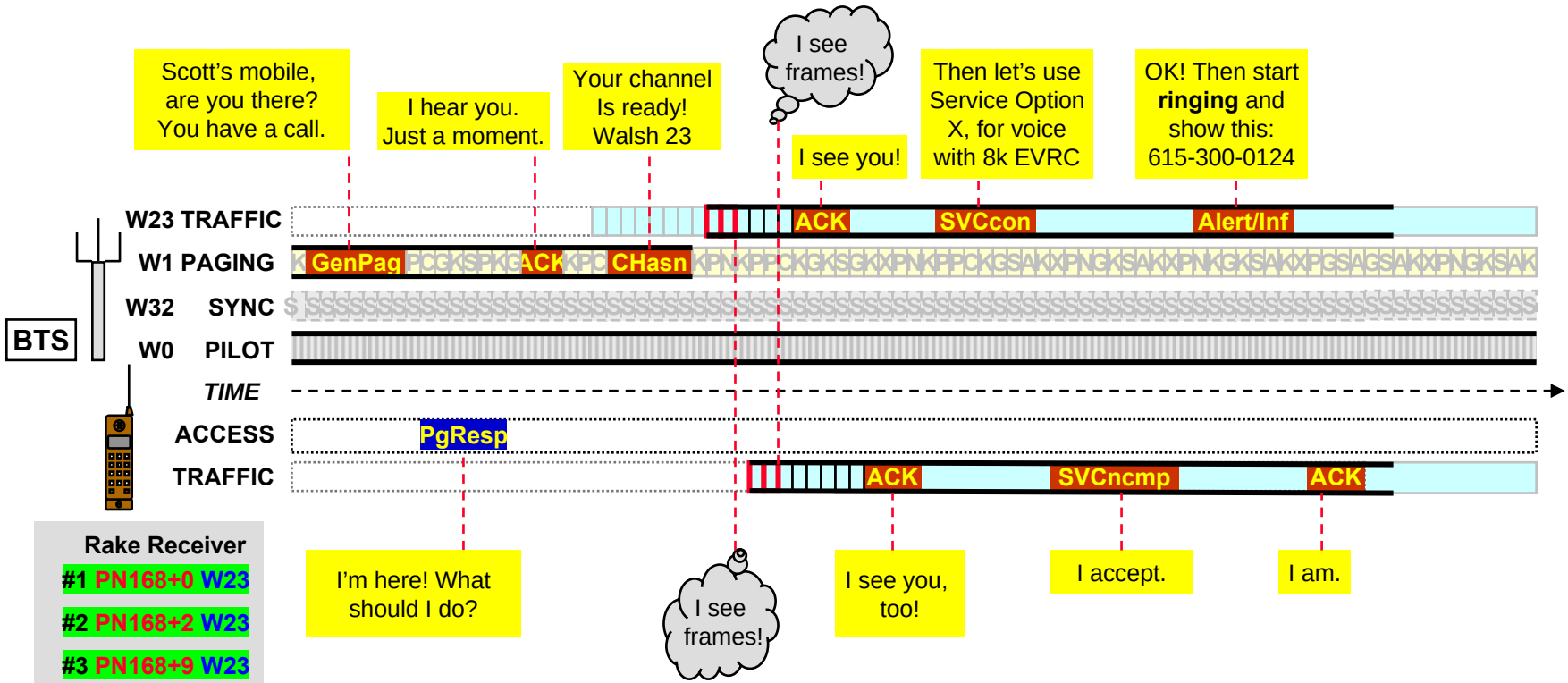
Incoming Call Termination – Voice



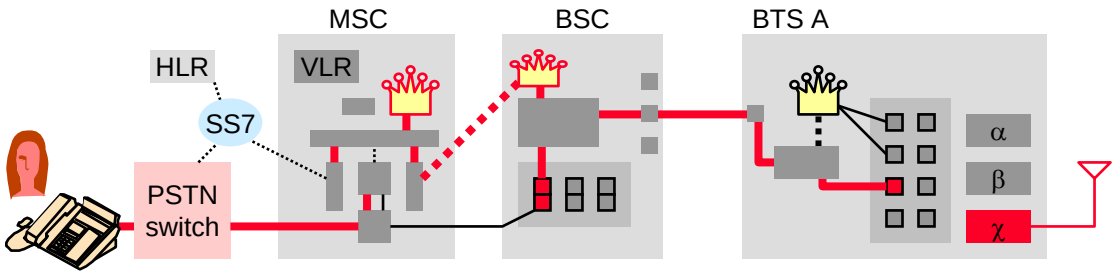


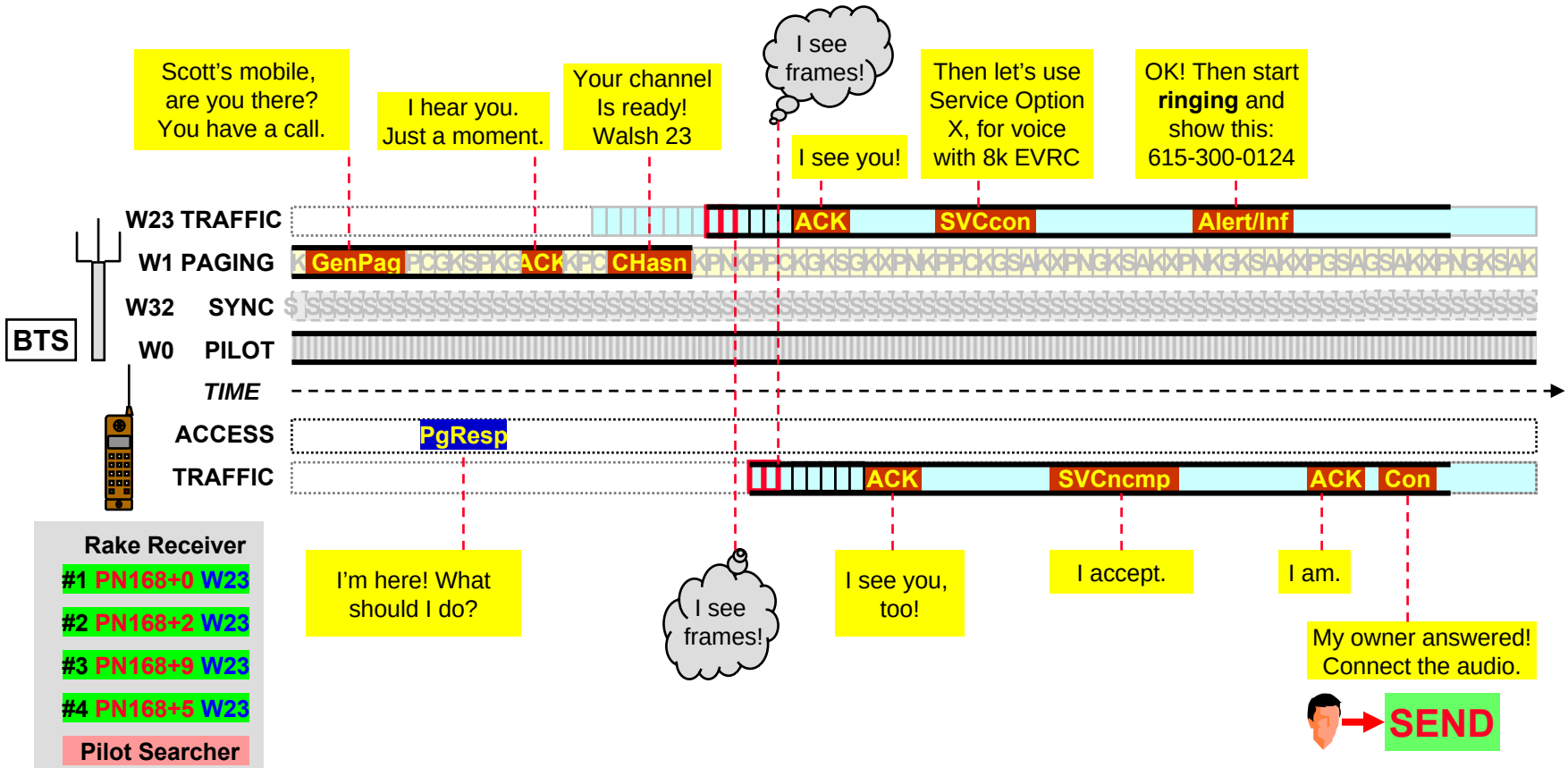
Incoming Call Termination – Voice



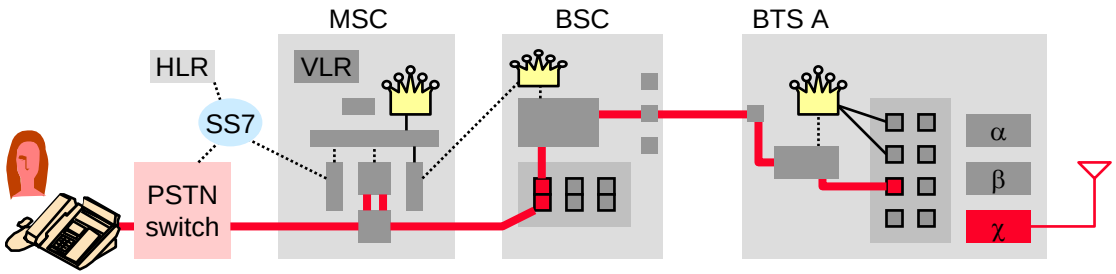


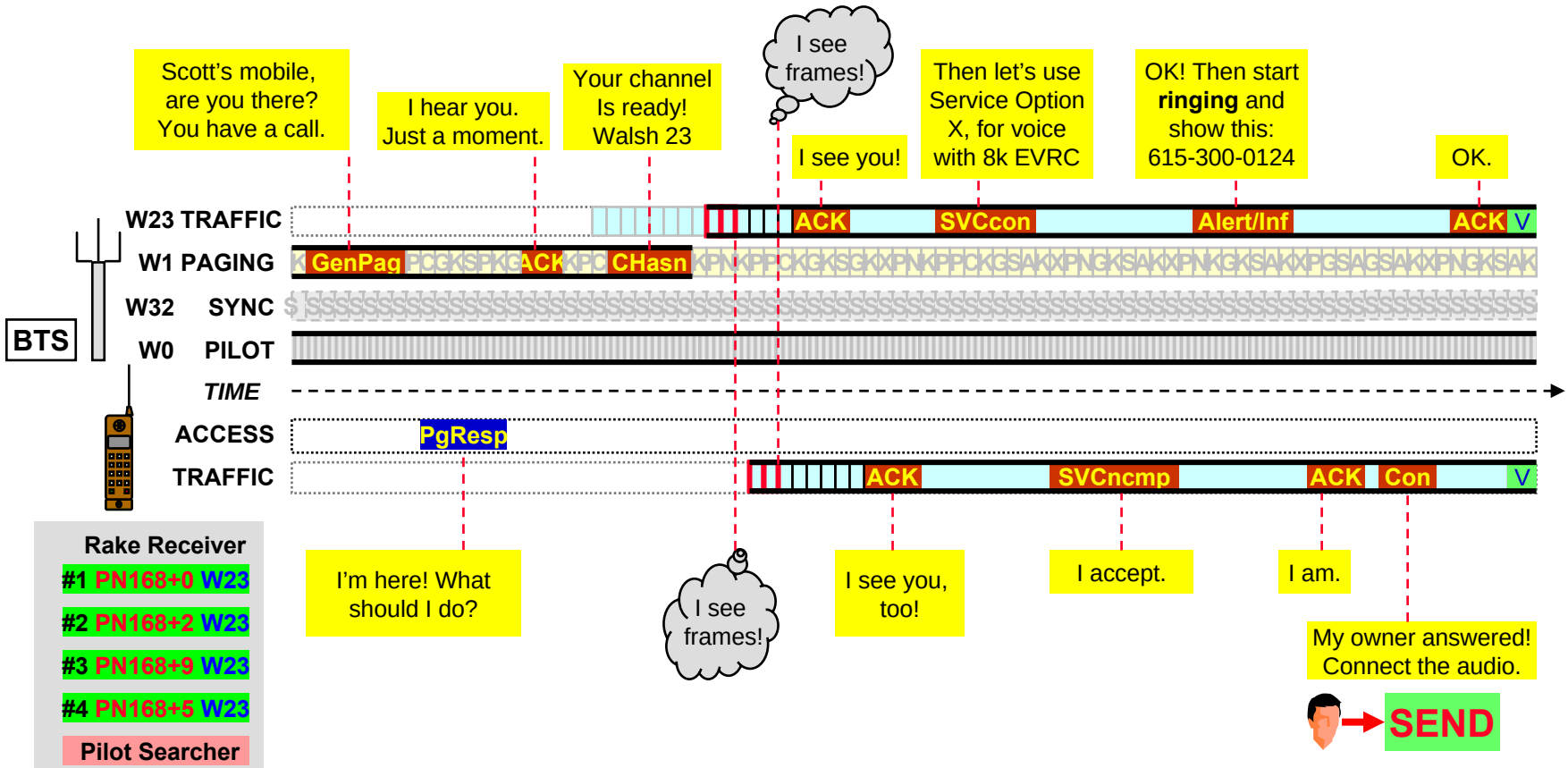
Incoming Call Termination – Voice





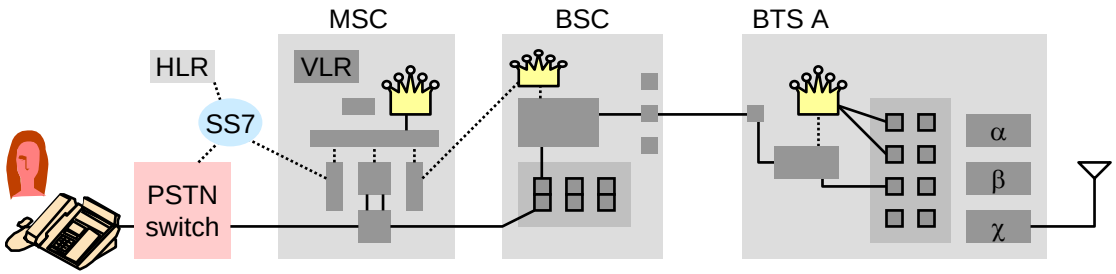
Incoming Call Termination – Voice

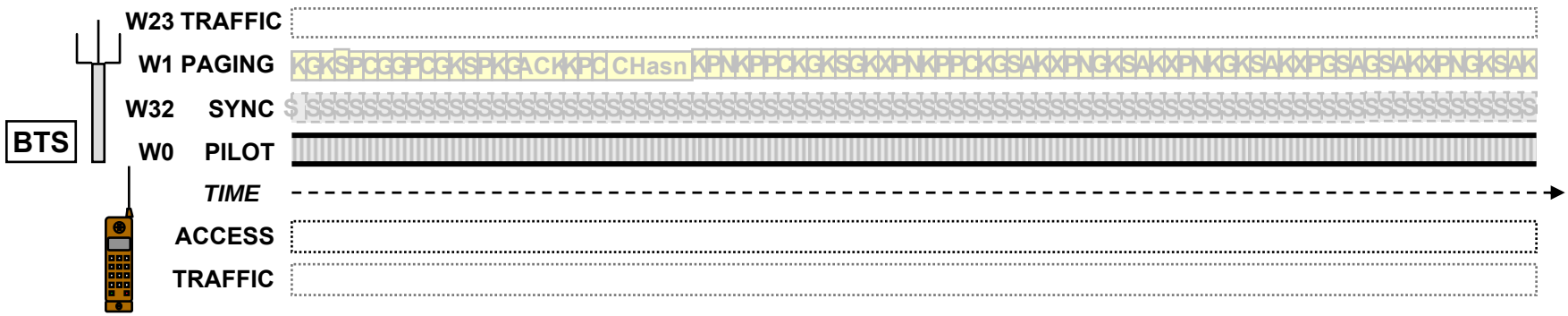




Making an *Outgoing* Call!

Outgoing Call Origination – IS-95 Voice





Rake Receiver

#1 PN168+0 W01

#2 PN168+2 W01

#3 PN168+9 W01

#4 PN168+5 W01

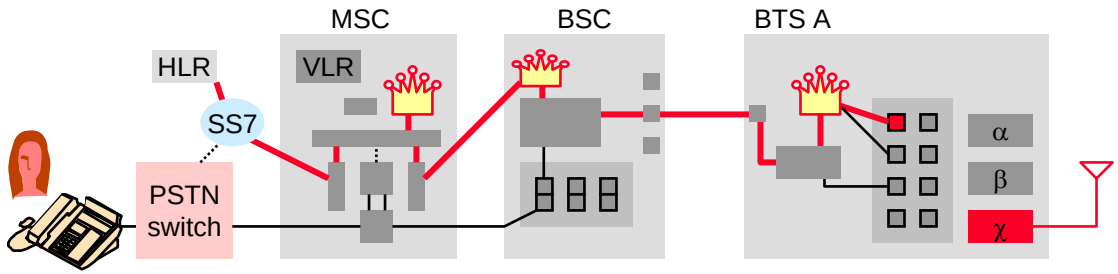
Pilot Searcher

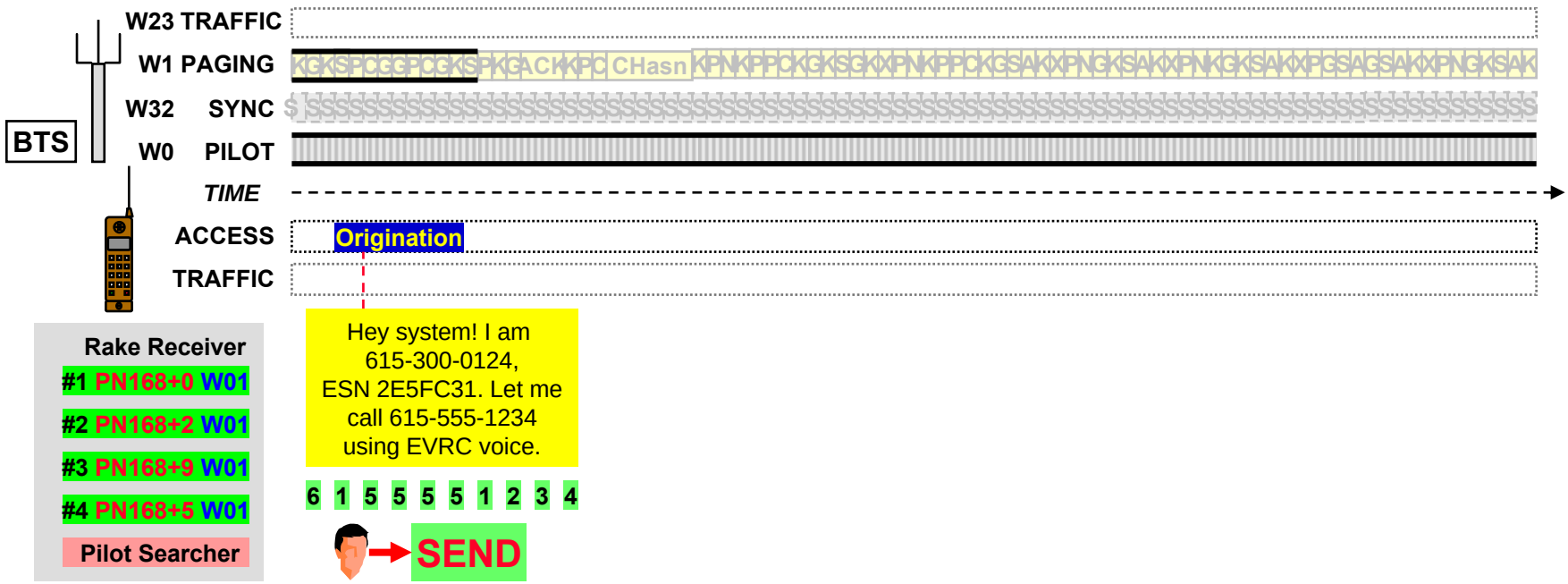
The mobile user dials,
Then presses SEND.

6 1 5 5 5 5 1 2 3 4

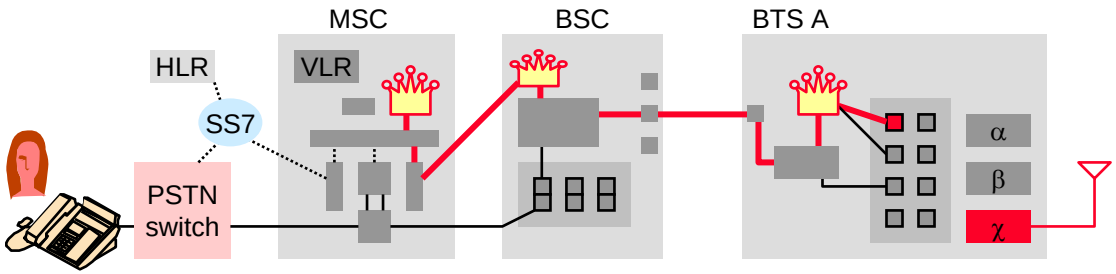
SEND

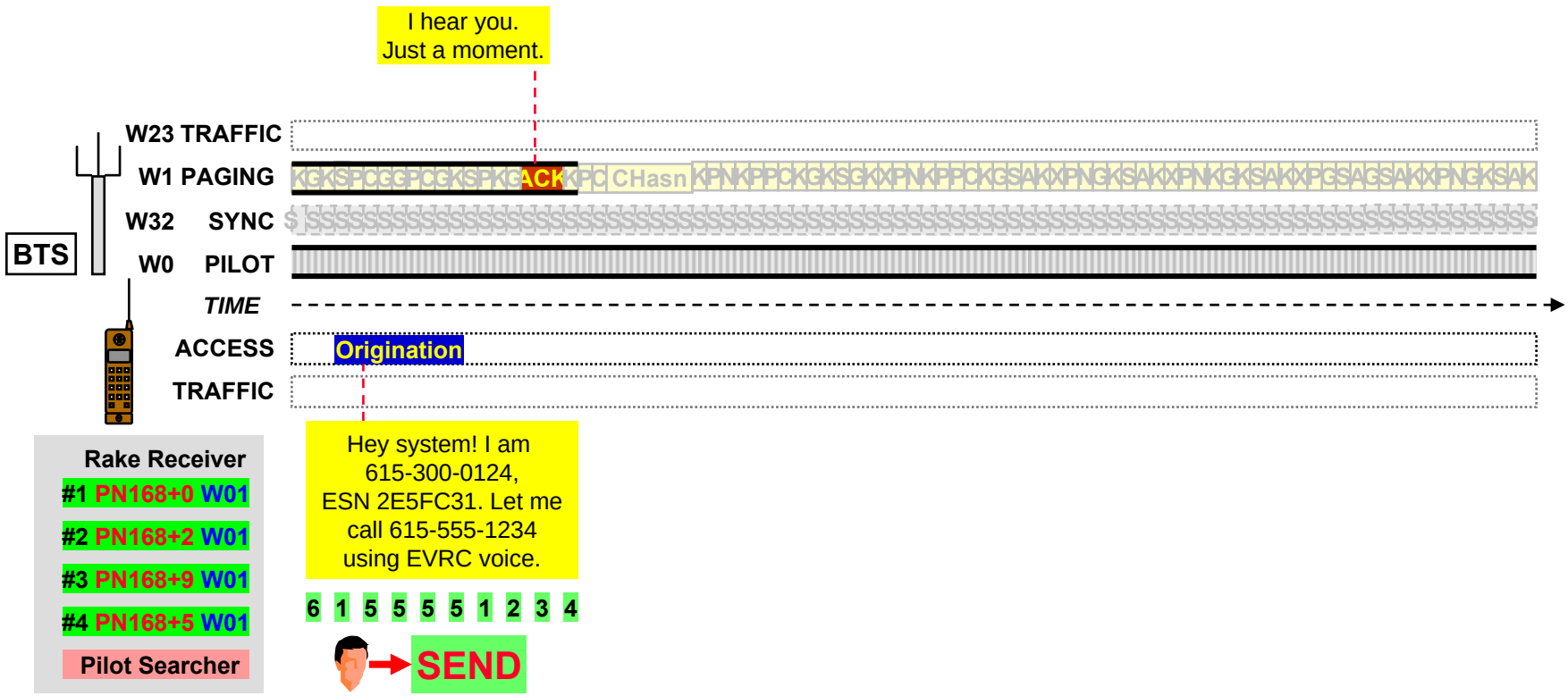
Outgoing Call Origination – IS-95 Voice



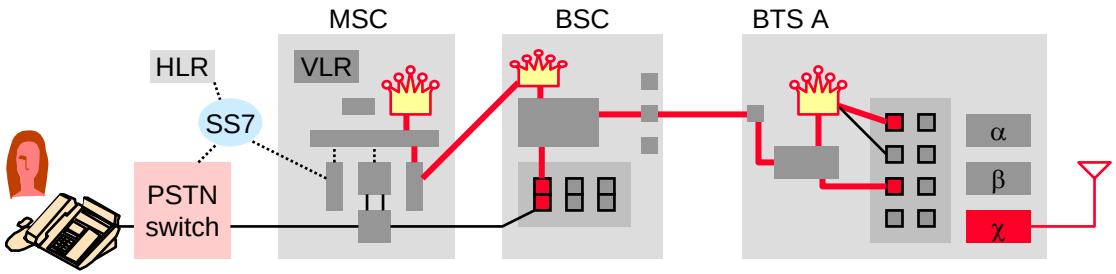


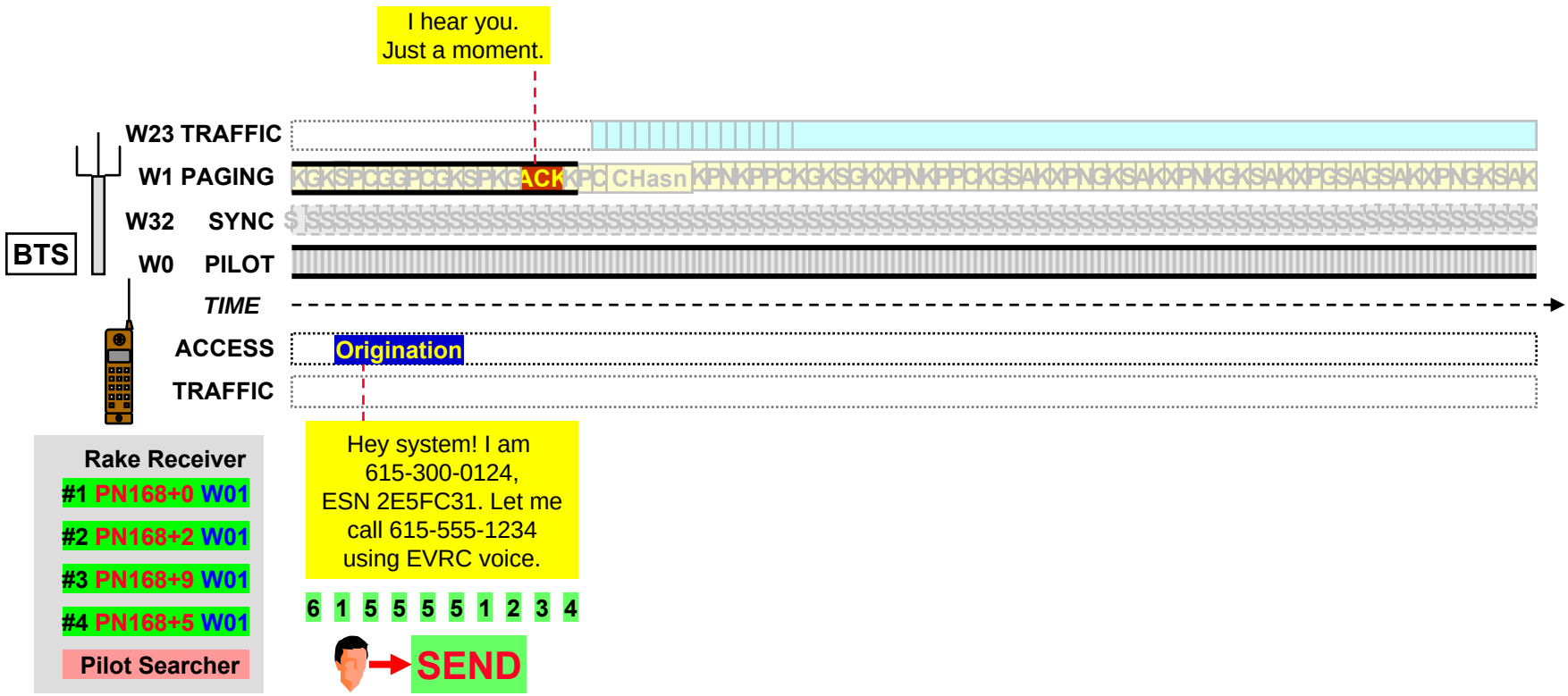
Outgoing Call Origination – IS-95 Voice



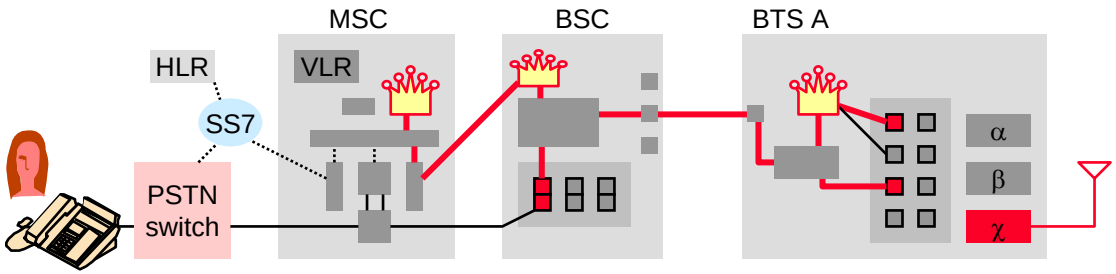


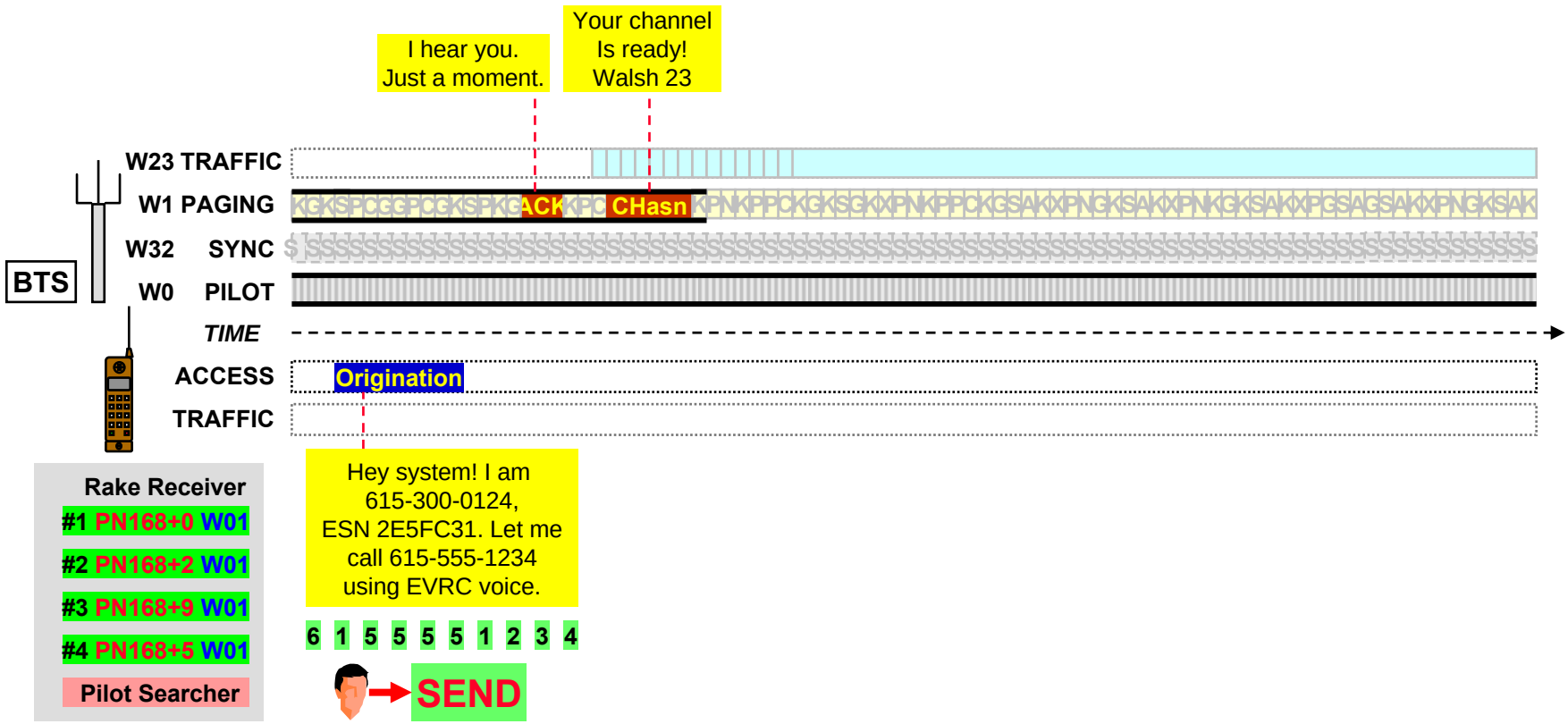
Outgoing Call Origination – IS-95 Voice



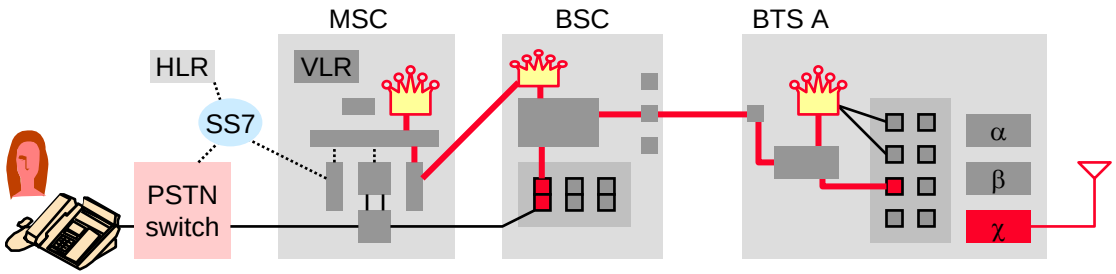


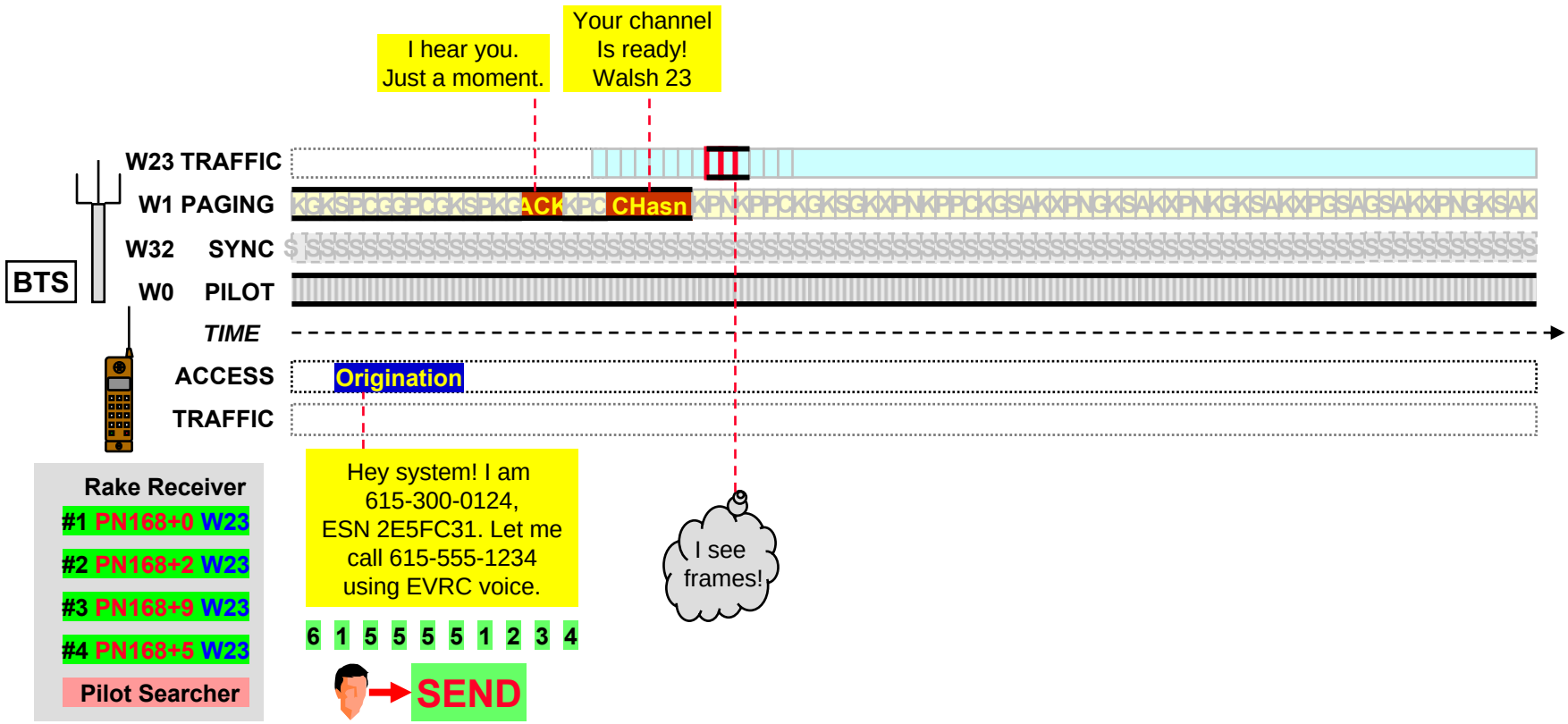
Outgoing Call Origination – IS-95 Voice



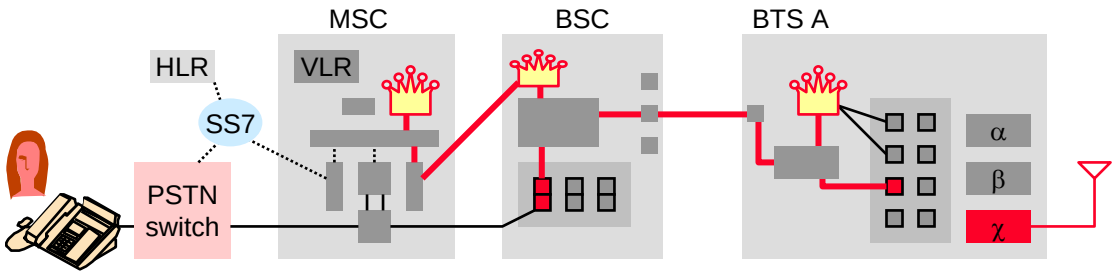


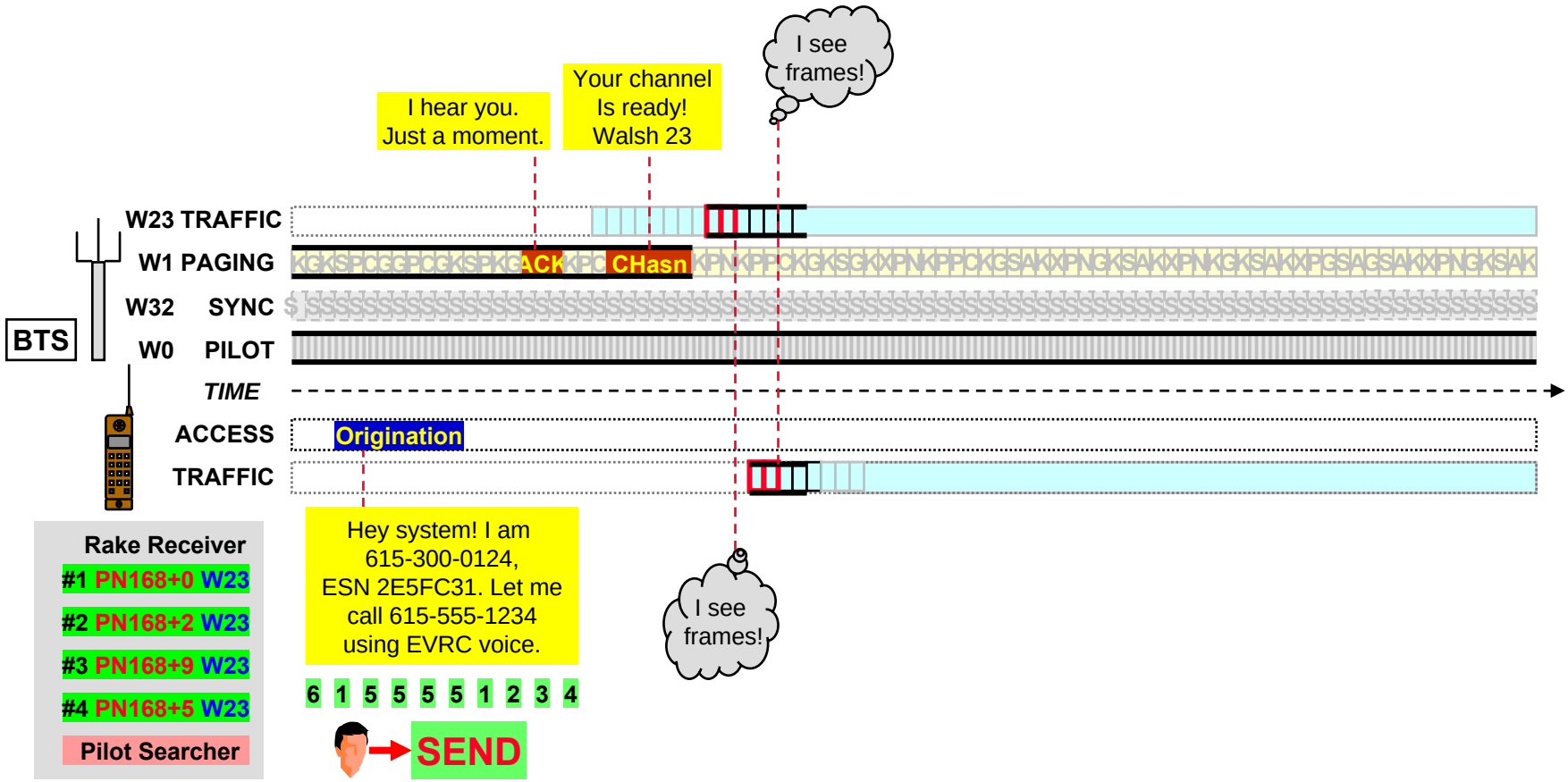
Outgoing Call Origination – IS-95 Voice



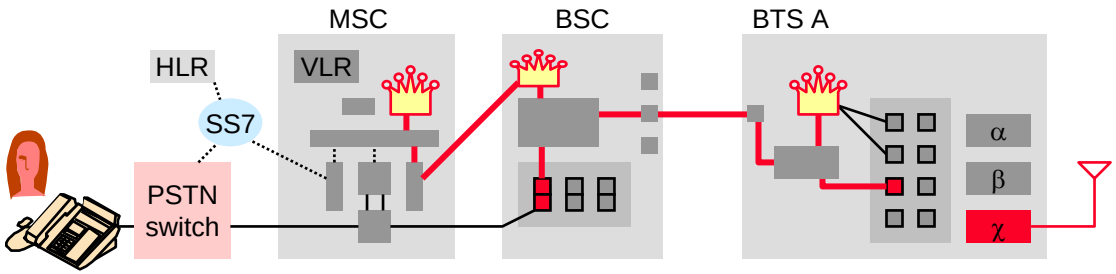


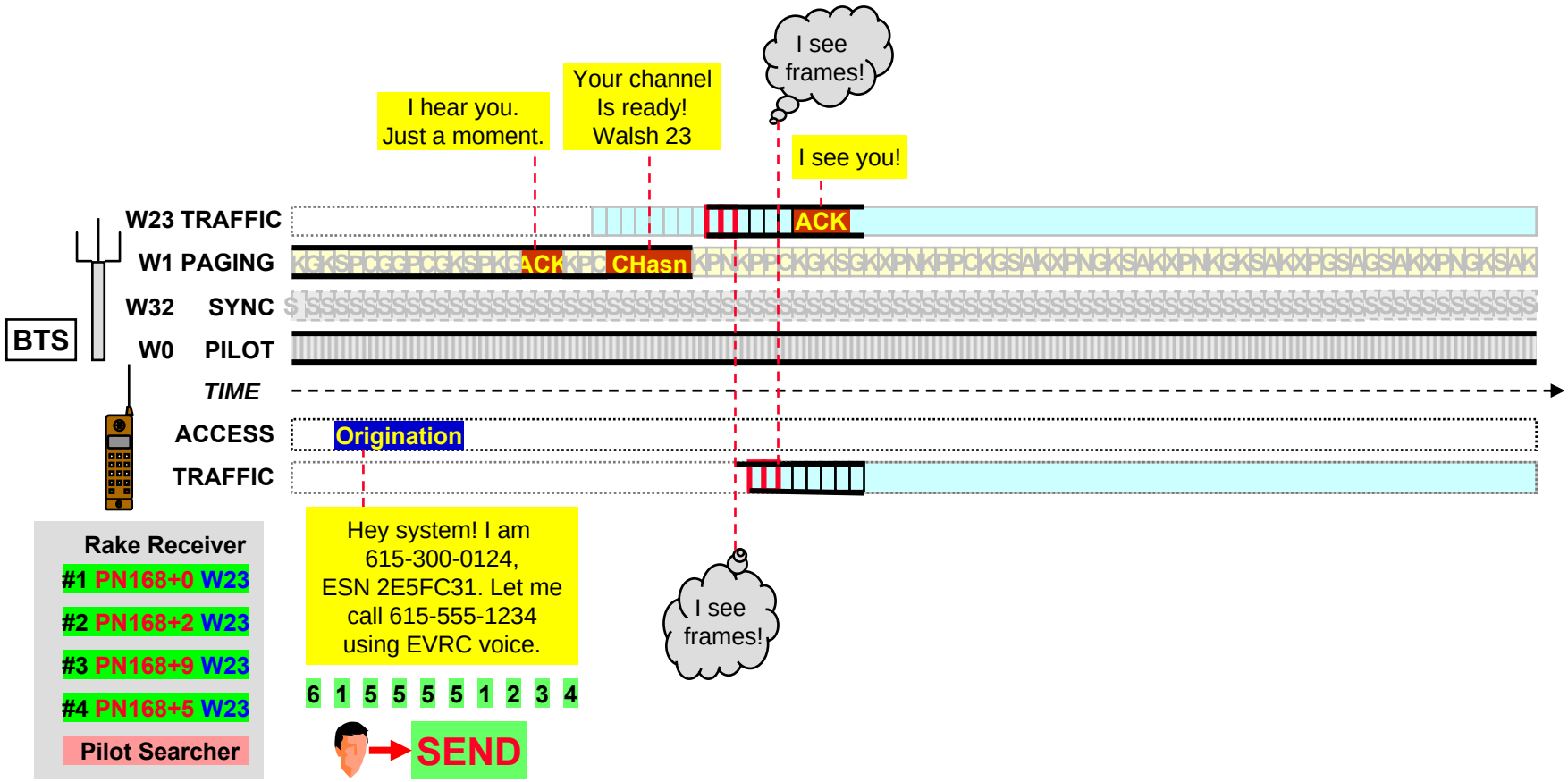
Outgoing Call Origination – IS-95 Voice



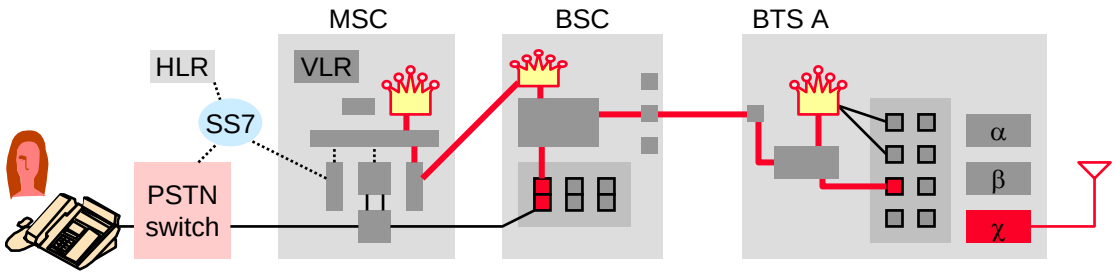


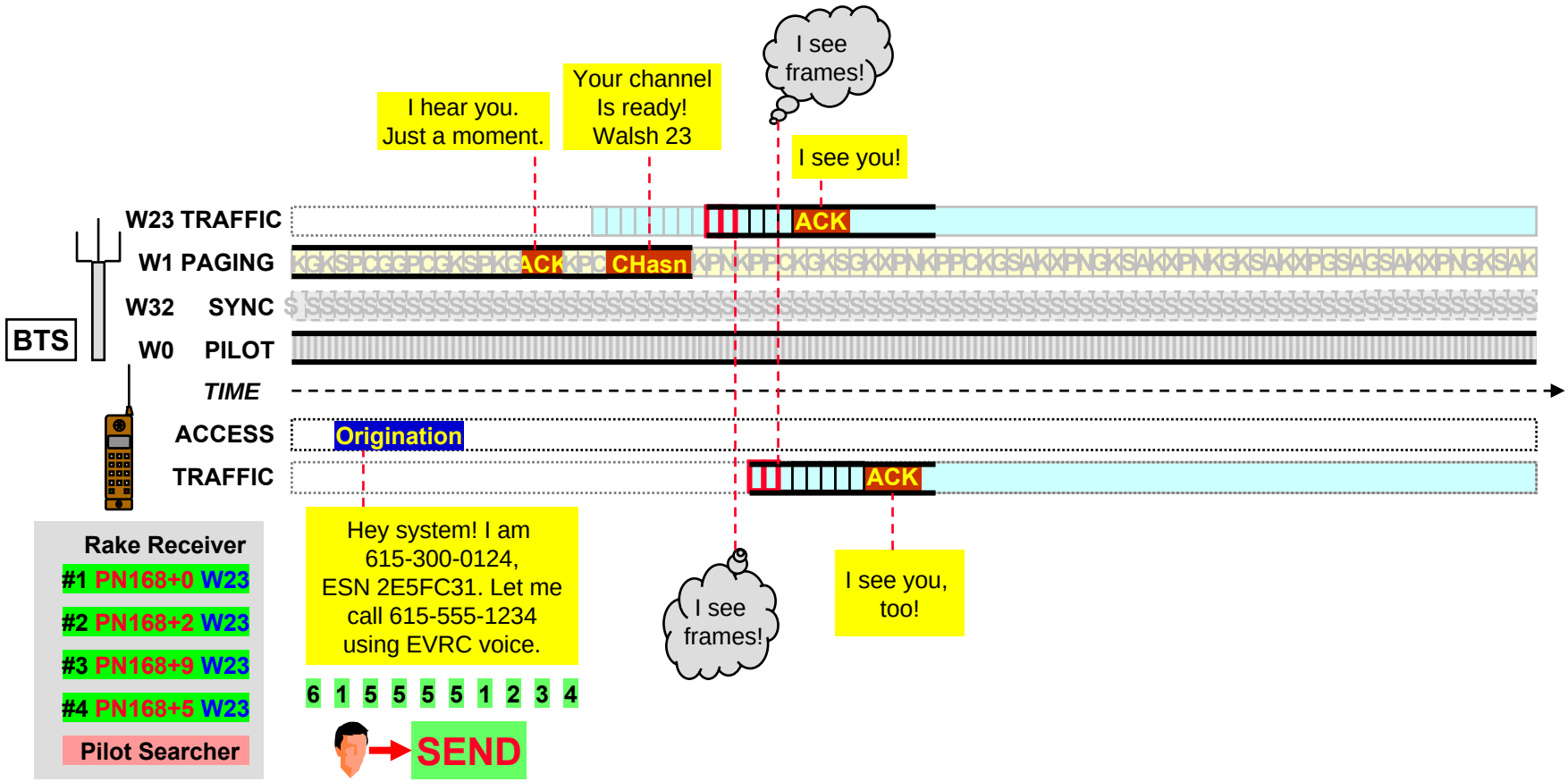
Outgoing Call Origination – IS-95 Voice



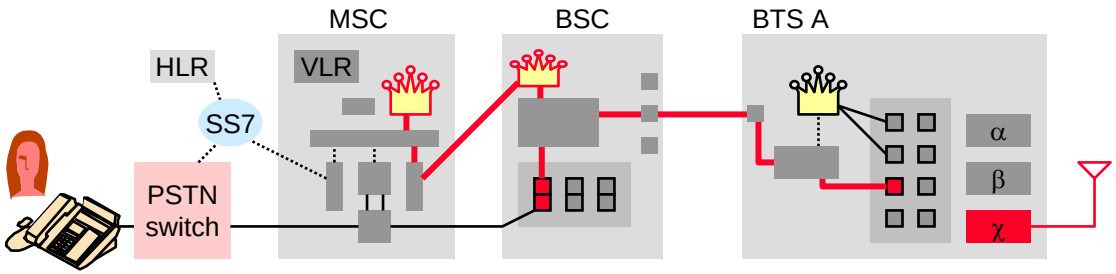


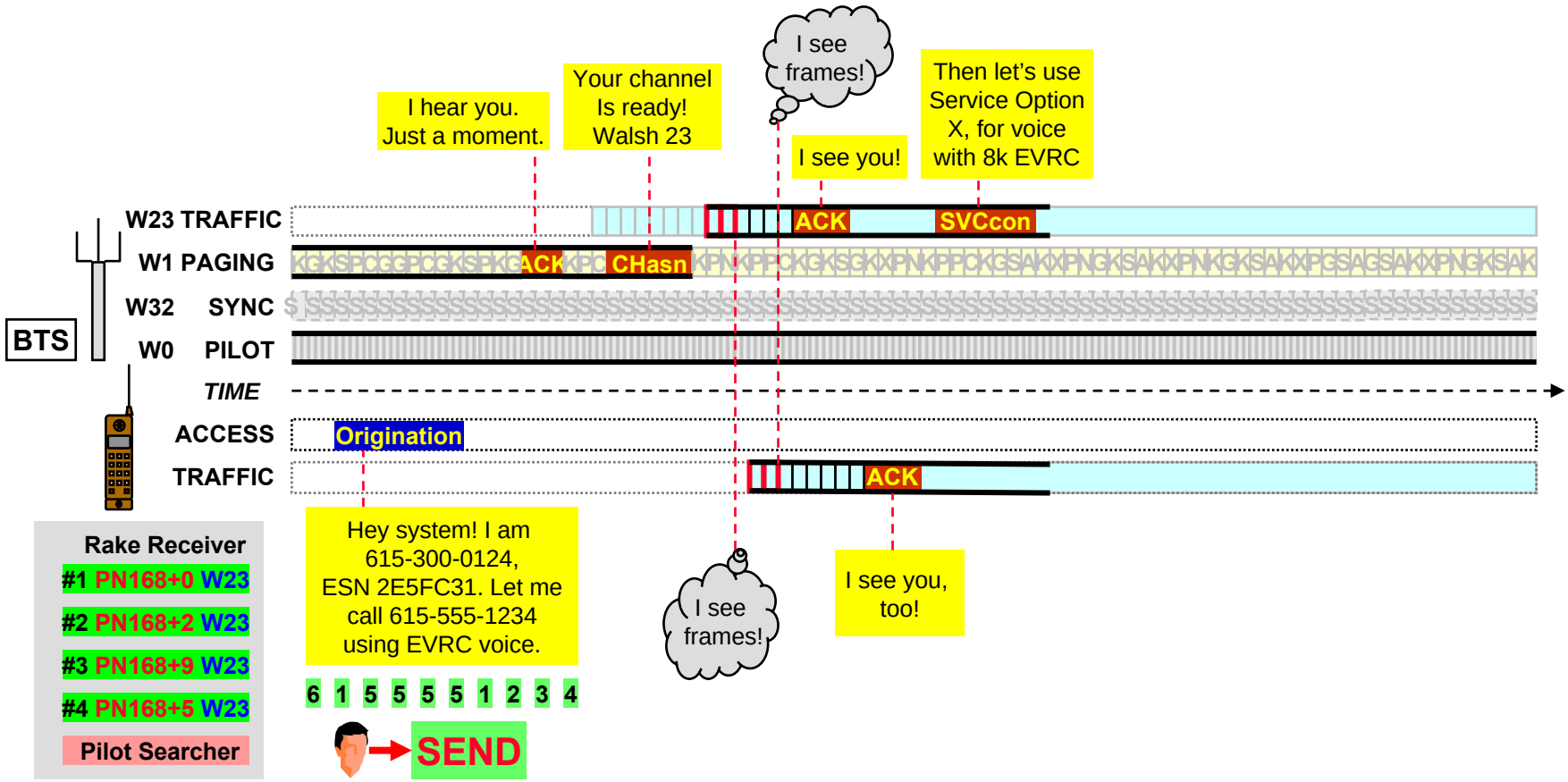
Outgoing Call Origination – IS-95 Voice



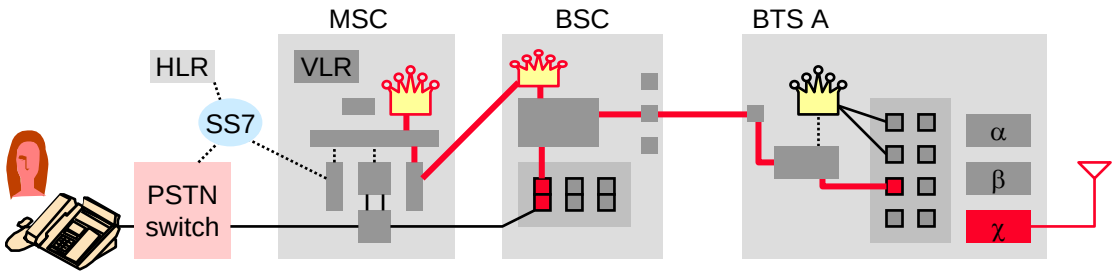


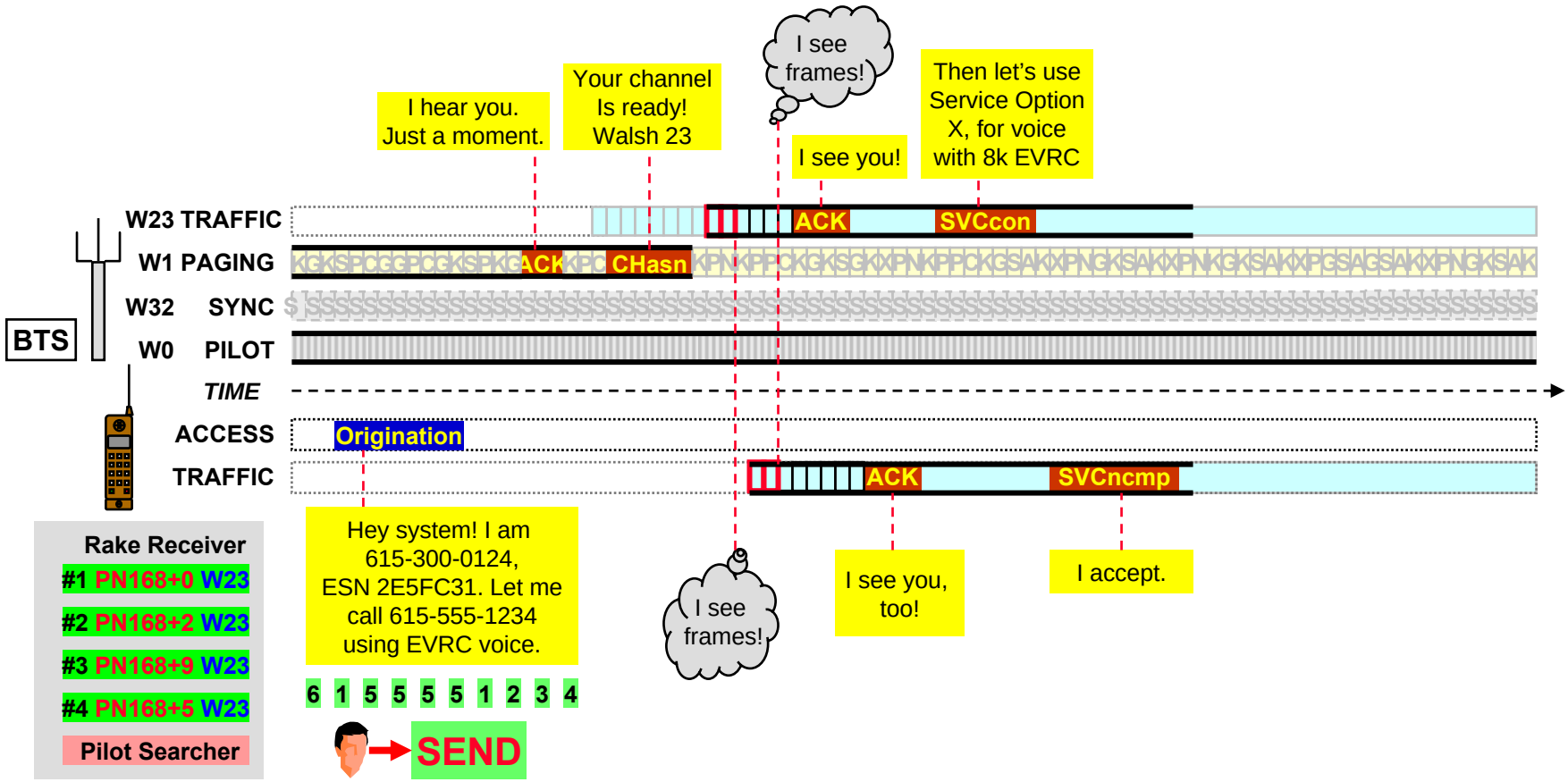
Outgoing Call Origination – IS-95 Voice



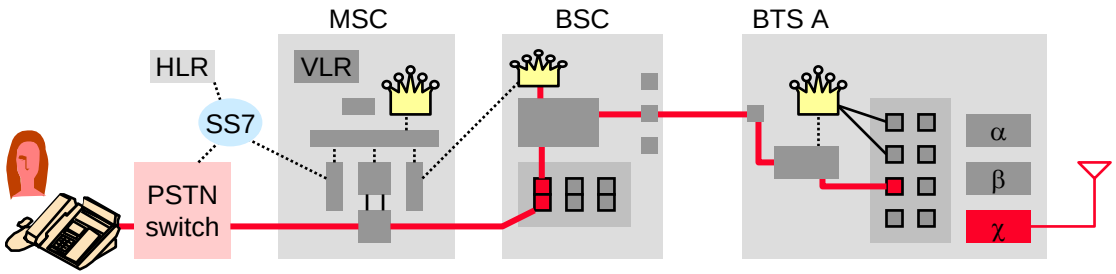


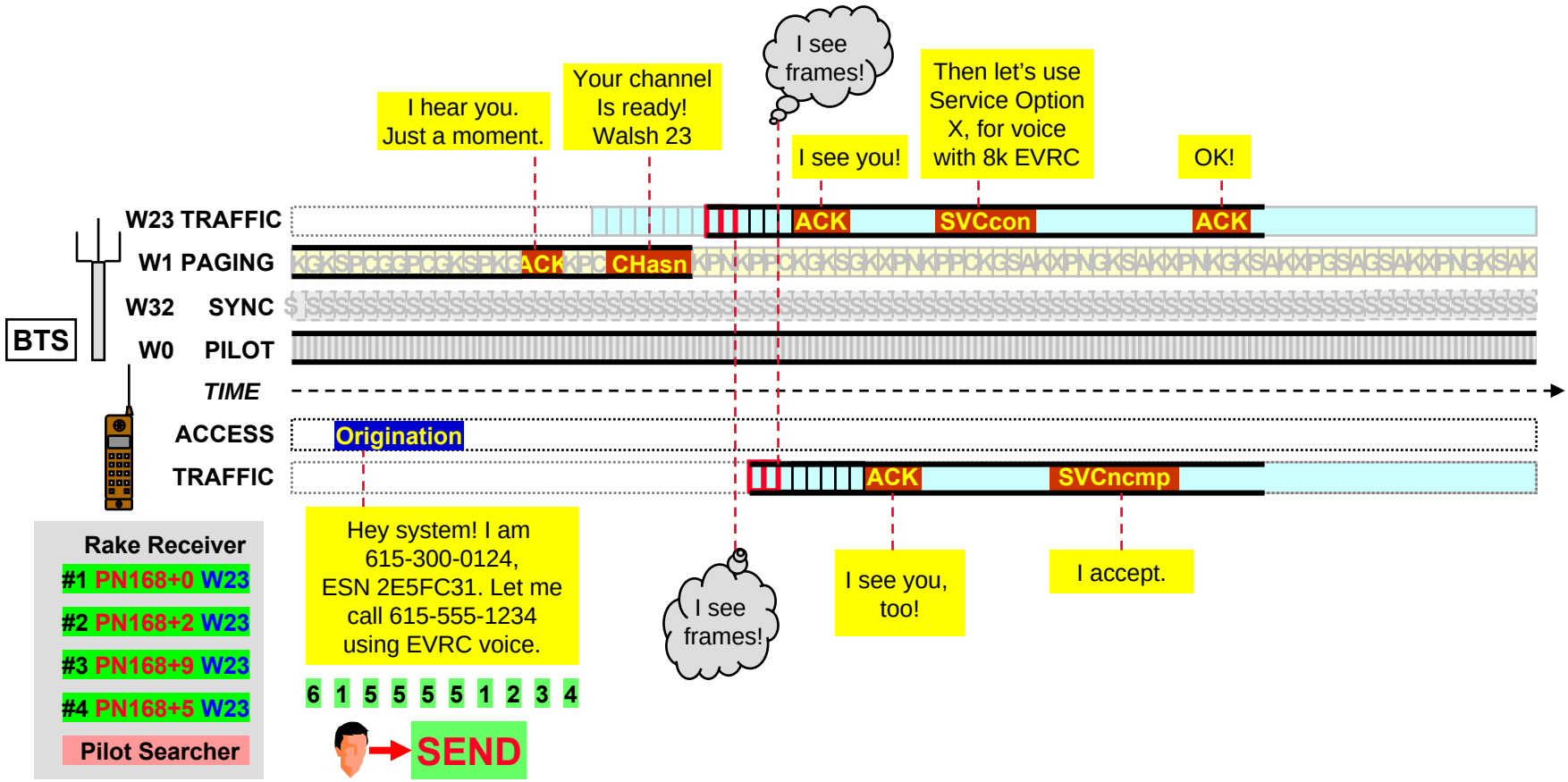
Outgoing Call Origination – IS-95 Voice



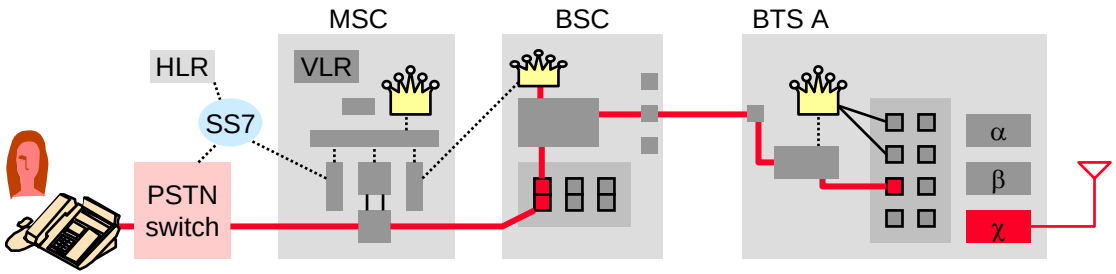


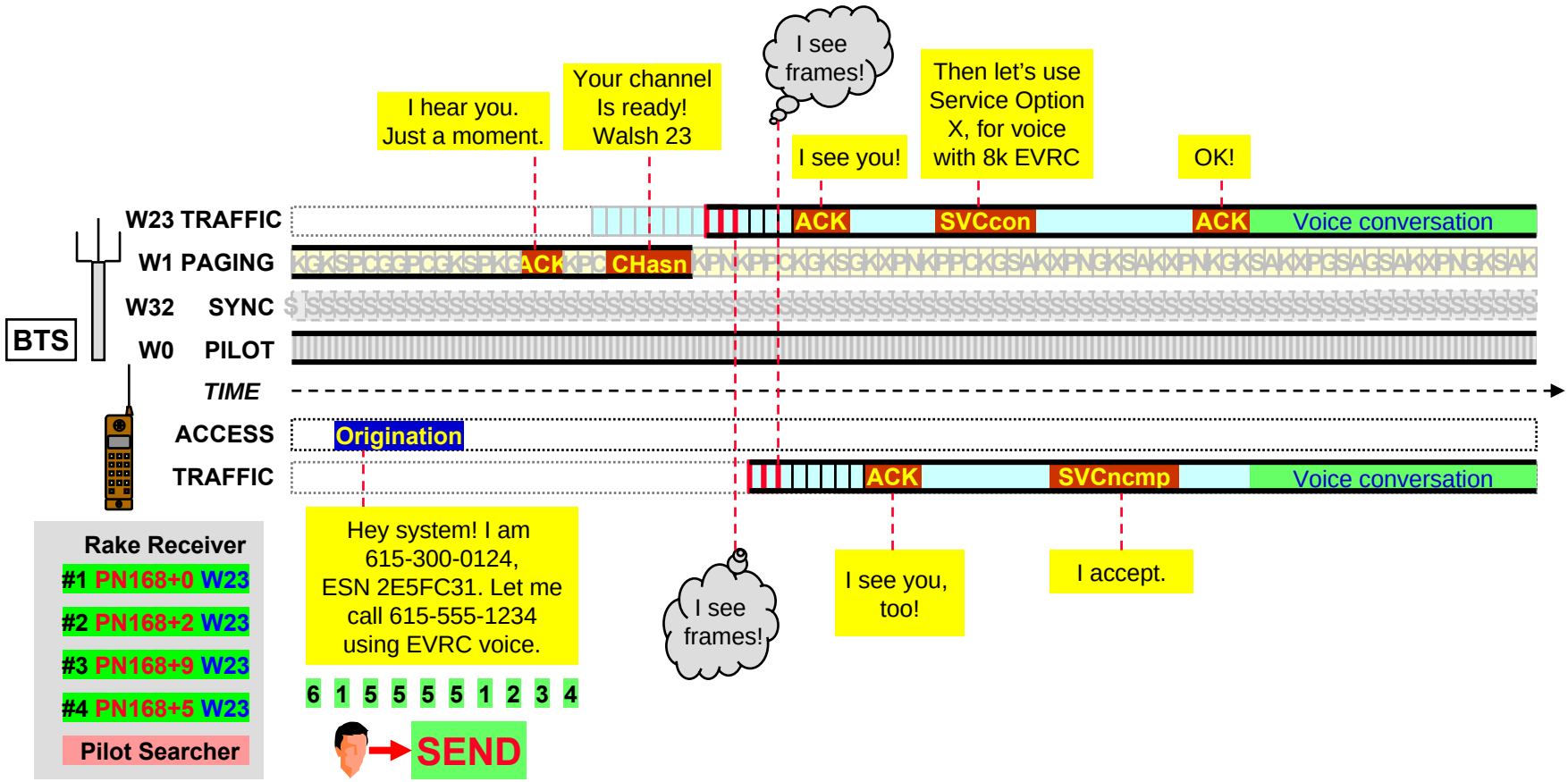
Outgoing Call Origination – IS-95 Voice





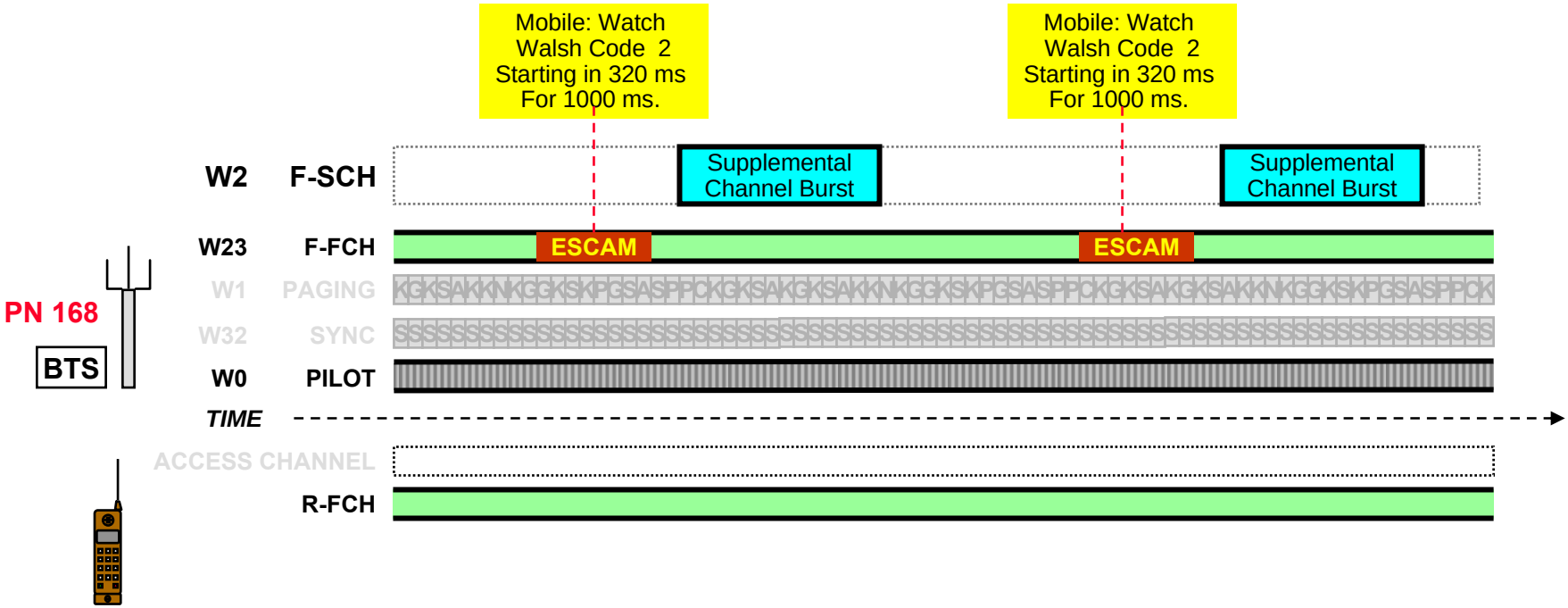
Outgoing Call Origination – IS-95 Voice





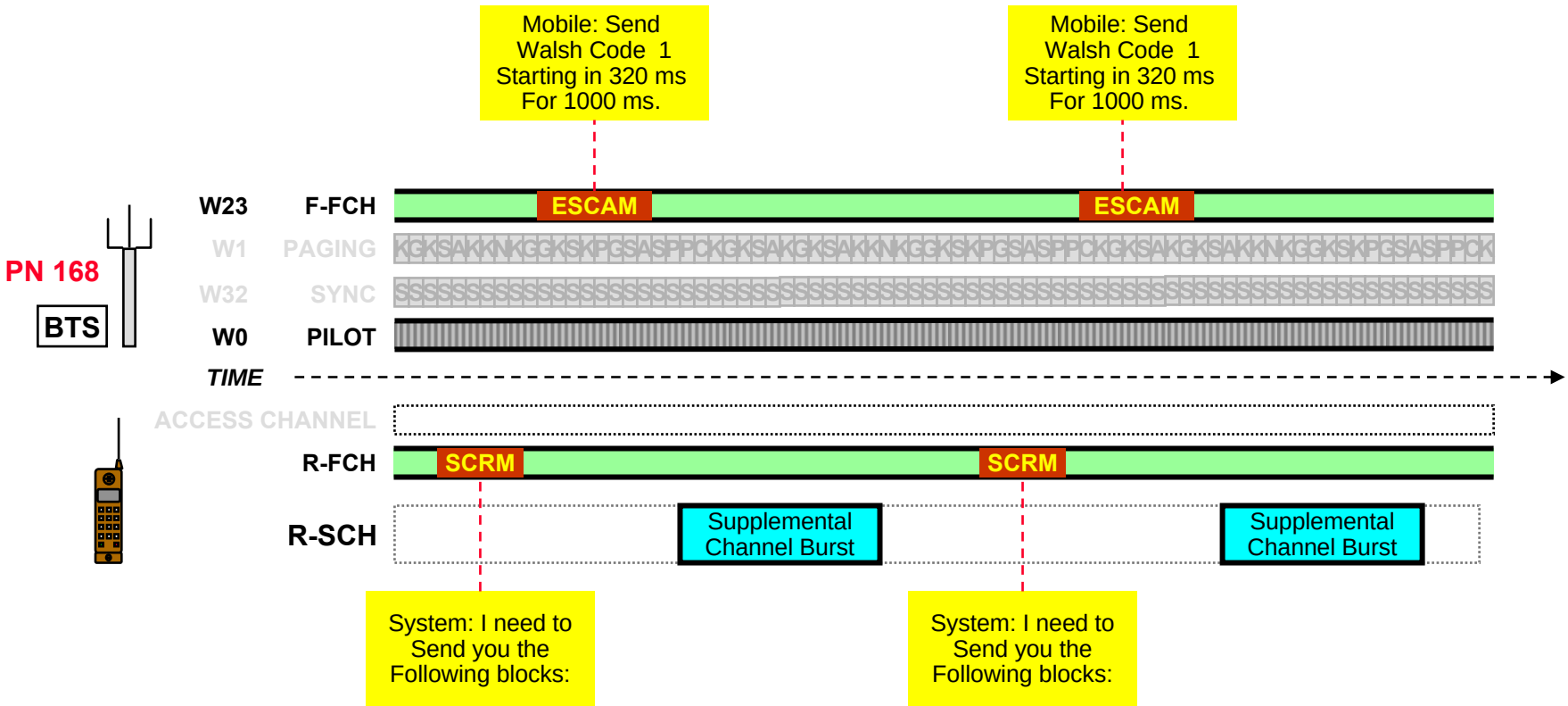
Downloading Data on a Forward Link Supplemental Channel

Forward Supplemental Channel Assignment



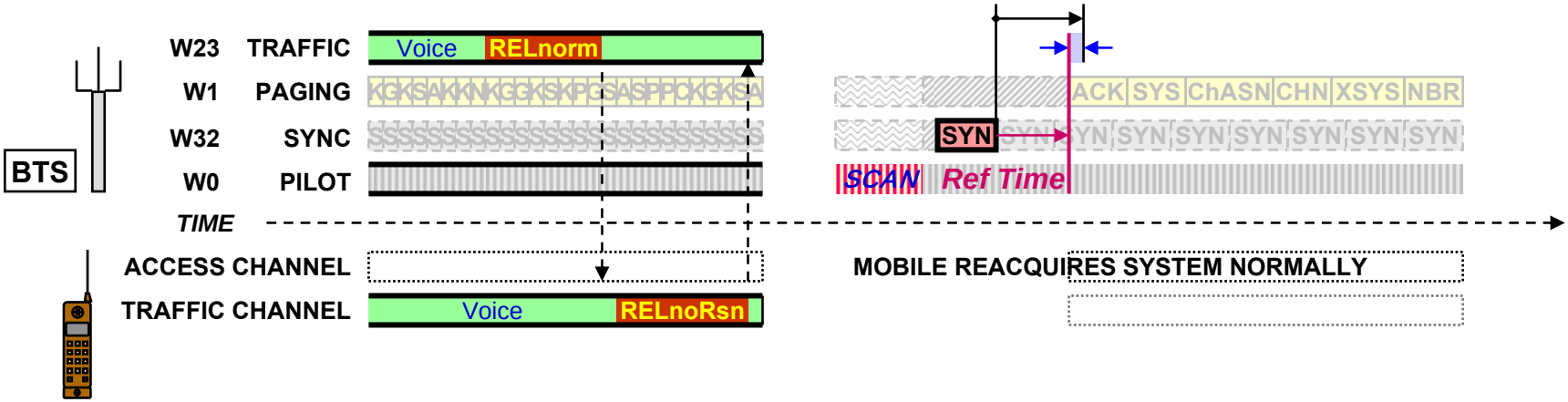
Uploading Data on a Reverse Link Supplemental Channel

Reverse Supplemental Channel Assignment



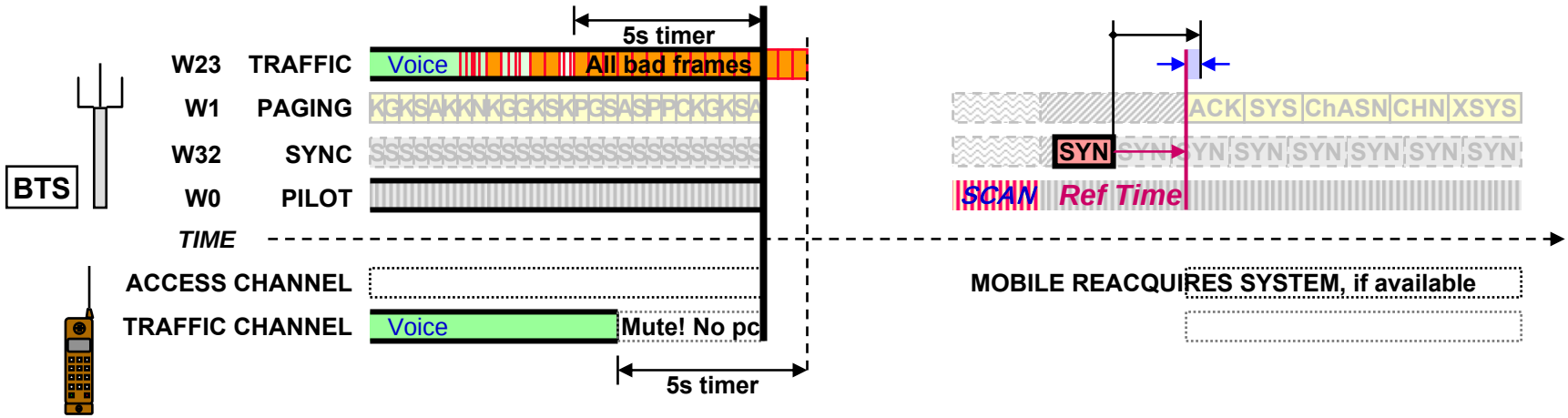
Ending A Call

Normal End of Call



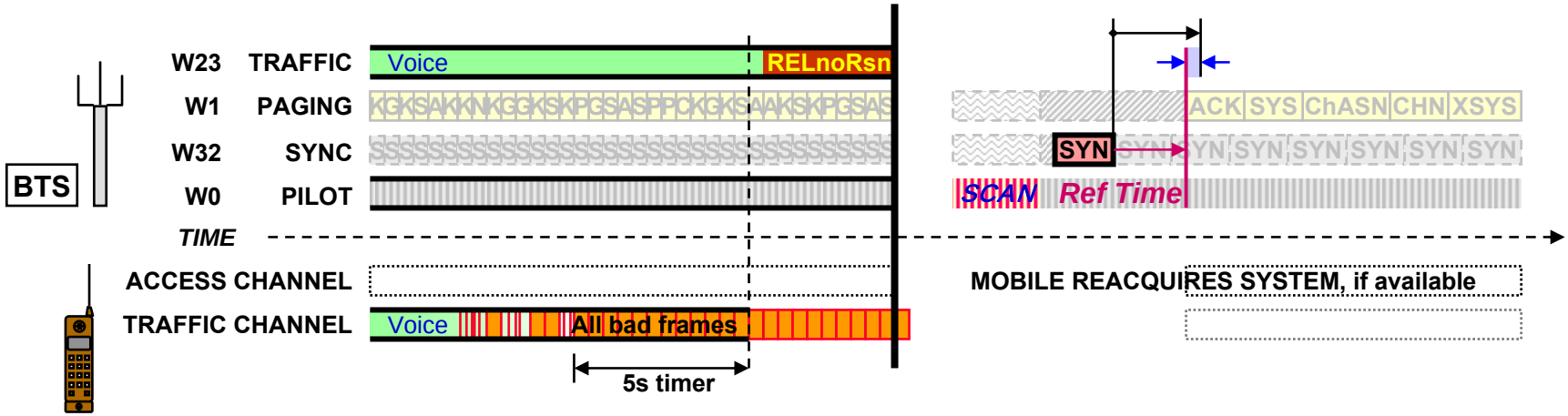
- When a call ends normally, it is because the caller on one side of the conversation decided to hang up
- The side ending the call sends a “Release – Normal” order
- The other side sends a “Release – No reason” order
  - It may send an acknowledgment first, if it cannot give the release order immediately
- After the system receives a release order from the mobile, it releases the resources it used for the call
- After the mobile receives a release order from the base station, it stops listening to the traffic channel and freshly reacquires the system

Abnormal End of Call – Forward Link Failure



- The mobile is always counting and tracking the bad frames it receives on the forward link
- Forward Link Fade Timer: If the mobile does not receive any good frames during a 5-second period, it aborts the call
- If a mobile receives 10 consecutive bad frames, it mutes its transmitter until at least 2 consecutive good frames are heard
  - If the mobile stays muted 5 seconds, the BTS will release too
- After a call ends for any reason, the mobile tries to reacquire the system, making an independent cold start

Abnormal End of Call – Reverse Link Failure



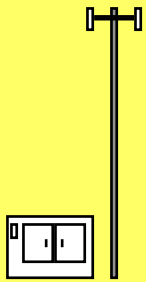
- The BTS is always counting and tracking the bad frames it receives on the reverse link from the mobile
- Reverse Link Fade Timer: If the BTS does not receive any good frames during a 5-second period, it releases the call
- After a call ends for any reason, the mobile tries to reacquire the system, making an independent cold start

Feature Notification: You Have Voicemail!

Feature Notification

FEATURE NOTIFICATION MESSAGE

98/06/30 21:16:44.368 [PCH] Feature Notification Message
MSG_LENGTH = 144 bits
MSG_TYPE = Feature Notification Message
ACK_SEQ = 0
MSG_SEQ = 0
ACK_REQ = 1
VALID_ACK = 0
ADDR_TYPE = IMSI
ADDR_LEN = 56 bits
IMSI_CLASS = 0
IMSI_CLASS_0_TYPE = 3
RESERVED = 0
MCC = 302
IMSI_11_12 = 00
IMSI_S = 9055170325
RELEASE = 0
RECORD_TYPE = Message Waiting
RECORD_LEN = 8 bits
MSG_COUNT = 1
RESERVED = 0







The Feature Notification Message on the Paging Channel tells a specific mobile it has voice messages waiting.

There are other record types to notify the mobile of other features.

MOBILE STATION ACKNOWLEDGMENT

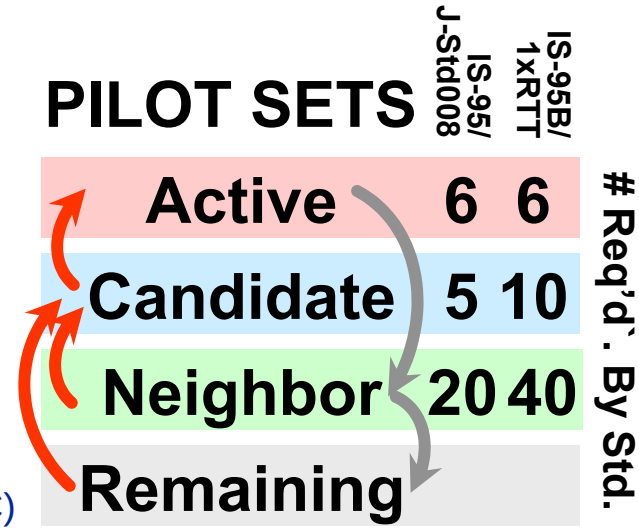
The mobile confirms it has received the notification by sending a Mobile Station Acknowledgment Order on the access channel.



A Soft Handoff

The Complete Rules of Soft Handoff

- The Handset considers pilots in ***sets***
  - **Active**: pilots of sectors actually in use
  - **Candidates**: pilots mobile requested, but not yet set up & transmitting by system
  - **Neighbors**: pilots told to mobile by system, as nearby sectors to check
  - **Remaining**: any pilots used by system but not already in the other sets (div. by PILOT_INC)
- Handset sends **Pilot Strength Measurement Message** to the system whenever:
  - It notices a pilot in neighbor or remaining set exceeds **T_ADD**
  - An active set pilot drops below **T_DROP** for **T_TDROP** time
  - A candidate pilot exceeds an active by **T_COMP**
- The System may set up all requested handoffs, or it may apply special manufacturer-specific screening criteria and only authorize some



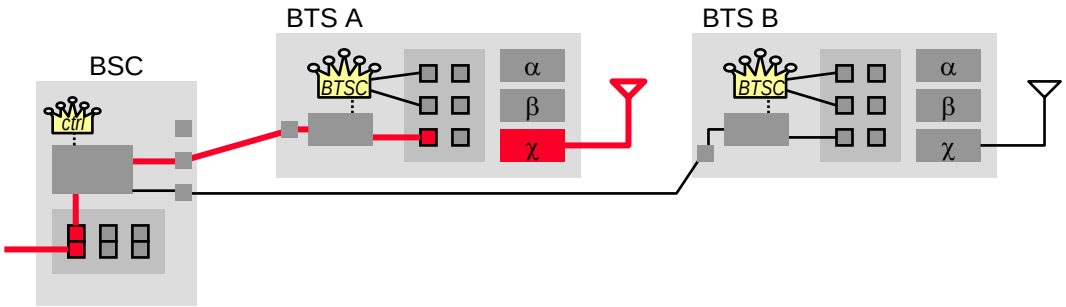
HANDOFF PARAMETERS

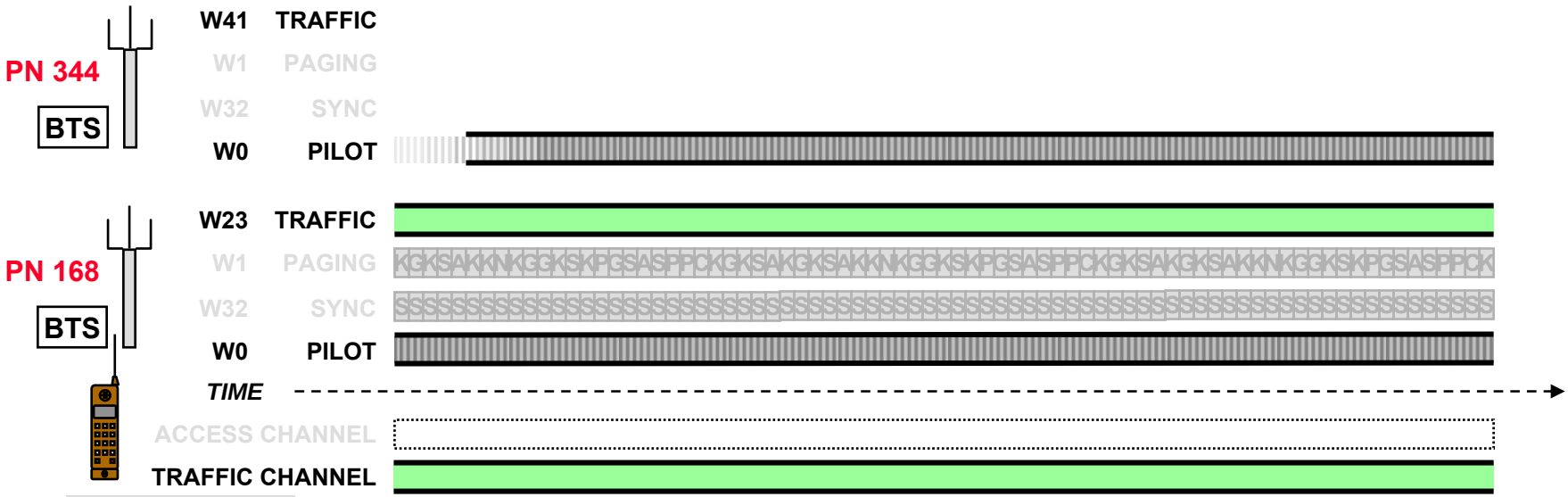
T_ADD **T_DROP**

T_TDROP **T_COMP**

Exercise: How does a pilot in one set migrate into another set, for all cases? Identify the trigger, and the messages involved.

Basic Soft/Softer Handoff





Rake Receiver

#1 PN168+0 W23

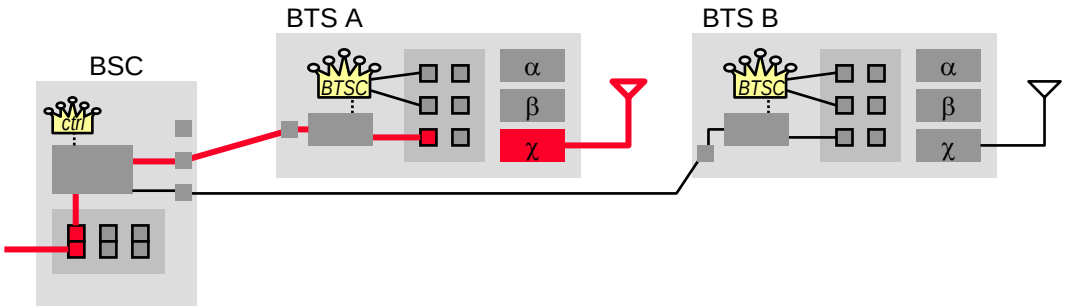
#2 PN168+2 W23

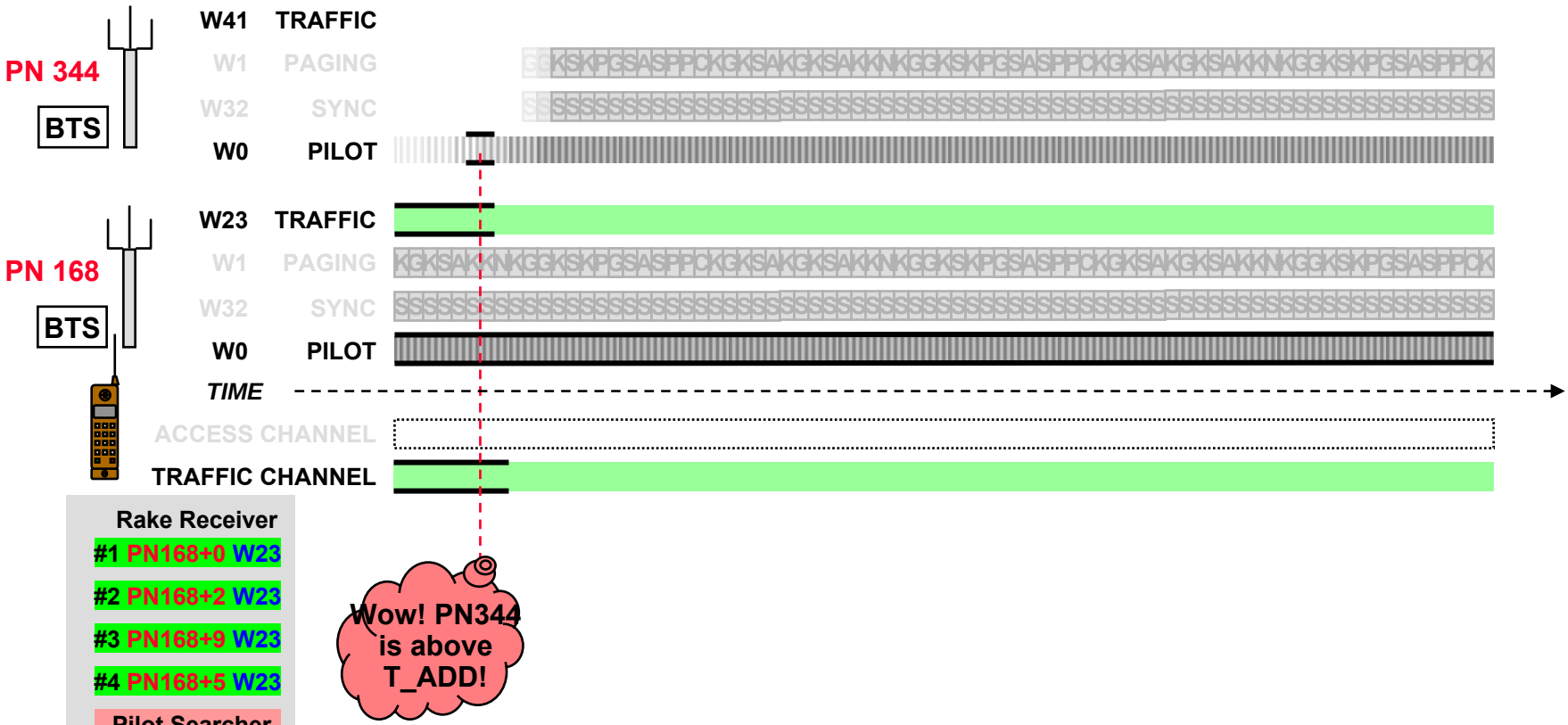
#3 PN168+9 W23

#4 PN168+5 W23

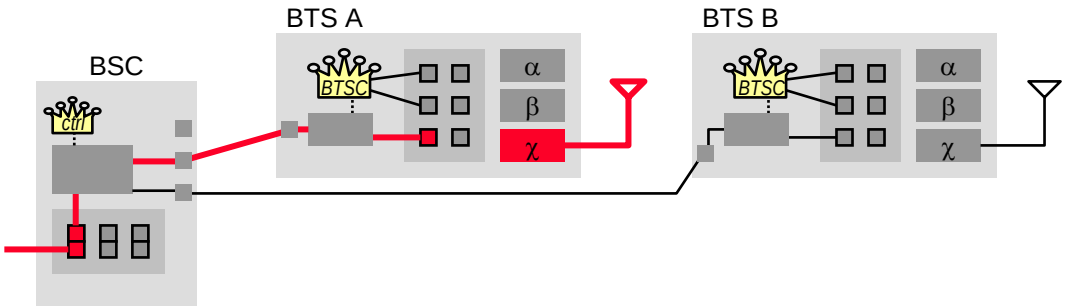
Pilot Searcher

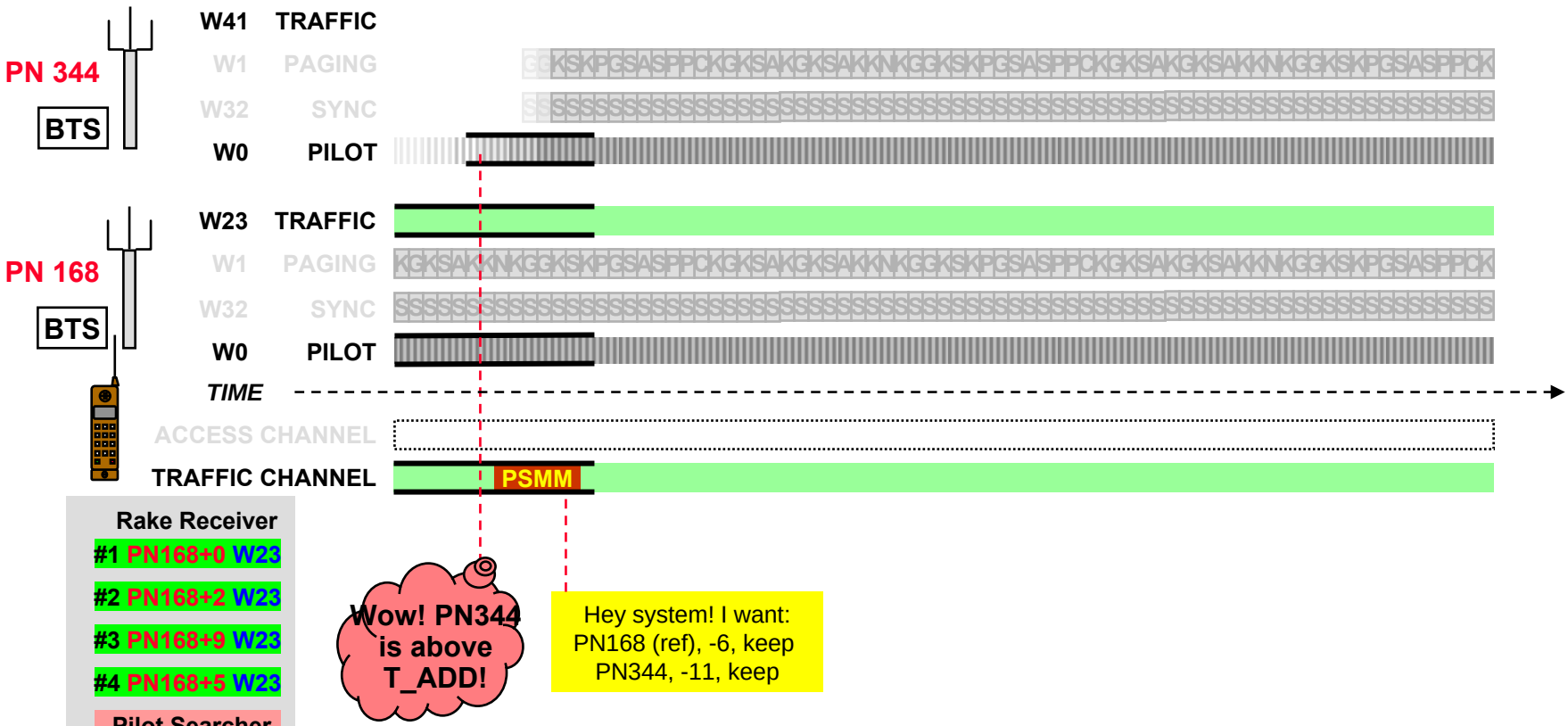
Basic Soft/Softer Handoff





Basic Soft/Softer Handoff





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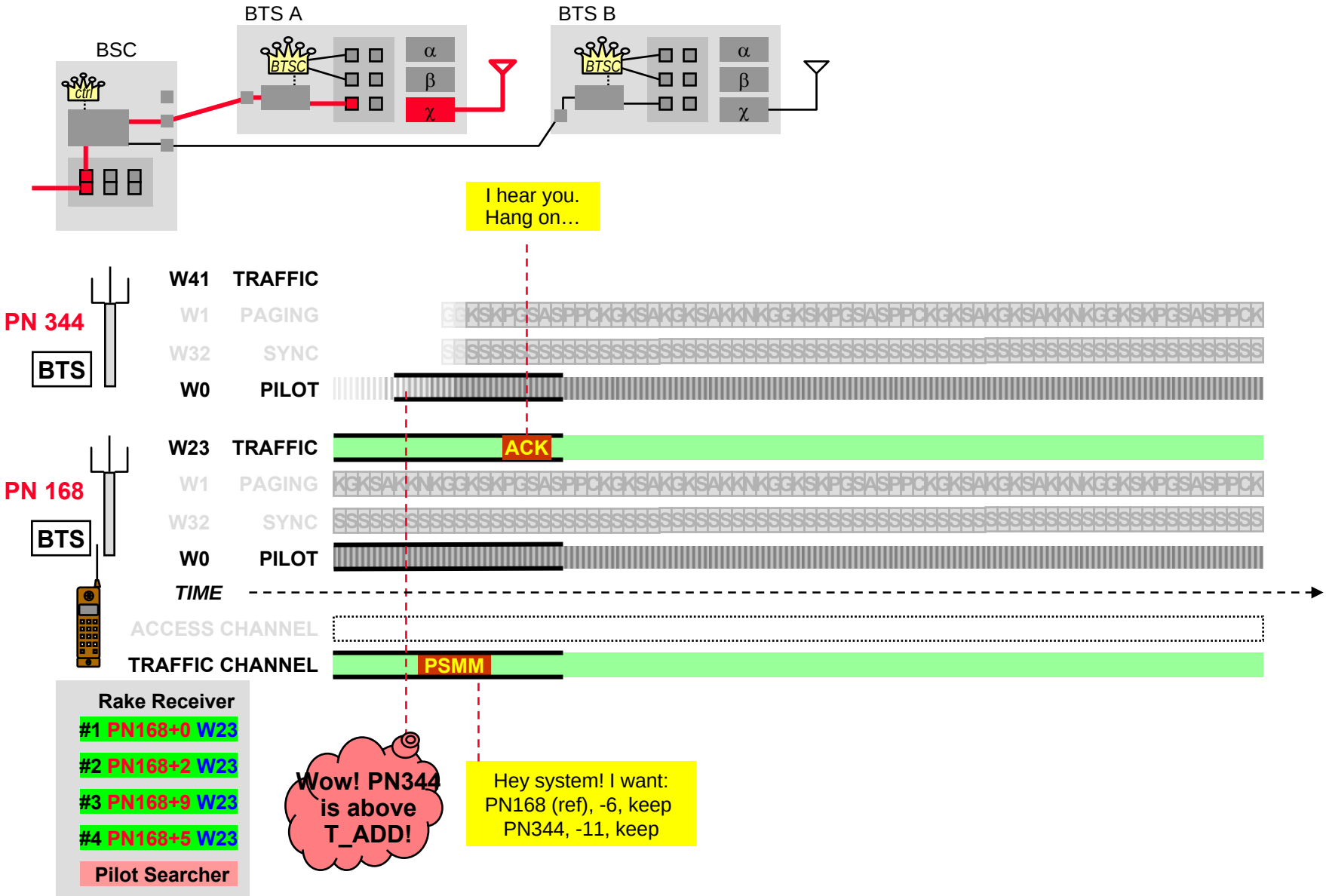
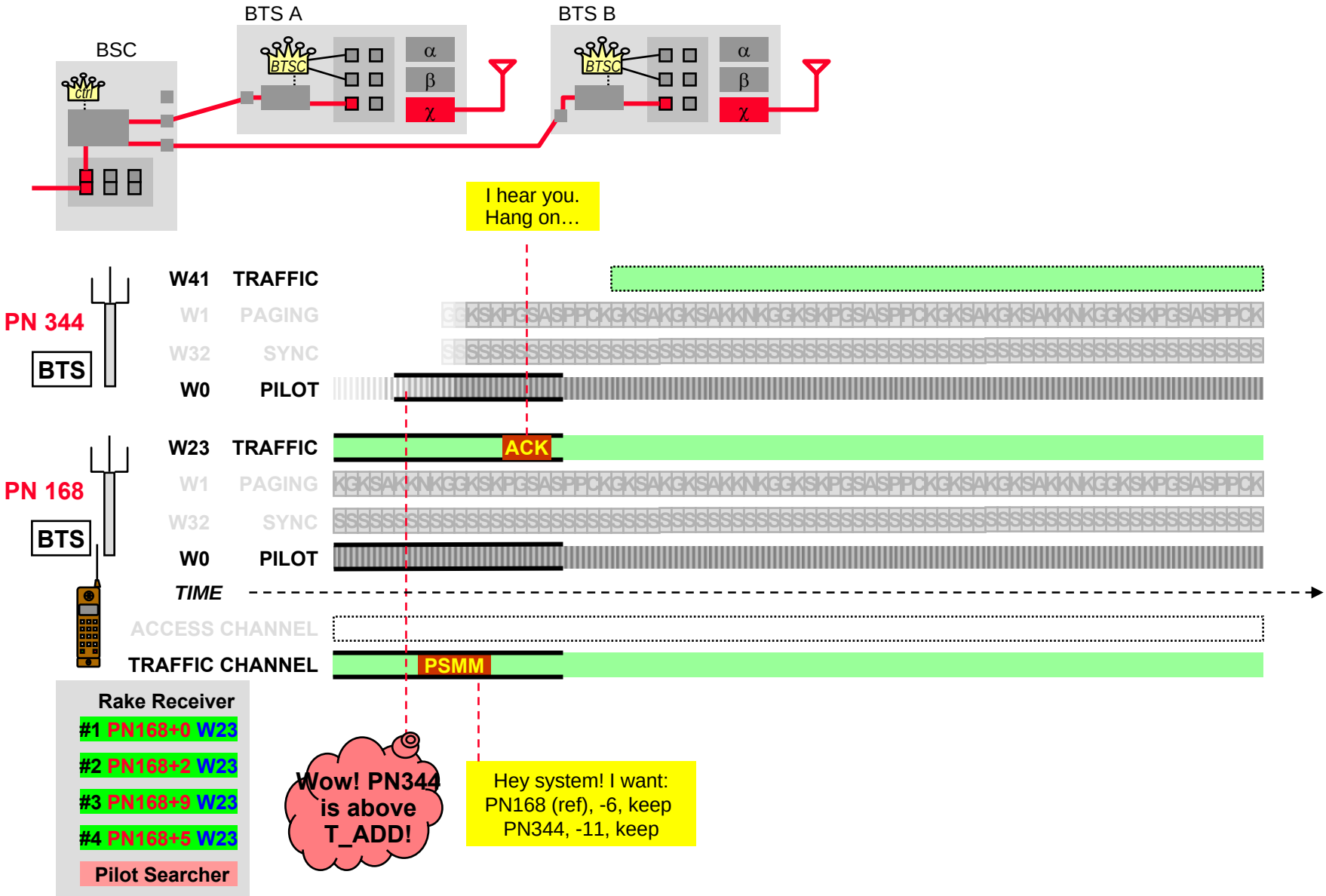
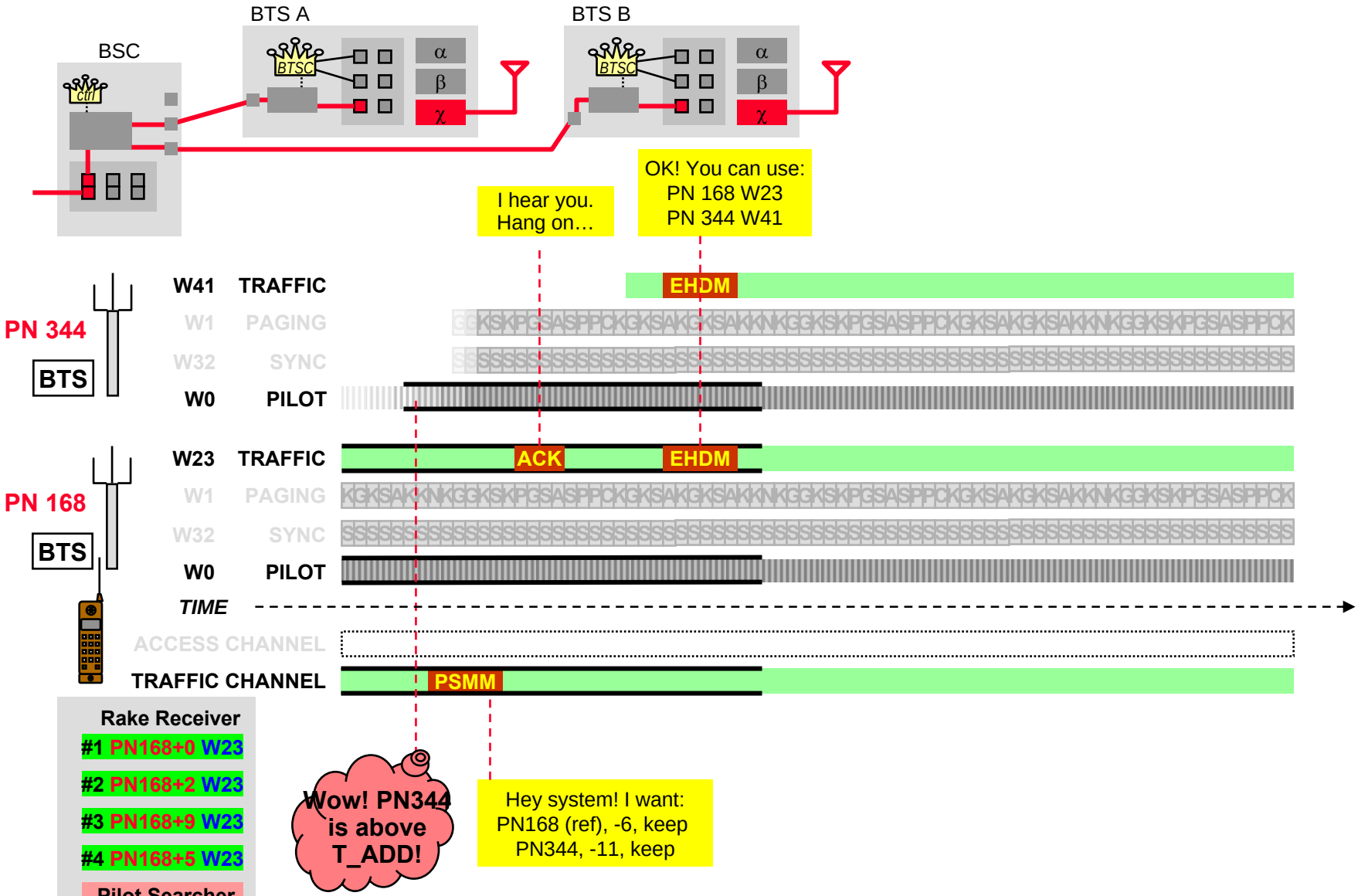


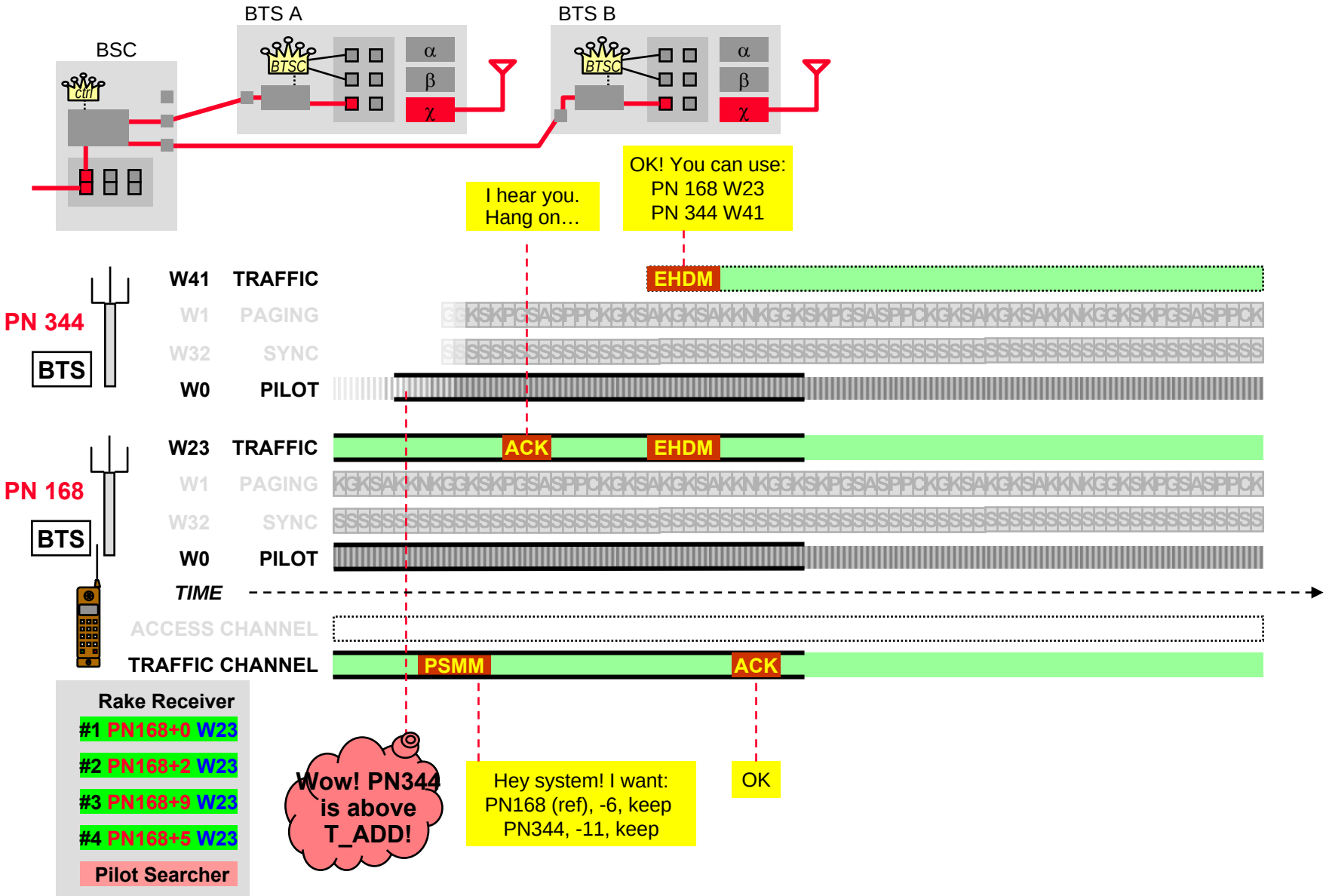
Basic Soft/Softer Handoff



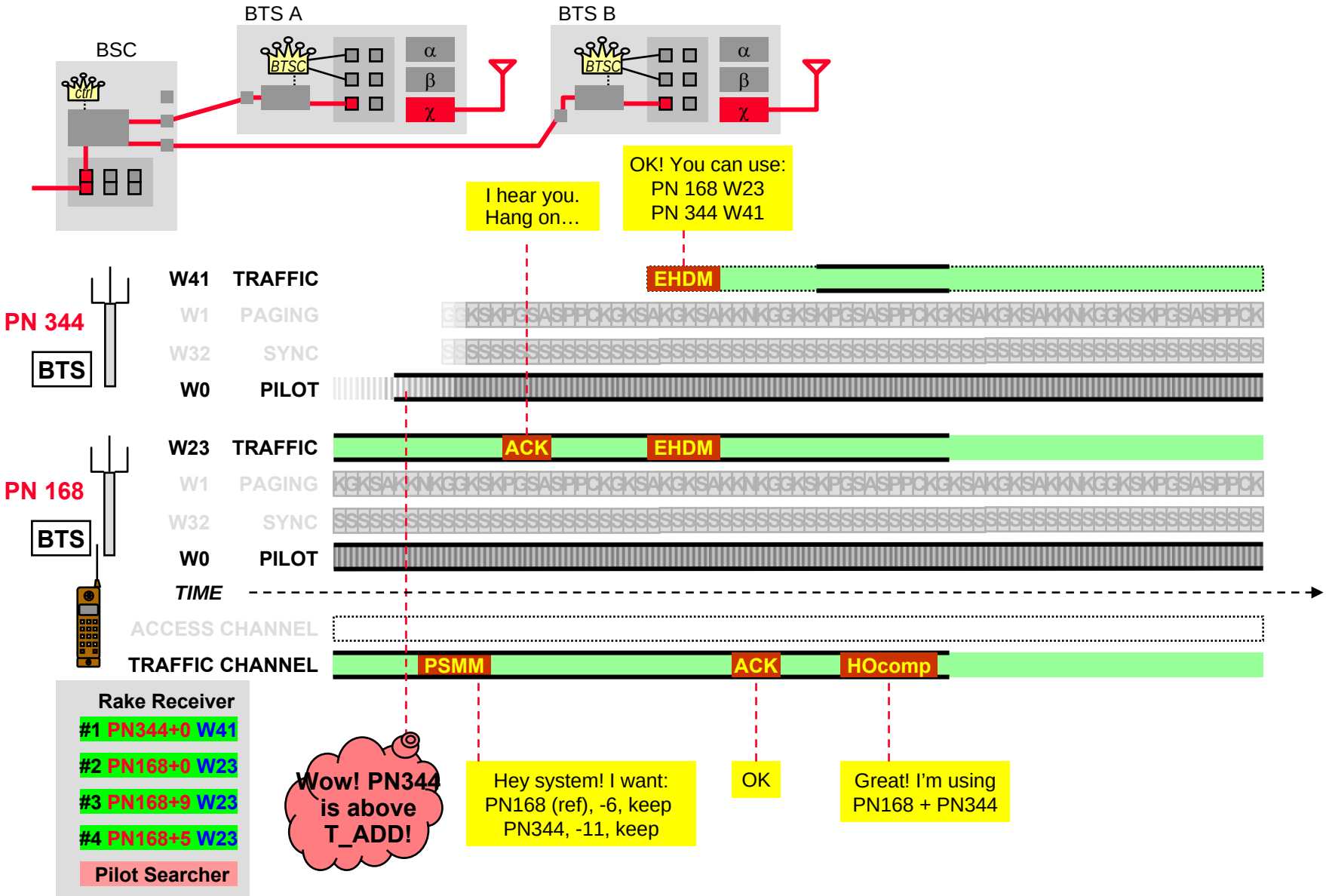
Basic Soft/Softer Handoff



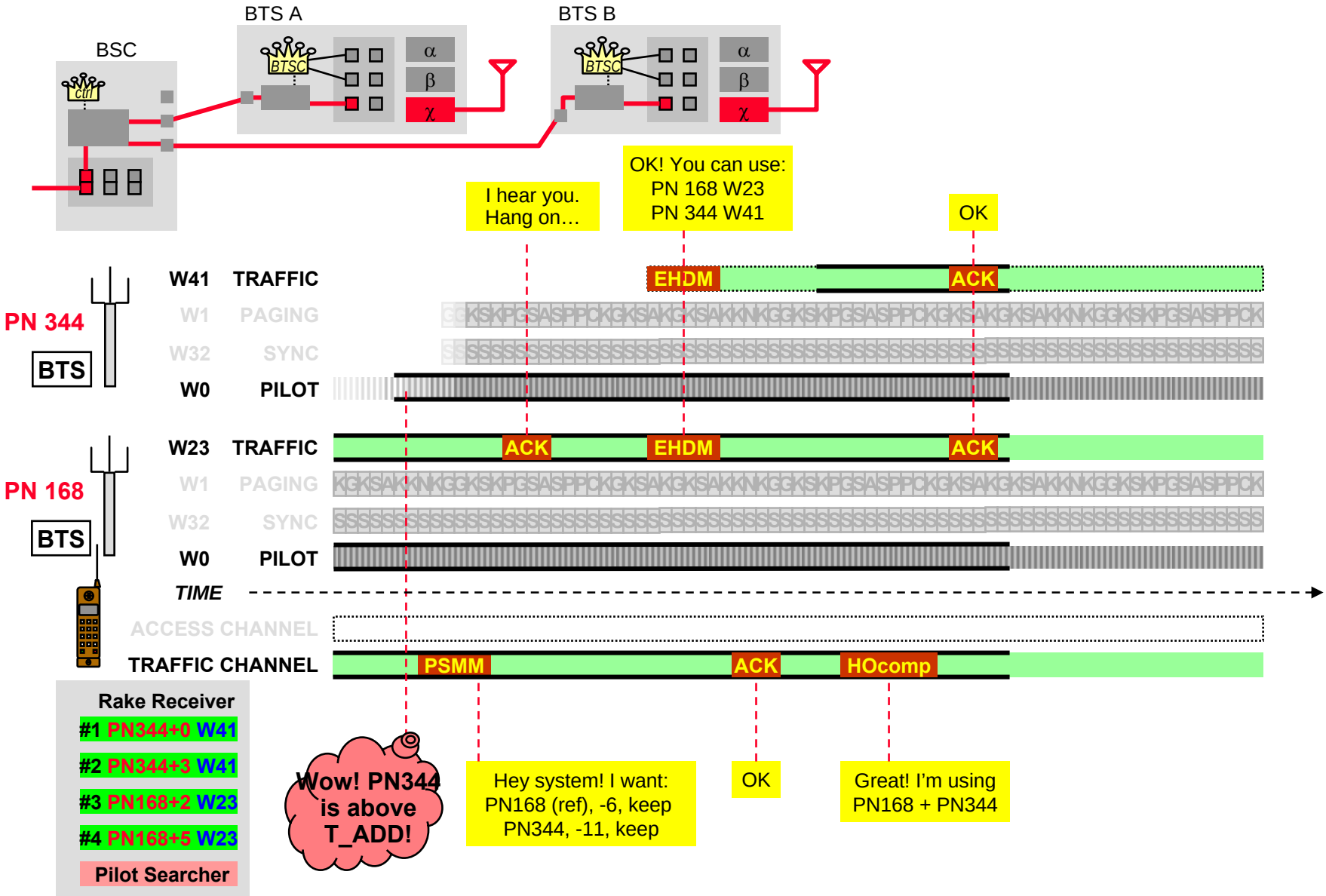
Basic Soft/Softer Handoff



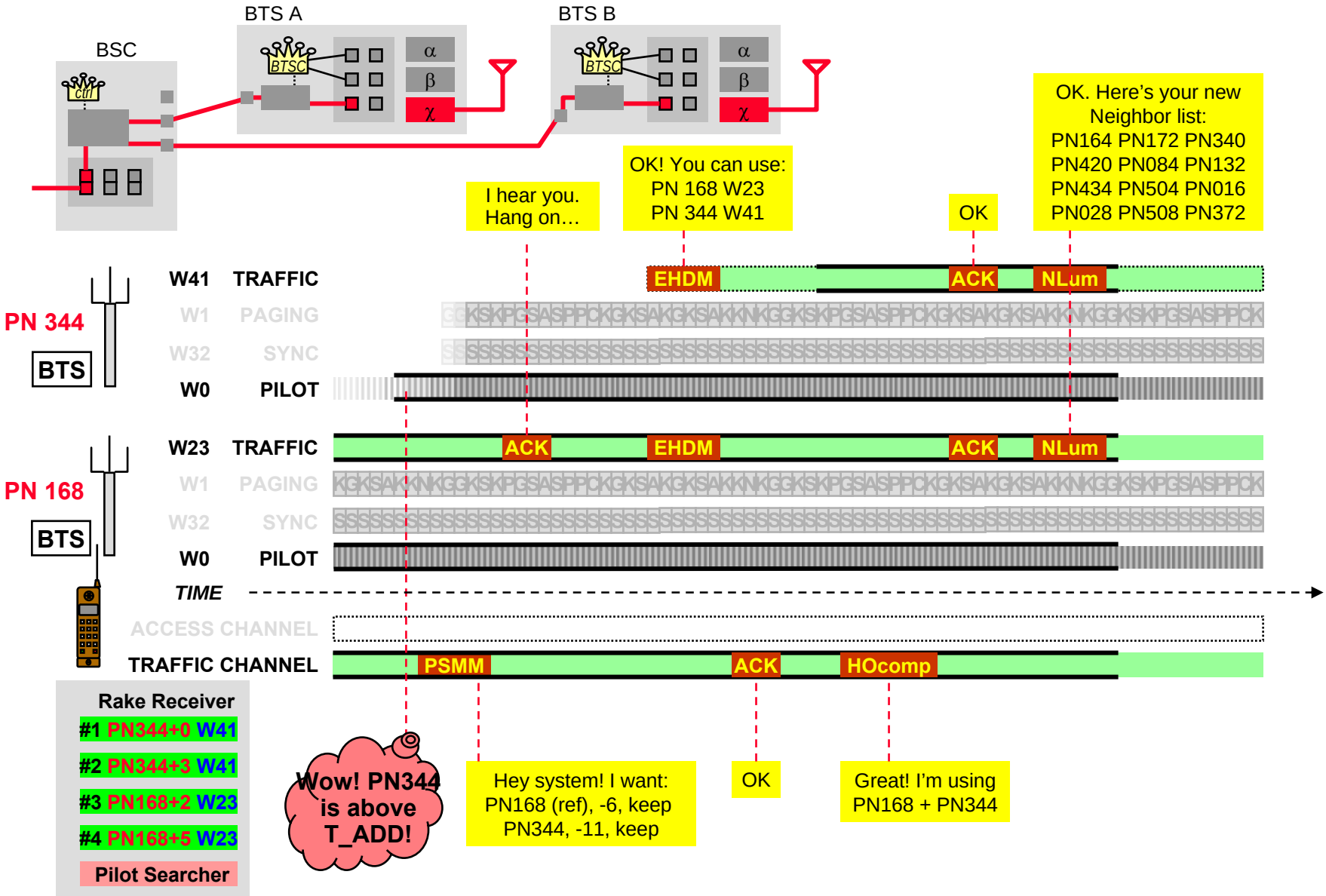
Basic Soft/Softer Handoff



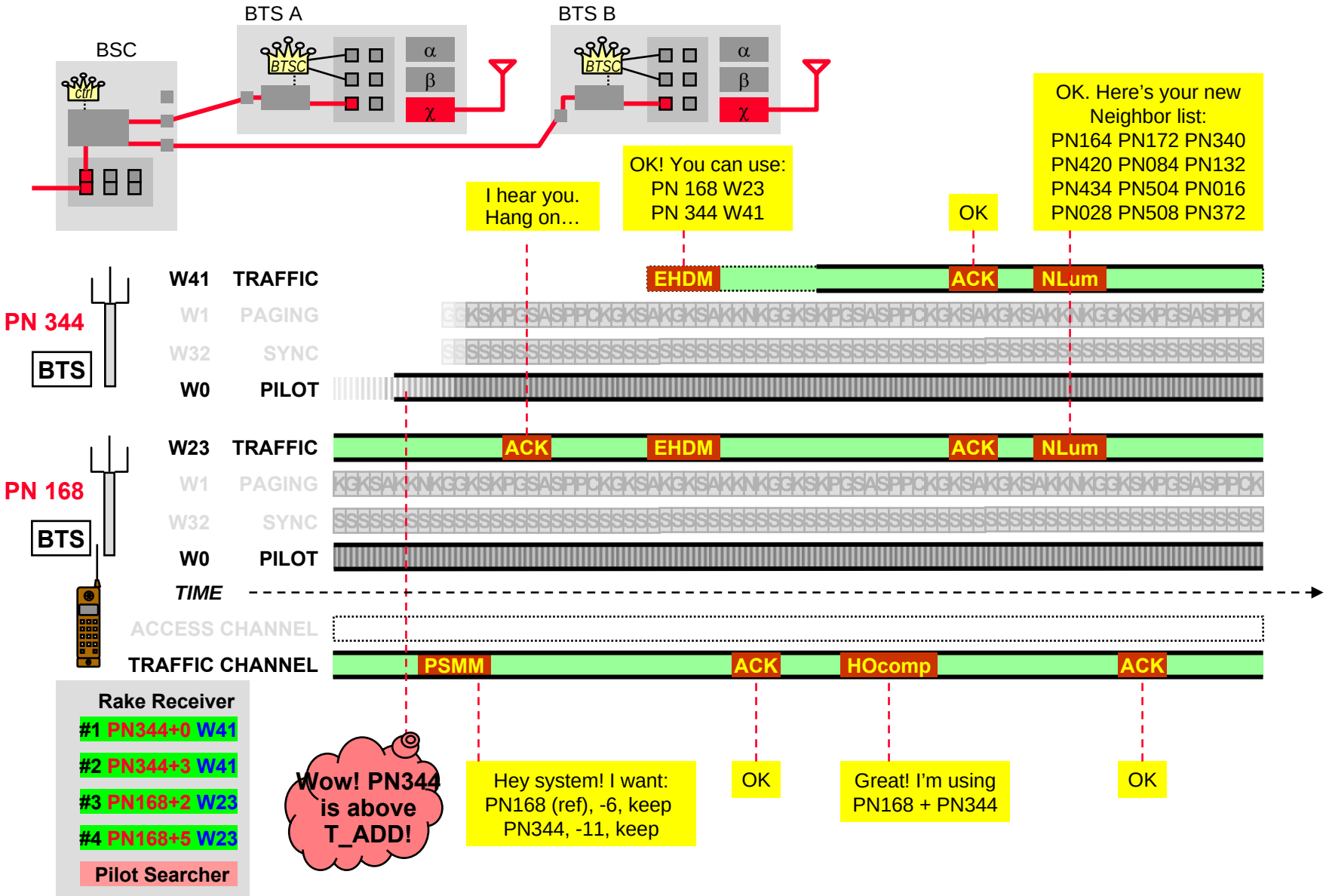
Basic Soft/Softer Handoff



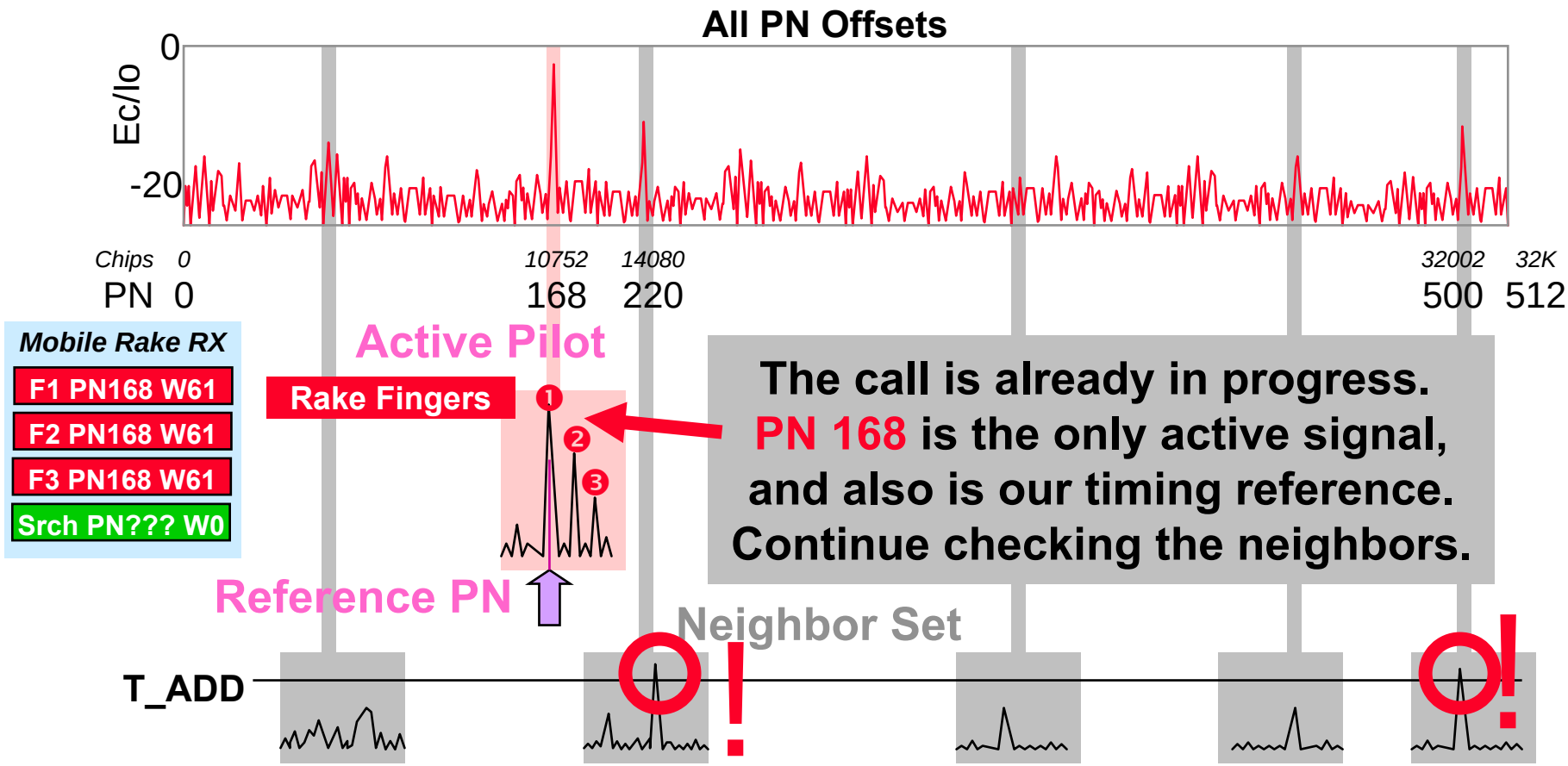
Basic Soft/Softer Handoff



Basic Soft/Softer Handoff

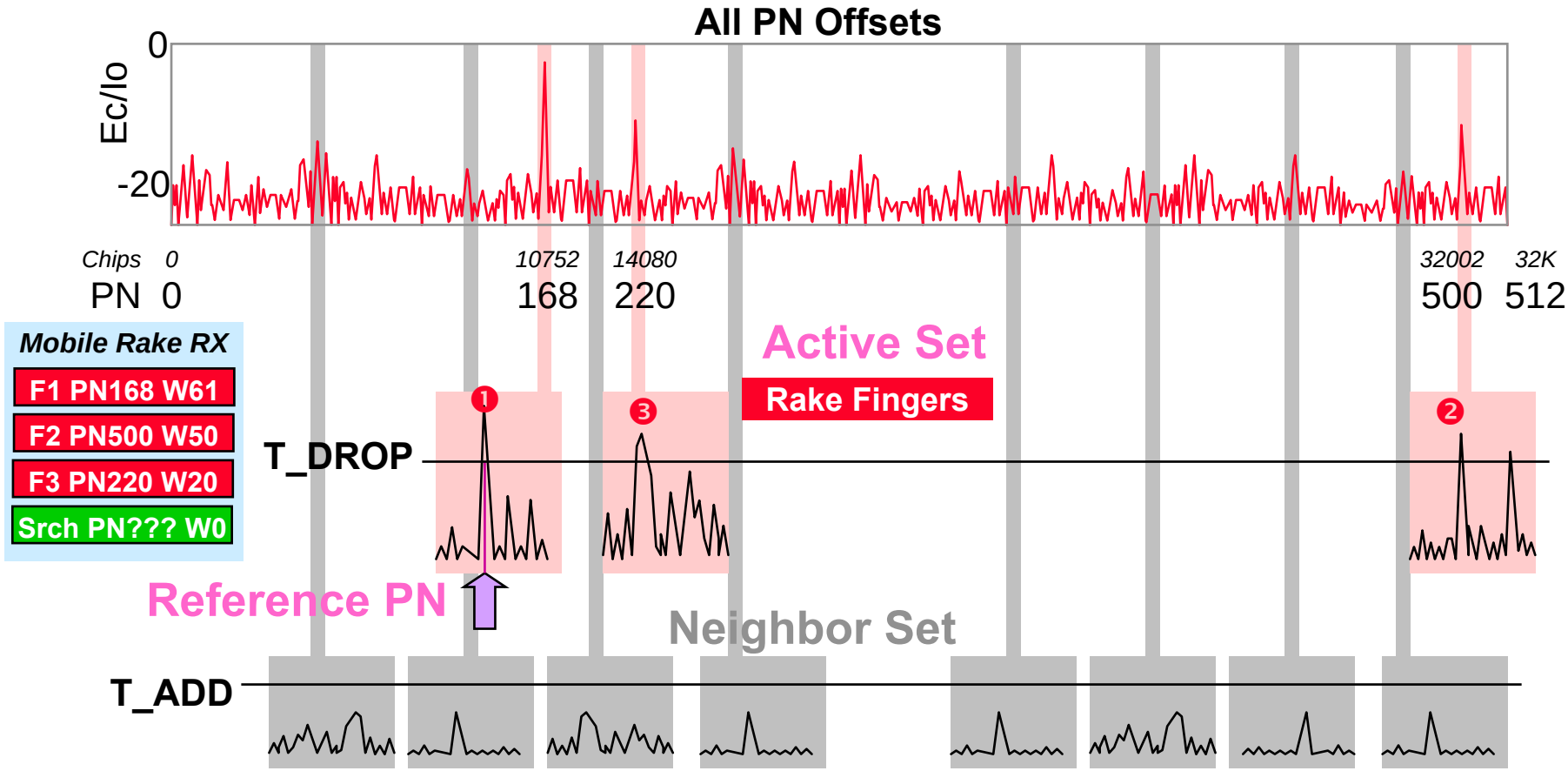


Handoff Example



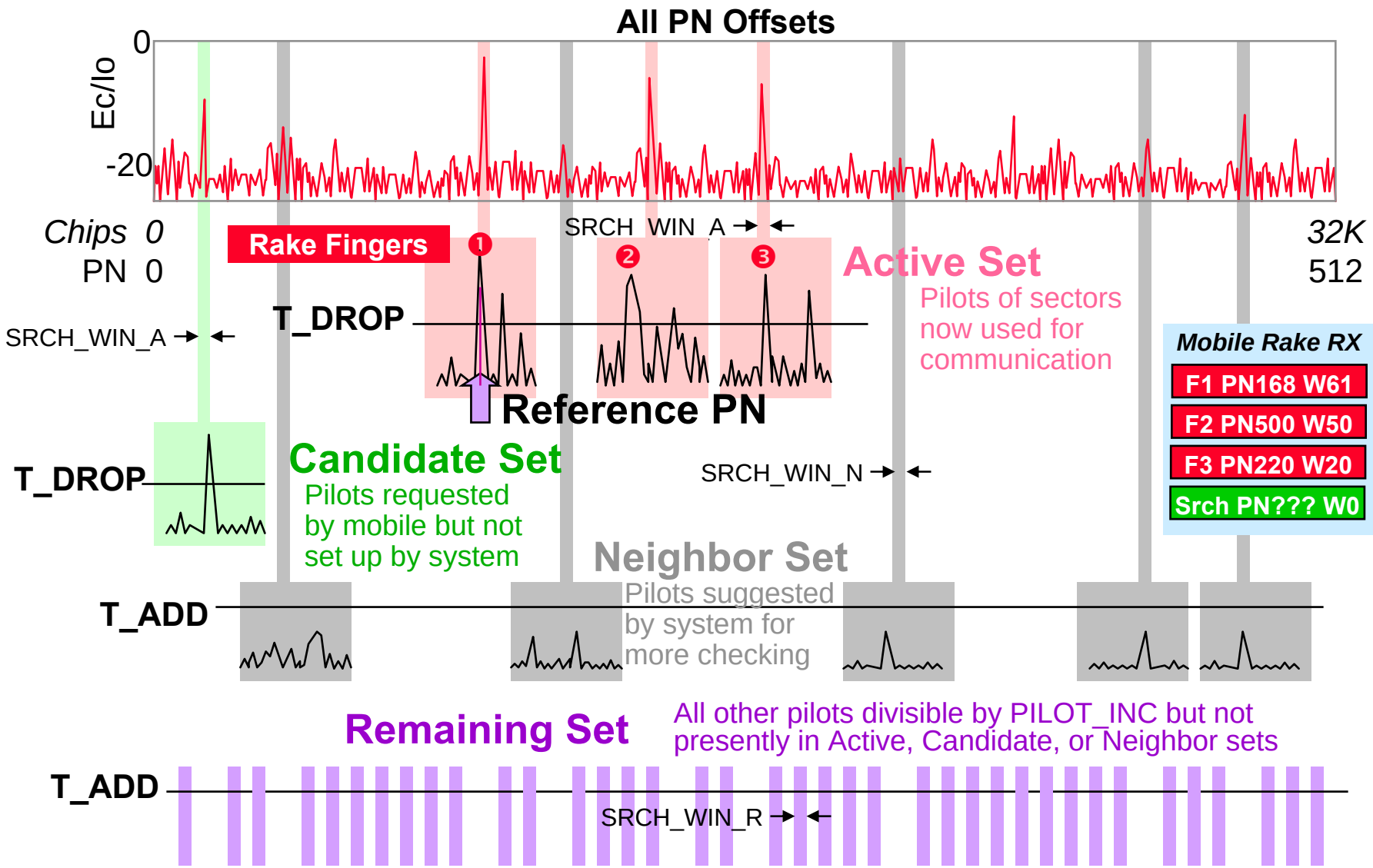
If we ever notice a neighbor with Ec/Io above T_ADD,
ask to use it! Send a Pilot Strength Measurement Message!

Handoff Now In Effect, but still check Pilots!



Continue checking each ACTIVE pilot. If any are less than T_DROP and remain so for T_TDROP time, send Pilot Strength Measurement Message, DROP IT!! Continue looking at each NEIGHBOR pilot. If any ever rises above T_ADD, send Pilot Strength Measurement Message, ADD IT!

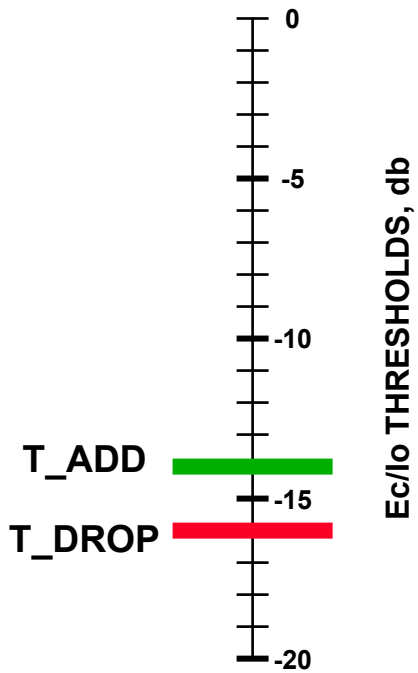
The Complete Picture of Handoff & Pilot Sets



Improved Handoff Control in 1xRTT

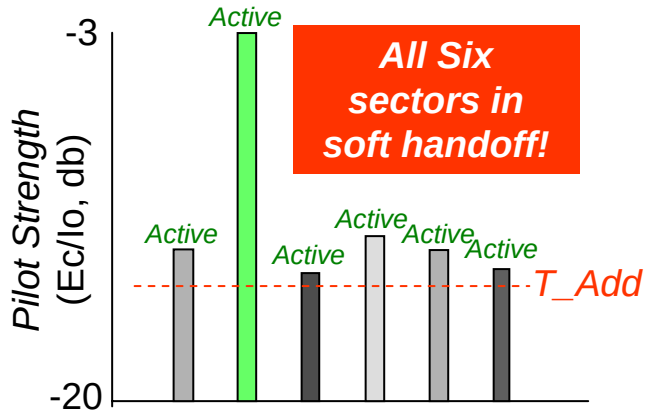
The IS-95 Situation

- IS-95 handoff is driven by fixed thresholds of pilot strength (Ec/Io)
- If the mobile notices a new pilot stronger than T_Add, it asks for it immediately
- If an active pilot drops below T_Drop and stays below for T_Tdrop seconds, the mobile asks for permission to stop using it
- The mobile has no discretion – the T_Add and T_Drop values apply no matter what



IS-95A Handoff: Fixed Thresholds Control It

- Mobile requests soft handoff with all pilots above T_Add
  - This occasionally leads to some rigid, less-than-optimum decisions!
- Problem Situation 1
  - One dominant, strong signal and a lot of weak ones:
    - Mobile asks for them all, but only one is really needed!
- Problem Situation 2
  - Heavy pilot pollution, many signals lurk barely below the threshold
    - Mobile may request one or two, but ignore the others which could have helped call survive





1xRTT Allows Dynamic Handoff Thresholds

- A handoff process more intelligent than fixed thresholds
  - Handoff events driven by smarter, situation-influenced triggers
- Candidate Set Removal: *if that sector isn't worth adding anymore*

$$10 log PS_c > softslope \times 10\log\left(\sum_{i \in AS} PS_i\right) + addintercept$$

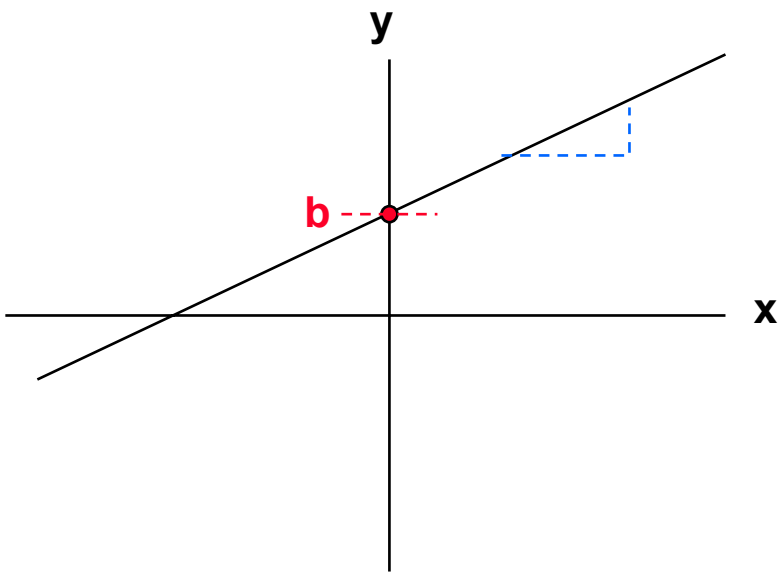
- Neighbor-to-Active transition: *only if it's a worthwhile improvement*

$$10\log PS_n > max\left[softslope \times 10\log\left(\sum_{i \in AS} PS_i\right) + addintercept, TADD\right]$$

- Removal from Active Set: *if that sector isn't needed anymore*

$$10\log PS_i < max\left[softslope \times 10\log\left(\sum_{j > i \in AS} PS_j\right) + dropintercept, TDROP\right]$$

Standard Equation of a Line



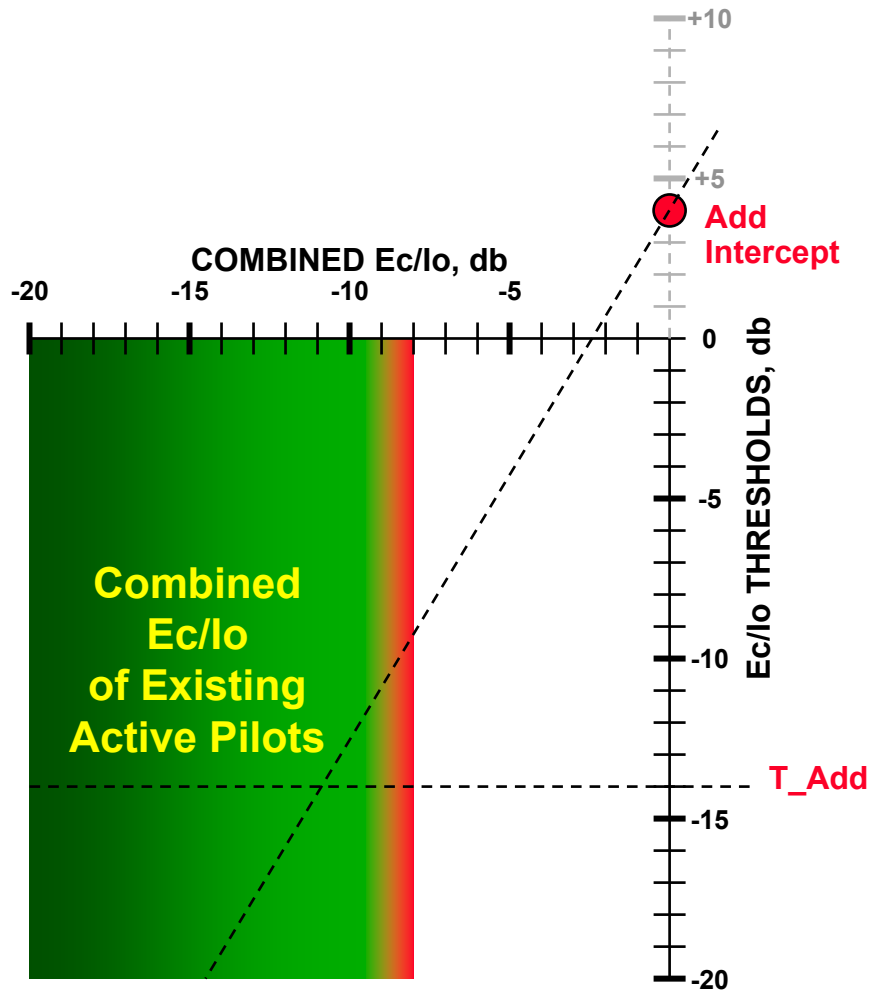
- The equation of a straight line is pretty simple. It includes
  - y, the vertical-axis value
  - m, the slope of the line
    - the ratio of rise/run
  - x, the horizontal-axis value
  - b, the y intercept
    - the value of y where the line crosses the y axis

$$y = mx + b$$

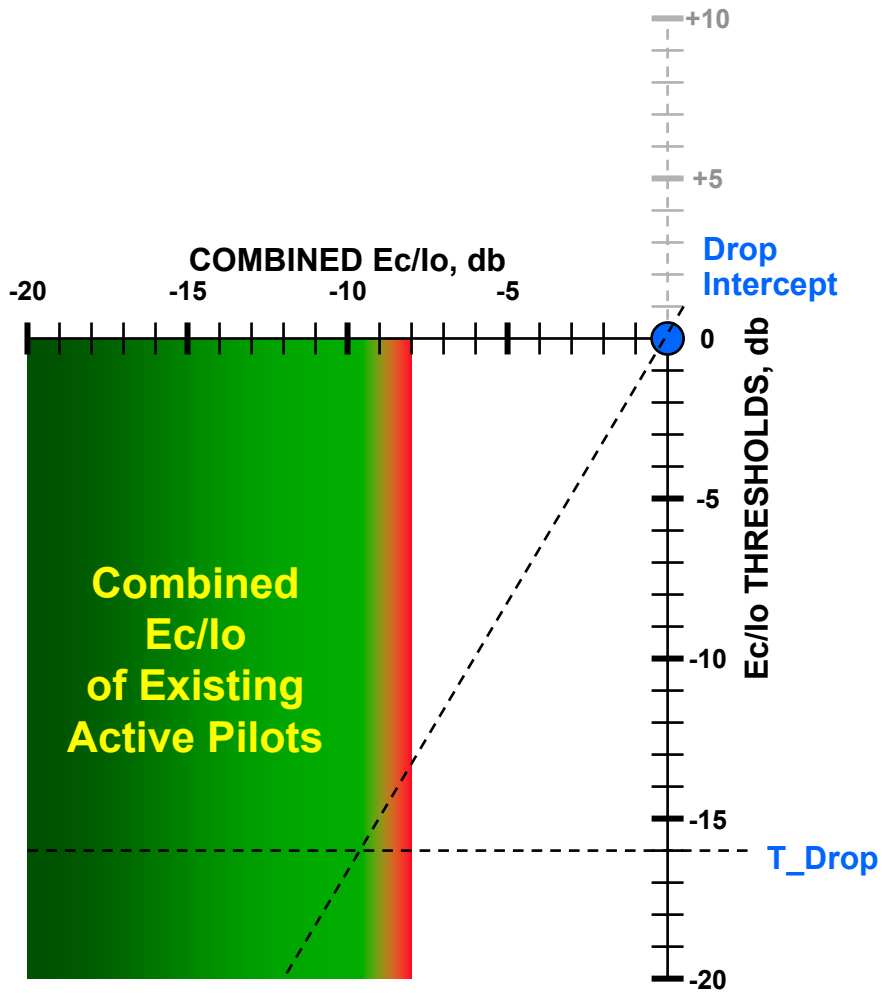
slope

intercept

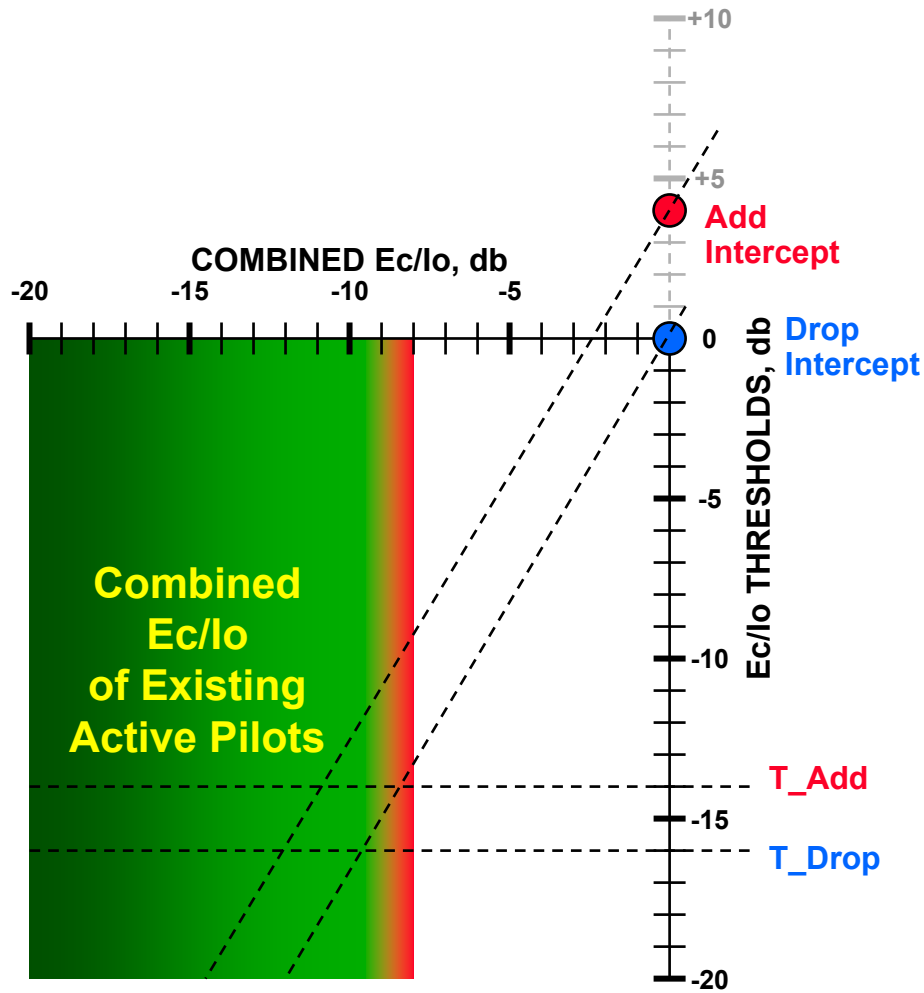
The Dynamic Handoff Threshold Line



The Dynamic Handoff Threshold Line

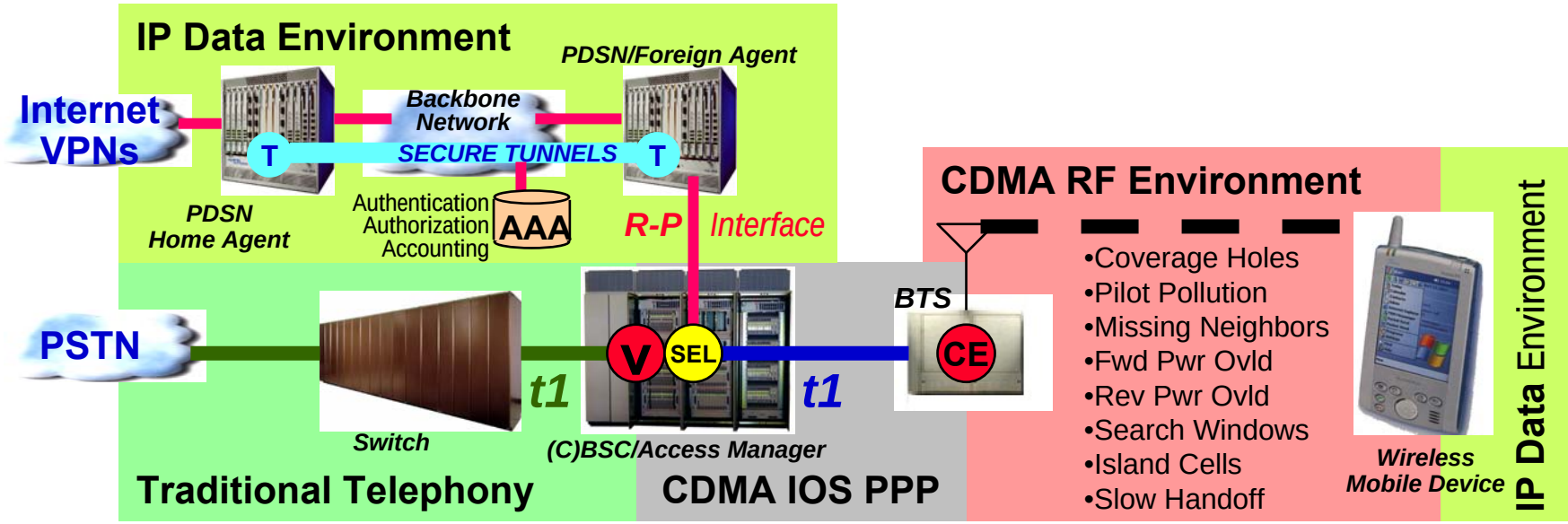


The Dynamic Handoff Threshold Line



Optimizing Performance of CDMA2000 1xRTT Systems

The Big Picture:



- 1xRTT services may include both traditional circuit-switched voice and new fast IP data connections
  - A User's link is in multiple jeopardy, both radio and packet worlds
- Radio environment portion
  - Problems: FER, drops, access failures, capacity woes
  - Causes: mainly in the RF world, because of mainly RF problems
- Packet environment
  - Problems: Setup failures, dropped connections, low throughput
  - Causes: could be IP-related, or could be RF related

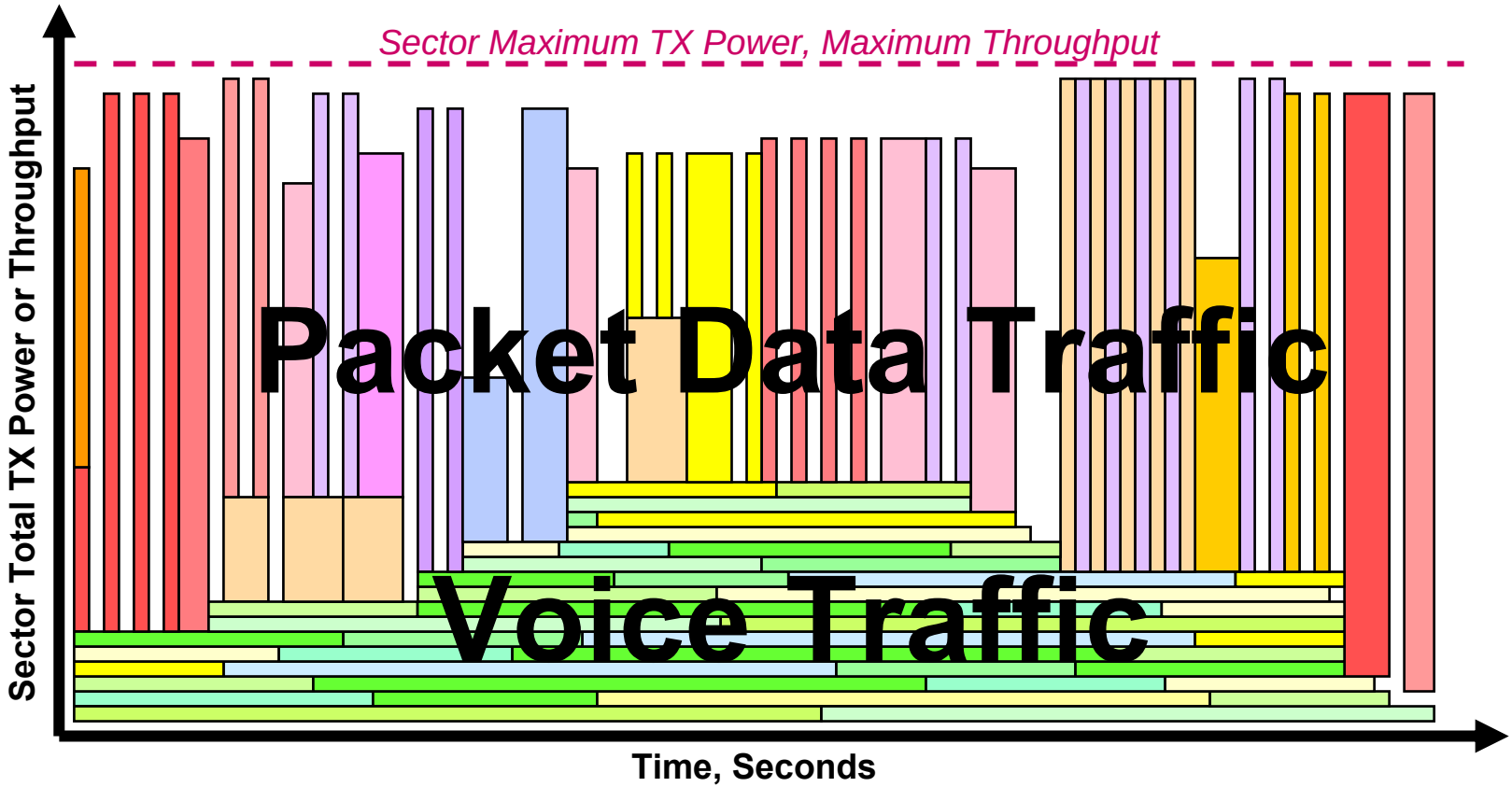
Optimization Issues

- Network Design and Configuration
  - Coverage holes, excessive coverage overlap
- Call Processing Problems due to Misconfiguration
  - Neighbor Lists
  - Search Windows
  - Power control parameters
- Physical Problems/Hardware Problems
  - Mismatched multicarrier sector coverage
- Capacity Issues
  - Forward and Reverse Power Control Overload
  - Physical resource congestion
    - Channel elements, packet pipes
    - IP network congestion
- Managing A New Dimension: circuit-switched and IP traffic blend
  - QoS-related competitive issues

Optimizing in Two Worlds

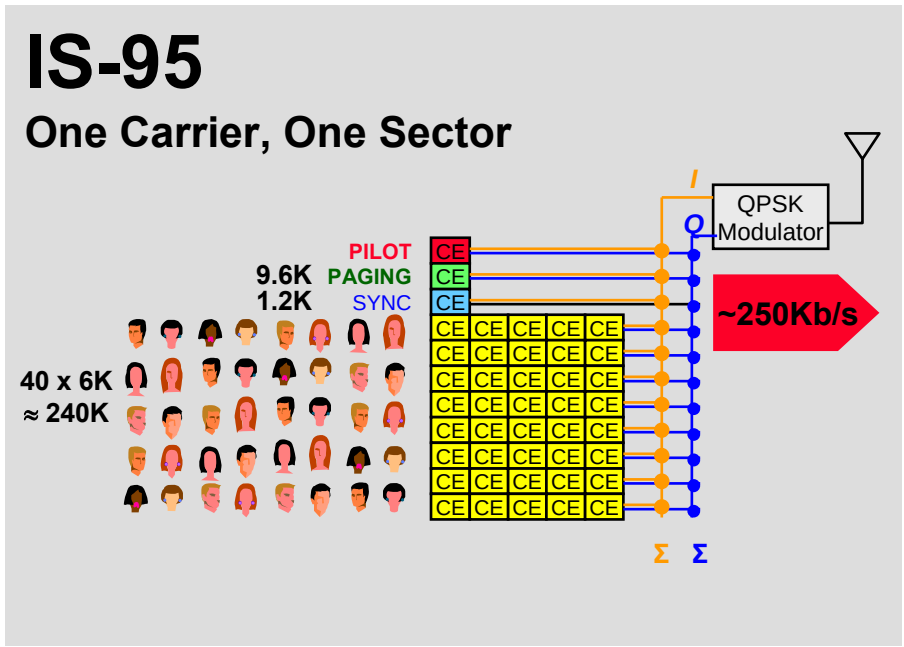
- Circuit-Switched Voice Traffic
  - Some operators are implementing 1xRTT mainly to gain capacity for additional voice traffic
  - Their optimization techniques remain about the same as for 2G voice networks today
    - Keep network adequately dimensioned
    - Control RF environment
    - Monitor and manage capacity utilization
- IP Data Traffic
  - Operators adding IP traffic to upgraded voice networks
  - Conventional optimization techniques are still appropriate for general RF environment and circuit-switched network performance
  - New IP and QoS issues require a new optimization focus for the blended total network
    - IP performance depends on both IP and RF factors
    - IP and Voice performance involve competitive tradeoffs

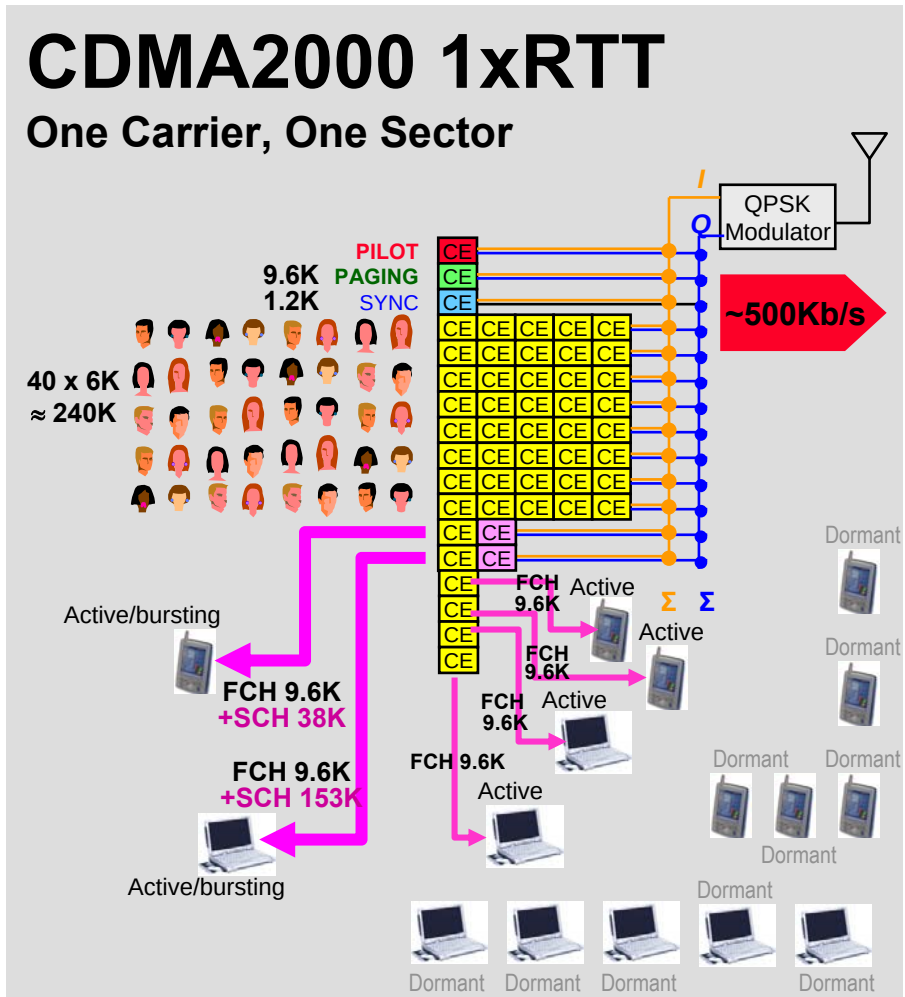
Managing Forward Link Sector Loading vs. Time



- Both voice and data traffic loads a sector, driving up transmit power
  - Voice calls are typically given higher priority than data
  - MAC-layer throttling holds lower-priority data sessions off until there is enough free power available

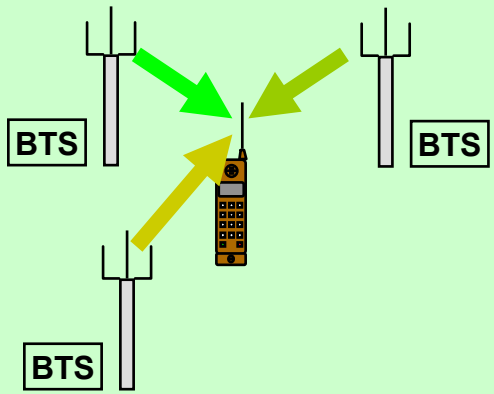
Basic Forward Link Physical Capacity

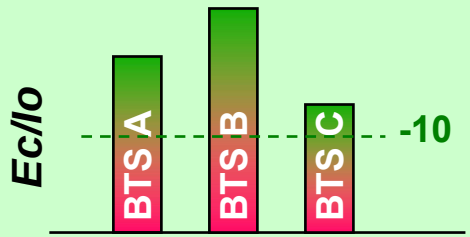


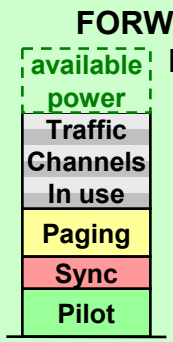


- 1xRTT throughput is approximately twice IS-95 throughput
- Extra capacity of 1xRTT sectors can be used for fast data or more voice users

Good Performance is really Simple!!







- One, Two, or Three good signals in handoff
  - Composite Ec/Io > -10 db
- Enough capacity for the offered traffic
  - No resource problems

In principle,
A COW next door
Can solve almost any CDMA problem!



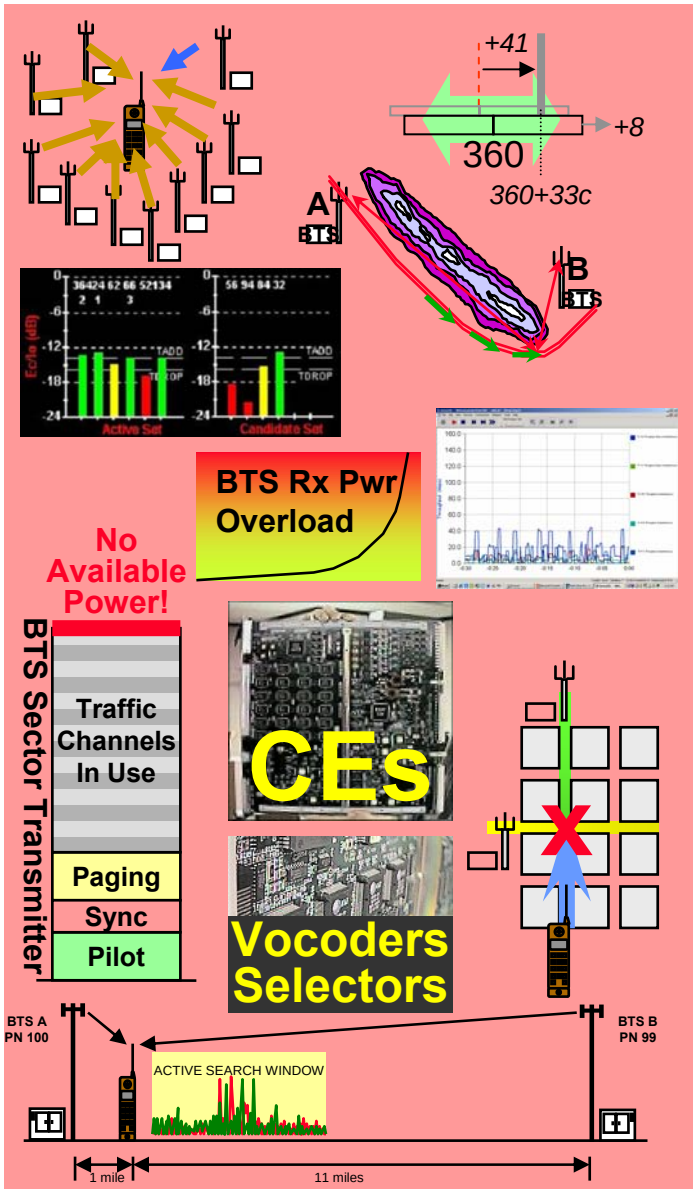
Reality Check:

1. But who has enough regular cells OR cows or money to fix every problem location?!!

2. Problems occur in the areas between cells' dominant coverage. Adding a cow only pushes the problems out to its own boundary with other cells.

Conclusion: We need to design better, and to use our existing cells more effectively. We need to provide one, two, or three dominant signals everywhere.

Bad Performance Has Many Causes



- Weak Signal / Coverage Hole
- Pilot Pollution
  - Excessive Soft Handoff
- Handoff Failures, "Rogue" mobiles
  - Missing Neighbors
  - Search Windows Too Small
  - BTS Resource Overload / No Resources
    - No Forward Power, Channel Elements
    - No available Walsh Codes
    - No space in Packet Pipes
- Pilot "Surprise" ambush; Slow Handoffs
- PN Plan errors
- Slow Data Problems: RF or IP congestion
- Improper cell or reradiator configuration
- Hardware and software failures
- But on analysis, all of these problems' bad effects happen because the simple few-signal ideal CDMA environment isn't possible.

Early Assessment and RF Optimization Steps

- **RF Coverage Control**
  - try to contain each sector's coverage, avoiding gross spillover into other sectors
  - tools: PN Plots, Handoff State Plots, Mobile TX plots
- **Neighbor List Tuning**
  - try to groom each sector's neighbors to only those necessary but be alert to special needs due to topography and traffic
  - tools: PSMM data from mobiles; propagation prediction
- **Search Window Settings**
  - find best settings for SRCH_WIN_A, _N, _R
  - especially optimize SRCH_WIN_A per sector using collected finger separation data; has major impact on pilot search speed

Repeat as necessary until no large problems remain

- **Access Failures, Dropped Call Analysis**
  - finally, iterative corrections until within numerical goals
- **IP Data Performance Assessment**
  - Identify, manage, resolve latency and throughput issues

Getting these items into shape provides a solid baseline and foundation for comparison, tracking, and planning in the future.

Performance Monitoring/Growth Management

- **Benchmark Existing Performance from system-side data**
  - Dropped Call %, Access Failure %, traffic levels
- **Identify Problem Cells and Clusters**
  - weigh cells and clusters against one another
  - Investigate and resolve any problems, using field drive data if needed
- **Look for signs of Overload**
  - TCE or Walsh minutes -- excessive ? Soft handoff excessive?
  - Required number of channel elements -- excessive?
  - Forward Power Overloads: Originations, Handoffs blocked
- **Traffic Trending and Projection**
  - track busy-hour traffic on each sector; predict exhaustion
  - develop plan for expansion and capacity relief
    - split cells, multi-sector expansions, multiple carriers
- **Use high-level simulation tools to gain insight into user statistics**
  - Compare different cell configurations against statistically generated traffic simulations to identify what works best, and try it out!

This process never ends. The community, the system, and the customers are always growing and presenting new problems and capacity needs.

CDMA Problems, Causes, and Cures

PROBLEMS

- Excessive Access Failures
- Excessive Dropped Calls
- Forward Link Interference
- Slow Handoff
- Handoff Pilot Search Window Issues
- PN Planning Considerations
- Excessive Soft Handoff
- Grooming Neighbor Lists
- Software Bugs, Protocol Violations

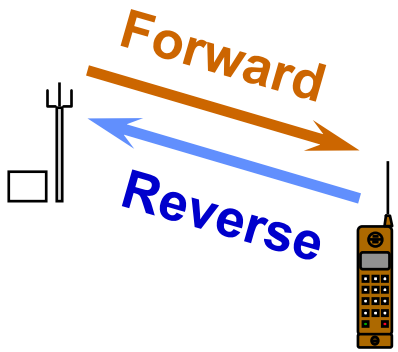
EXAMPLES

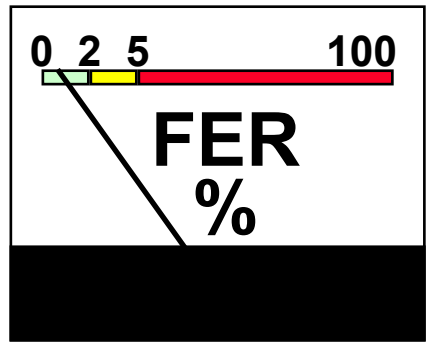
- Normal Call
- Dropped Call - Coverage
- Dropped Call - Neighbor List
- Dropped Call - Search Window

Meet the CDMA Performance Indicators

Indicator #1: FER

- **FER Frame Erasure Rate**
  - on forward channel (realized at Handset)
  - on reverse channel (realized at base station)
  - FER is an excellent call quality “summary” statistic

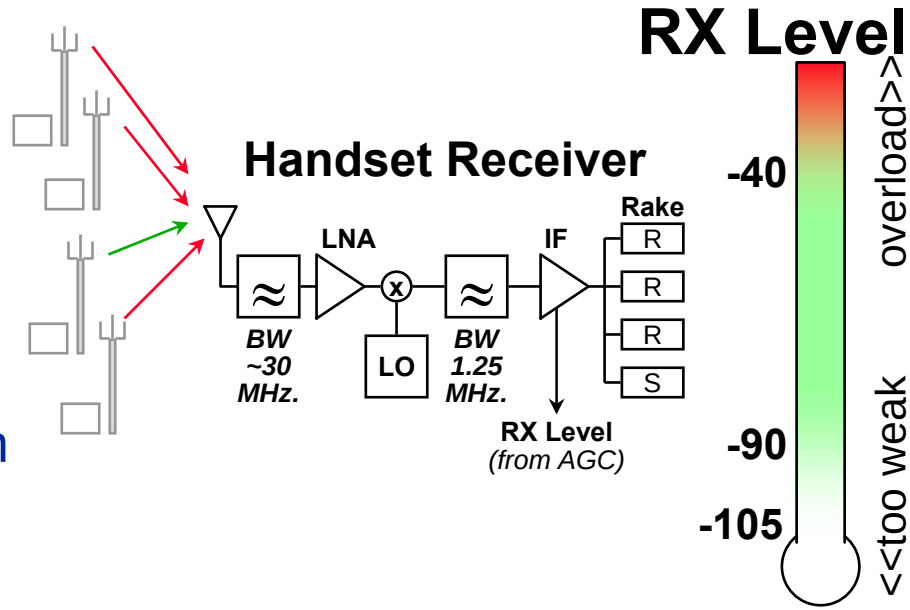




- **FER is the end-result of the whole transmission link**
  - if FER is good, then any other problems aren’t having much effect
  - if FER is bad, that’s not the problem - it is just the end-result of the problem
    - we must investigate other indicators to get a clue what is going on

Indicator #2: Received Power at the Handset

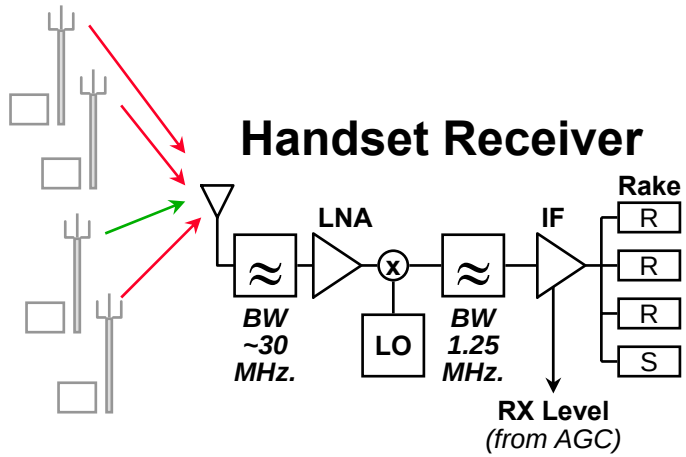
- **Mobile Receive Power**
  - usually expressed in dBm
  - measured derived from handset IF AGC voltage
  - broadband, “unintelligent” measurement: includes all RF in the carrier bandwidth regardless of source, *not* just RF from serving BTS



- **Receive power is important, but it’s exact value isn’t critical**
  - too much received signal (-35 dbm or higher) could drive the phone’s sensitive first amplifier into overload, causing intermod and code distortion on received CDMA signals
  - too little received signal (-105 or weaker) would leave too much noise in the signal after de-spreading, resulting in symbol errors, bit errors, bad FER, and other problems

Indicator #3, Ec/Io - What does it mean?

- CDMA phones can't use raw RF signal measurements to choose sectors
  - all base stations are transmitting on the same frequency, the measurement is their total signal



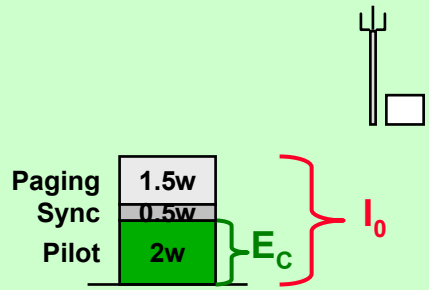
- We must digitally measure each sector's strength individually
- Each sector's pilot (Walsh 0) is the test signal to guide handoffs
  - If a sector's pilot is strong, we ought to include it in handoff
  - If a sector's pilot is weak, we don't need a traffic channel on it
- The phone can't measure absolute pilot strengths in dbm
  - it measures them as ratios – each pilot vs. all received power
  - the measurement is called Ec/Io – one pilot's energy per chip (Ec) compared against the analog measurement of total power, (Io) – and it's always expressed in db

How Ec/Io Varies with Traffic Loading

- Each sector transmits a certain amount of power, the sum of:
  - pilot, sync, and paging
  - any traffic channels in use at that moment
- Ec/Io is the ratio of pilot power to total power
  - On a sector with nobody talking, Ec/Io is typically about 50%, which is -3 db
  - On a sector with maximum traffic, Ec/Io is typically about 20%, which is -7 db.

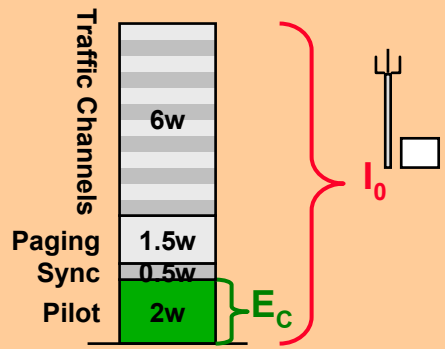
Light Traffic Loading

Ec/Io = (2/4)
= 50%
= -3 db.



Heavily Loaded

Ec/Io = (2/10)
= 20%
= -7 db.

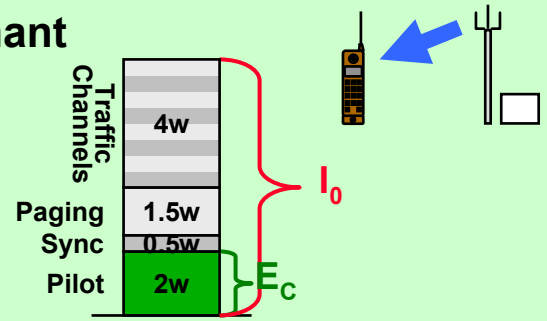


How Ec/Io varies with RF Environment

- In a “clean situation”, one sector is dominant and the mobile enjoys an Ec/Io just as good as it was when transmitted
- In “pilot pollution”, too many sectors overlap and the mobile hears a “soup” made up of all their signals
  - Io is the power sum of all the signals reaching the mobile
  - Ec is the energy of a single sector’s pilot
  - The large Io overrides the weak Ec; Ec/Io is low!

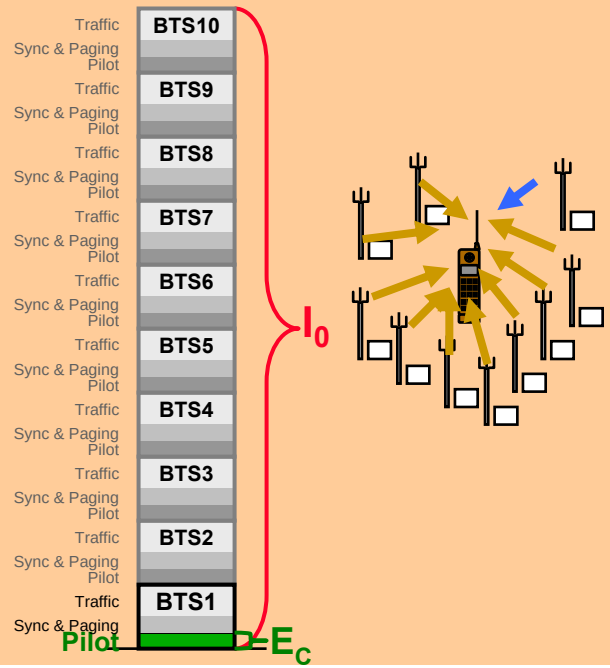
One Sector Dominant

Io = -90 dbm
Ec = -96 dbm
Ec/Io = -6 db



Many Sectors, Nobody Dominant

Io = 10 signals each -90 dbm = -80 dbm
Ec of any one sector = -96
Ec/Io = -16 db

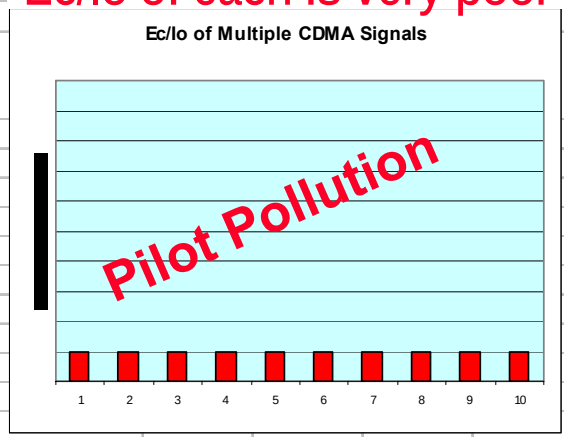


Ec/lo and Pilot Pollution

- When multiple sectors are about the same strength, and there is no dominant server, we call this “pilot pollution”
- To get acceptable reception during pilot pollution, the mobile must be using a majority of the sectors it is hearing. This causes too much soft handoff and consumes capacity.
- Overcoming pilot pollution requires careful coverage control of the related sectors
- EcIoPlay.xls is a good tool for experimenting

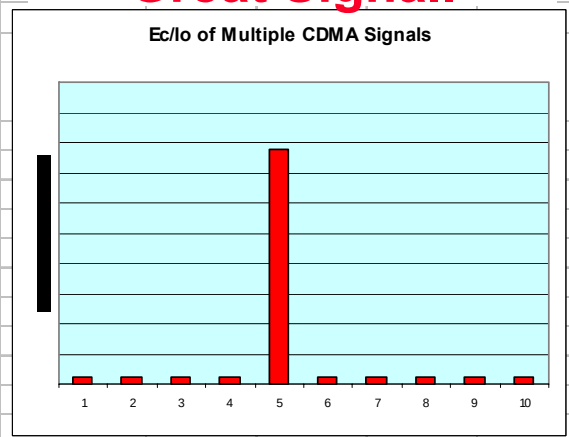
Too Many Similar Signals!
Ec/lo of each is very poor

Io	Ec/Io value at each BTS TX	
-80.0	-3	
Signal Strength	Ec/Io	
-90	-13.0	1
-90	-13.0	2
-90	-13.0	3
-90	-13.0	4
-90	-13.0	5
-90	-13.0	6
-90	-13.0	7
-90	-13.0	8
-90	-13.0	9
-90	-13.0	10
-80.0	Sum Power	



No Problem!
Great Signal.

Io	Ec/Io value at each BTS TX	
-73.9	-3	
Signal Strength	Ec/Io	
-90	-19.1	1
-90	-19.1	2
-90	-19.1	3
-90	-19.1	4
-75	-4.1	5
-90	-19.1	6
-90	-19.1	7
-90	-19.1	8
-90	-19.1	9
-90	-19.1	10
-73.9	Sum Power	



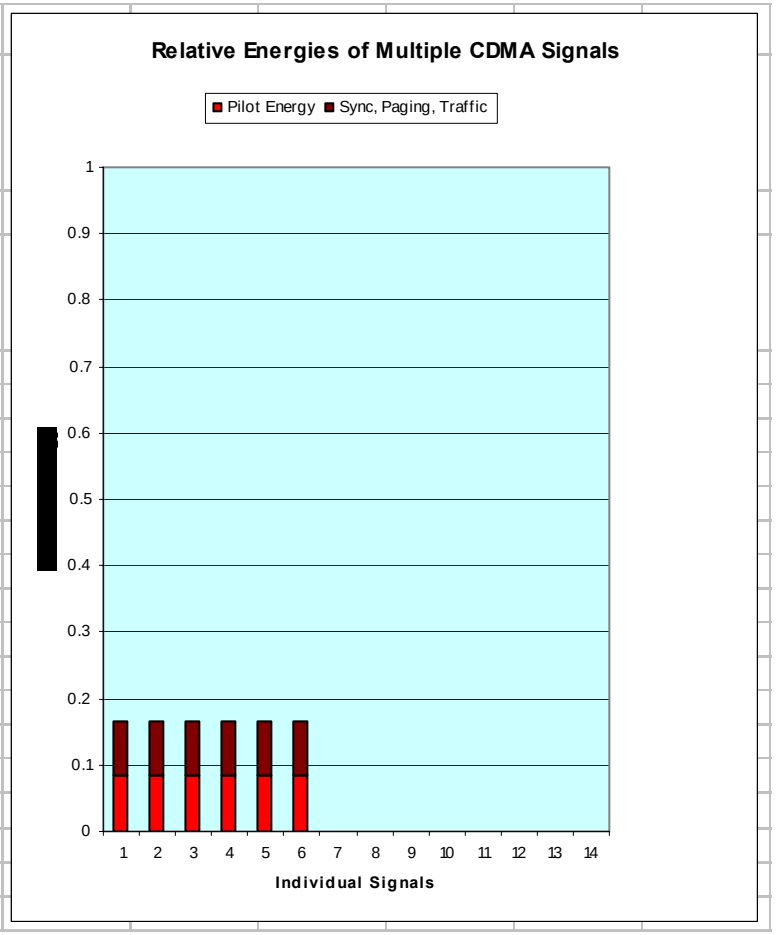
Ec/Io and Pilot Pollution: Handoff Effects

- This second workbook in EcIoPlay.xls demonstrates the benefits of soft handoff and the concept of composite ("combined") Ec/Io during soft handoff.

Ec/Io, Handoff, and Rake Finger Pilot Status

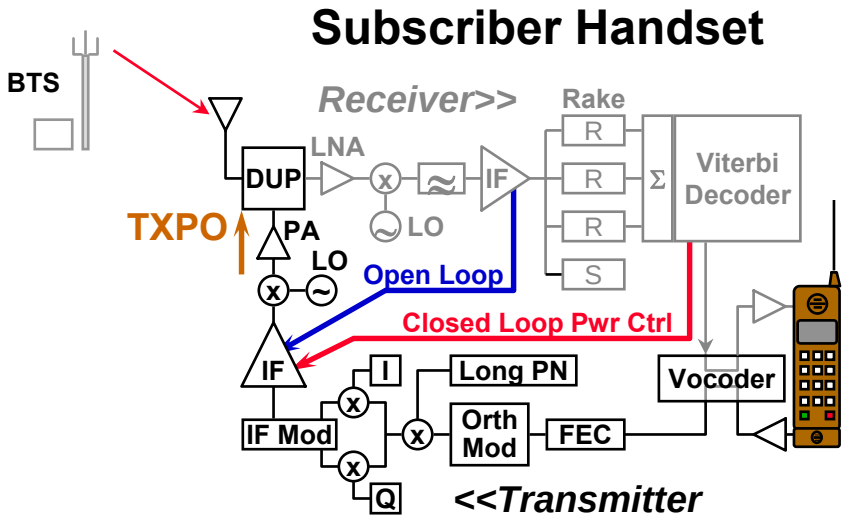
%Pilot Power	% Over-head Power	Nominal Max Power W	Sum RF Power Io	Composite Ec/Io	Max # Lockable Rake Fingers	Max # Pilots in Soft Handoff	T_ADD	
10%	**20%**	**16**	**-77.2**	**-4.8**	**4**	**6**	**-13**	
Traffic Loading %	Trans mitted Ec/Io	Path Loss, dB	Signal Strength	Ec/Io				
0%	-3.0	120	-84.9	-10.8	Rake Locked	Handoff		1
0%	-3.0	120	-84.9	-10.8	Rake Locked	Handoff		2
0%	-3.0	120	-84.9	-10.8	Rake Locked	Handoff		3
0%	-3.0	120	-84.9	-10.8	Rake Locked	Handoff		4
0%	-3.0	120	-84.9	-10.8		Handoff	Interferor	5
0%	-3.0	120	-84.9	-10.8		Handoff	Interferor	6
0%	-3.0	200	-164.9	-90.8			Interferor	7
0%	-3.0	200	-164.9	-90.8			Interferor	8
0%	-3.0	200	-164.9	-90.8			Interferor	9
0%	-3.0	200	-164.9	-90.8			Interferor	10
0%	-3.0	200	-164.9	-90.8			Interferor	11
0%	-3.0	200	-164.9	-90.8			Interferor	12
0%	-3.0	200	-164.9	-90.8			Interferor	13
0%	-3.0	200	-164.9	-90.8			Interferor	14

Only grey-shaded fields can be changed. Other fields calculate automatically.
To unlock all cells, select TOOLS>PROTECTION>UNPROTECT SHEET.



Indicator #4: Handset Transmitter Power

- **TXPO Handset Transmit Power**
  - Actual RF power output of the handset transmitter, including combined effects of **open loop power control** from receiver AGC *and* **closed loop power control** by BTS
  - can't exceed handset's maximum (typ. +23 dBm)



TXPO = -(RX_{dbm}) -C + TXGA
C = +73 for 800 MHz. systems
= +76 for 1900 MHz. systems

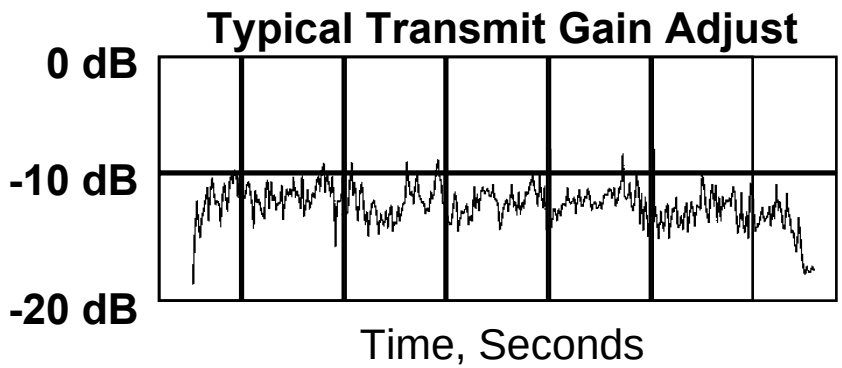
Typical TXPO:
+23 dBm in a coverage hole
0 dBm near middle of cell
-50 dBm up close to BTS

- **What is the right power TX level? Whatever the BTS asks for!**
  - As long as closed loop control is working, the phone's opinion isn't the last word. Just do what the BTS wants!!
  - However, if the BTS ever asks the phone to do the impossible, something is wrong (lower than -60 dbm, higher than +23 dbm)

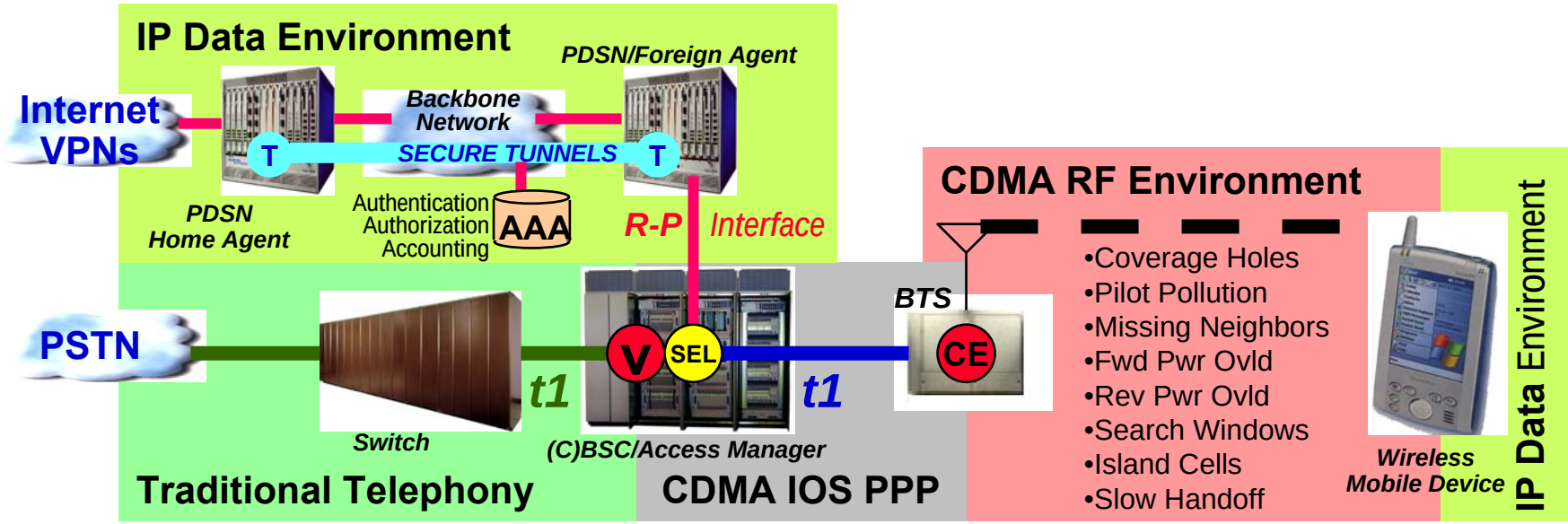
Indicator #5: Transmit Gain Adjust

- **What is Closed Loop Transmit Gain Adjust (TXGA)?**
  - The power correction the base station is asking the mobile to make right now, in real-time
  - At the beginning of a call, before the power control bits begin, it is zero. Then the power control bits begin, 800 per second.
  - During a call, TXGA is the running total of all the power control bits which have been received thus far.
  - Each power control bit asks for a 1 db correction, up or down
  - Each power control bit is based on the base station's latest new decision: mobile is too strong, or mobile is too weak -- there is no cumulative error, since each decision is "fresh"

TXPO = -(RX_{dbm}) -C + TXGA
C = +73 for 800 MHz. systems
= +76 for 1900 MHz. systems

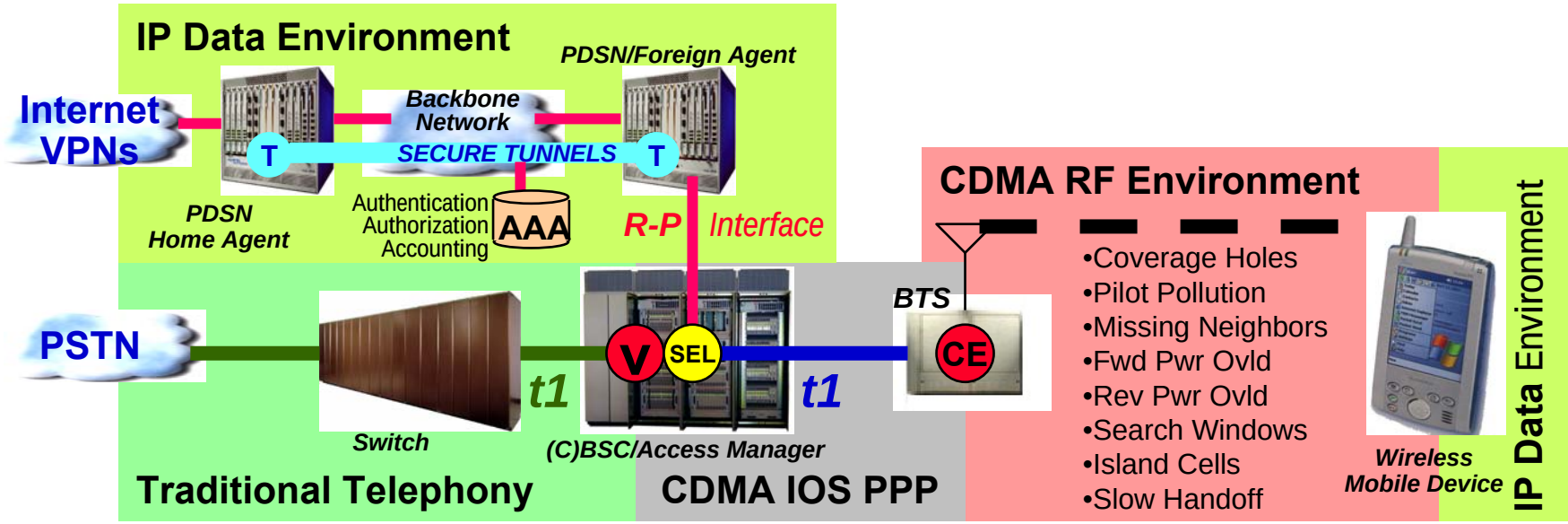


#6 Indicator: Data Latency



- **Latency can occur because of RF channel congestion or from IP network causes**
  - **RF overload can delay availability of supplemental channels**
  - **IP network congestion can delay availability of packets**
- **Ping and loopback tests with local PDSN and servers can identify whether problem is in backbone network**
- Does latency correlate with independent evidence of RF congestion?

#7 Indicator: Data Throughput

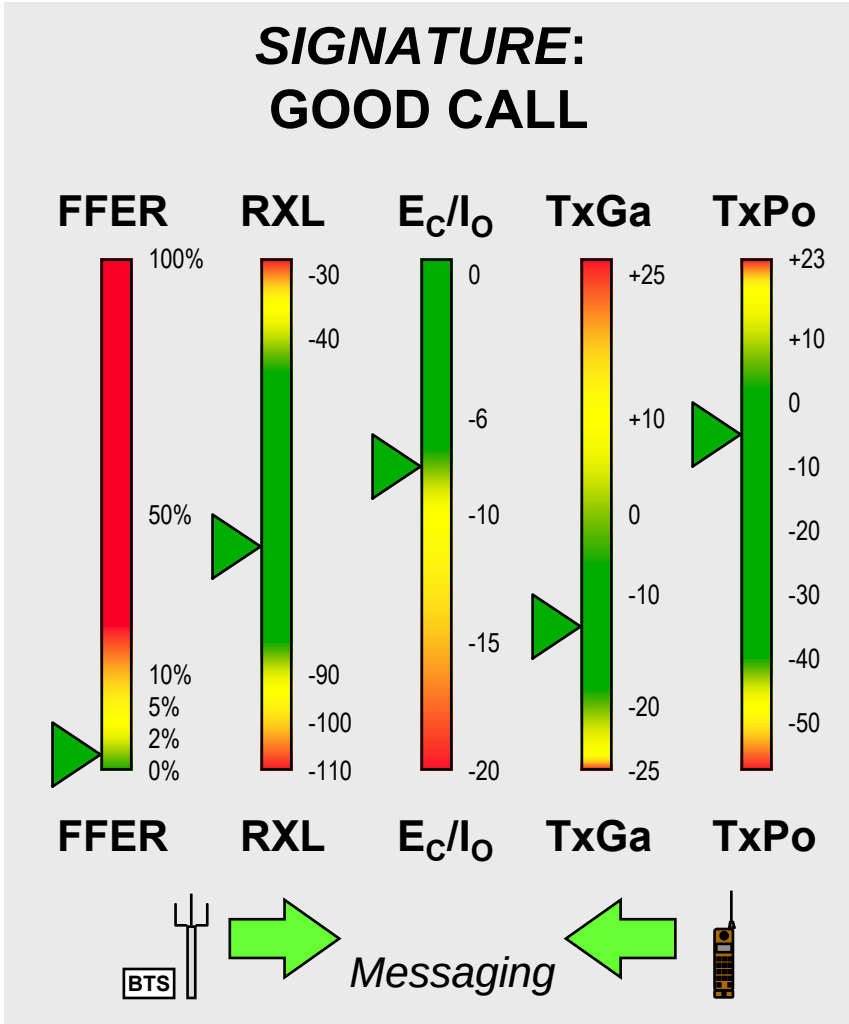


- **Throughput can be limited by RF and IP causes**
  - Traditional RF problems limit capacity of the channel
  - Congestion in the IP network can limit speed of data available
- Does low throughput correlate with independent RF indicators?
- Does low throughput correlate with independent IP pings and tests?

Problem “Signatures”

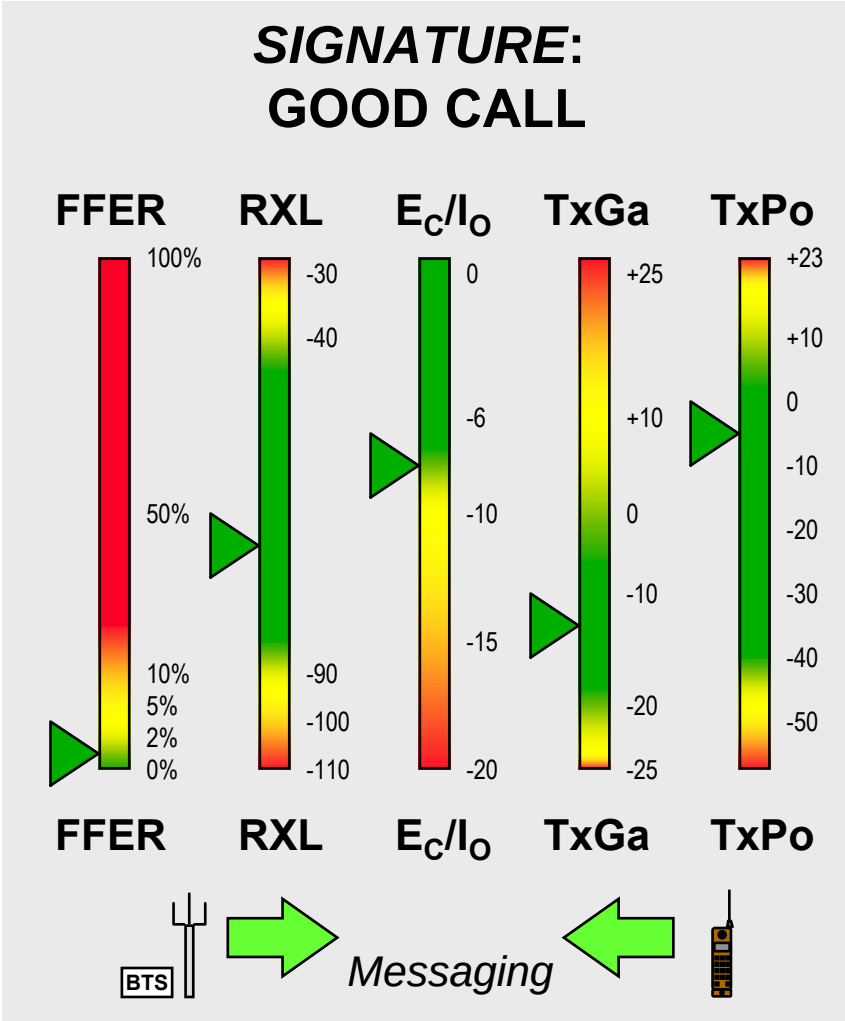
“Signatures” of Common Conditions

- The key CDMA RF Performance Indicators provide powerful clues in cause-and-effect analysis for understanding problem conditions
- There are many common conditions which are easy to recognize from their characteristic “signatures” -- unique relationships among the key indicators which are observed when these conditions exist
- We will use the simplified format shown at right to display the key indicators for each of several interesting cases.



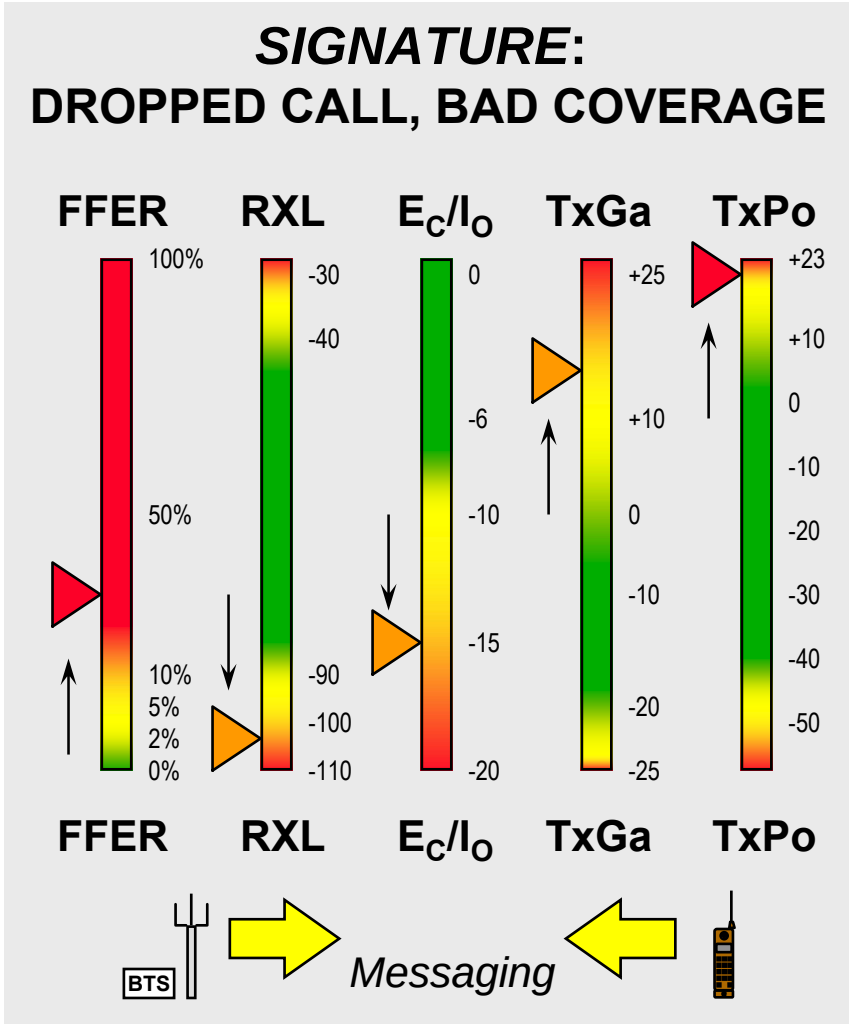
Signature of a Successful Call

- If the mobile station originates successfully, remains in service area, and makes normal release, data will show:
  - Low forward FER
  - Receive power > -100 dBm
  - Good Ec/Io (> -12 dB)
  - Normal Transmit Gain Adjust (actual value depends on site configurations, loading & NOM_PWR setting)
  - Transmit power < +20 dBm
  - Good Messaging
    - Parsed message files will contain a full set of normal messages.



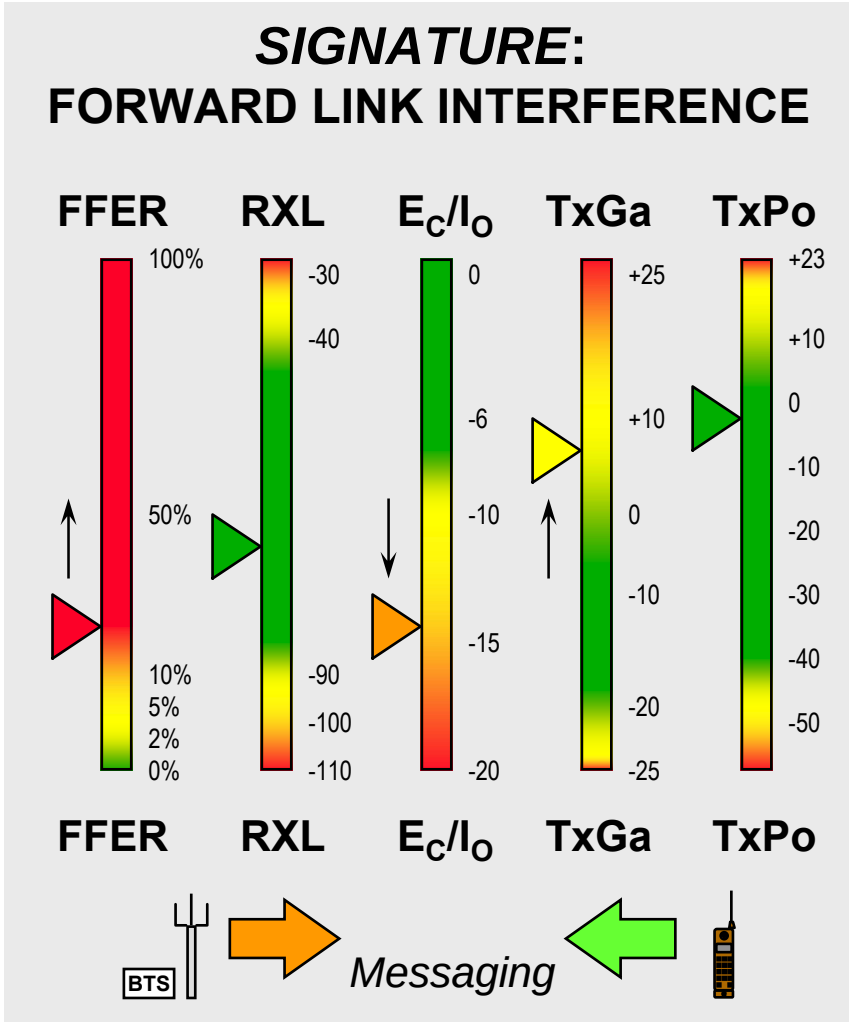
Signature of a Dropped Call in Poor Coverage

- If a mobile station is taken out of the service area or into a coverage hole, and only data from the mobile station is available, the log files will show the following characteristics:
  - High forward FER
  - Low receive power (<-100 dBm)
  - Low Ec/Io (< -10 dB)
  - Higher-than-normal Transmit Gain Adjust (actual value depends on site configurations, loading, NOM_PWR setting)
  - Higher-than-normal transmit power (> +20 dBm)
  - Poor messaging on both links



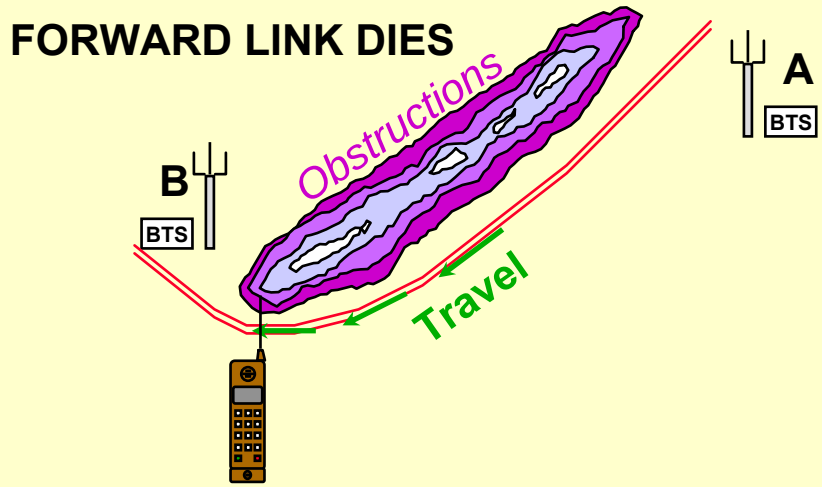
Signature of Forward Link Interference

- Characteristics of data for a phone experiencing forward link interference from a source other than the current BTS:
  - High forward FER
  - Good receive power (> -100 dBm)
  - Low Ec/Io (< -10 dB)
  - Higher-than-normal Transmit Gain Adjust
  - Normal transmit power (< +20 dBm)
  - Poor forward link messaging
    - unreliable at best and may be the actual cause of the drop.



A CDMA Drop Example: Forward Link Case

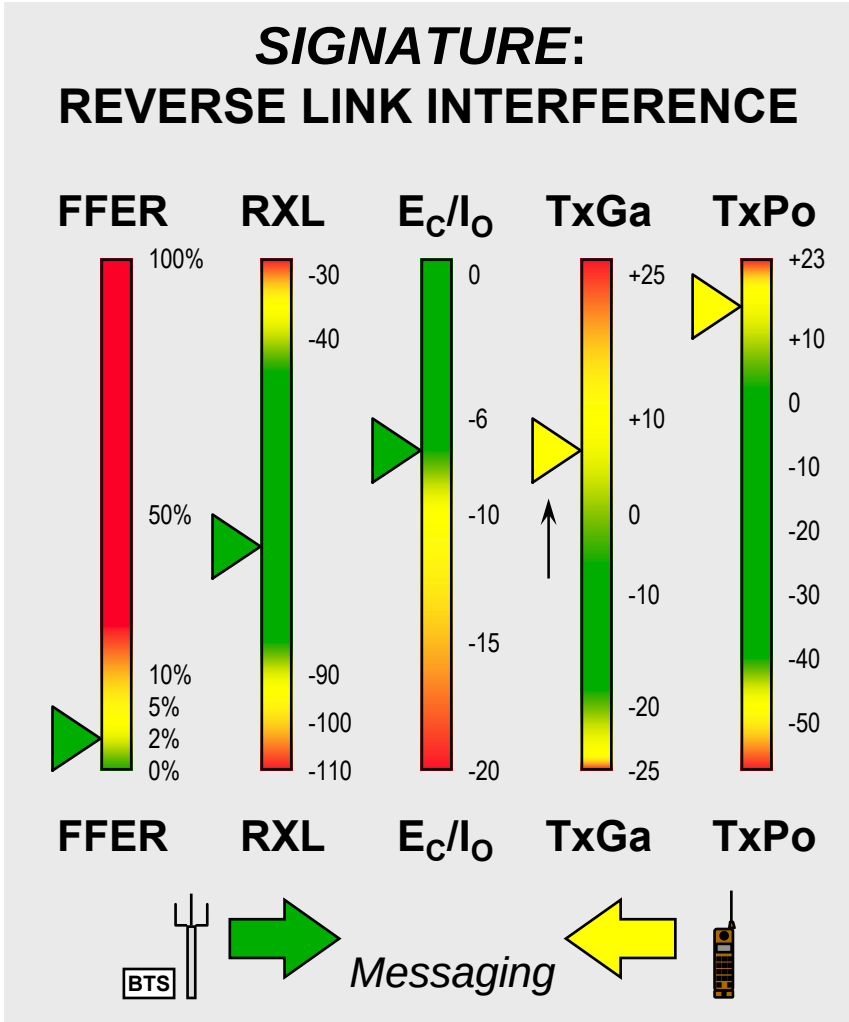
- A mobile using Site A comes down the highway and suddenly begins to see the signal of Site B
- If the mobile begins soft handoff with site B, everything continues to go well
- If the mobile cannot begin handoff with B for any reason, the call is doomed
  - site B's signal will override site A's signal, making it unreadable
  - as soon as the FER goes too high, a fade timer will start the the mobile will eventually die



B grows stronger and stronger. Mobile's open-loop instinct is to transmit weaker; closed-loop correction from A goes higher and higher, maintaining the mobile at the right power.
Finally B obscures A, which disappears in an explosion of FER. The mobile mutes since it can't hear power control bits, and a fade timer or message timer kills the call in a few seconds.

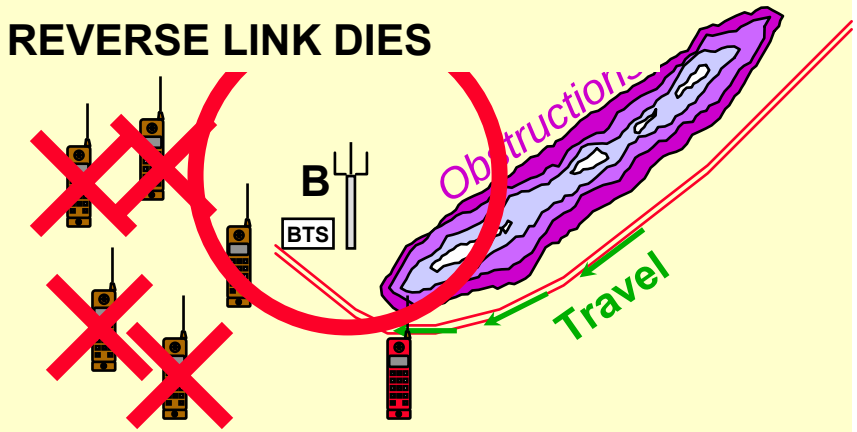
Signature of Reverse Link Interference

- Characteristics of data for a phone whose BTS has a raised noise floor due to reverse link interference
  - Good forward FER
  - Good receive power (> -100 dBm)
  - Good Ec/Io (> -10 dB)
  - Higher-than-normal Transmit Gain Adjust
  - Higher-than-normal transmit power (< +20 dBm)
  - Poor reverse link messaging
    - in the message files, you'll see repeats of messages on the forward link and reverse link



A CDMA Drop Example: Reverse Link Case

- When a cell is penetrated by a mobile not under its own power control, bad things happen!
  - The foreign mobile is being power controlled by a more distant cell, so it is transmitting louder than appropriate
  - the local mobiles must power up in a deadly race to keep up with the interferor
  - local mobiles can still hear the cell fine; the forward link is just great, to the very end

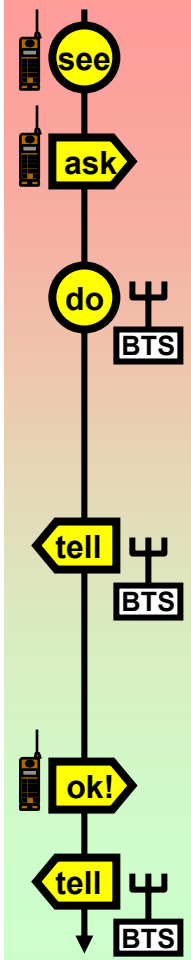


It was a beautiful day in the neighborhood for all the mobiles on site B until the grim reaper arrived, transmitting at high power to maintain its link with distant Cell A.
Cell B tried to power up each of its individual mobiles so they would be received as strong as the new interferor, but mobiles more distant than the interferor just couldn't keep up, and died.
Eventually the interferor died from forward link interference, too.
If only the interferor had a soft handoff, all of this violence could have been avoided.

Solving the #1 Death Scenario: Failed Handoff

What Went Wrong??!

Steps in the Handoff Process



Mobile's searcher notices the needed new pilot

Mobile sends PSMM requesting handoff

System sets up the handoff:
- channel elements
- forward power
- space in packet pipes

Simulcasting begins!

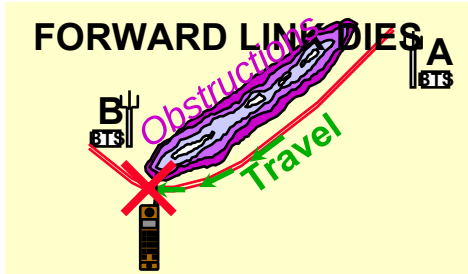
Now the system can hear the mobile better!

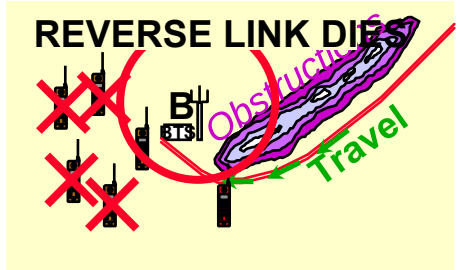
System tells mobile how to hear the new sectors: Handoff Direction Message

Now the mobile can hear the system better, too!

Mobile confirms completion: Handoff Completion Message

System makes new neighbor list, sends to mobile: Neighbor List Update Message

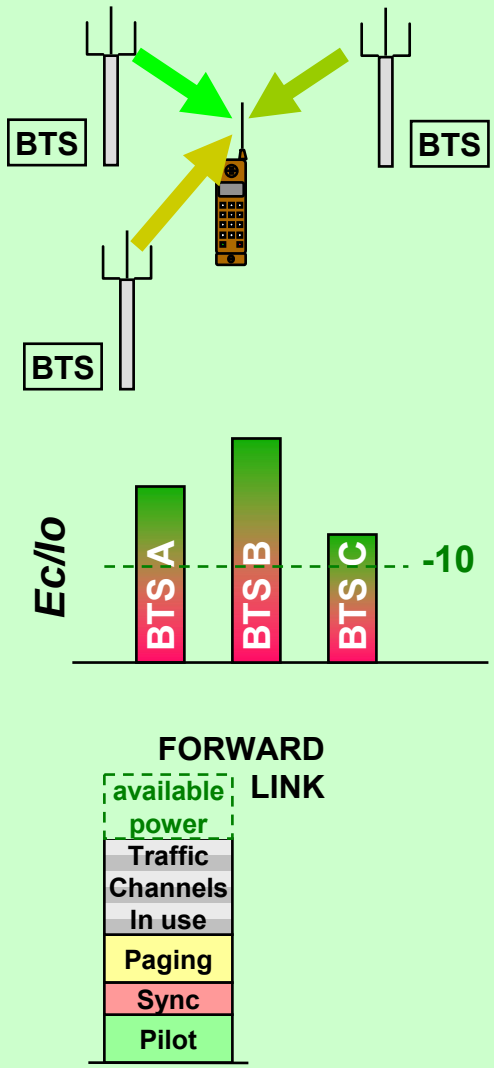




- Why didn't the mobile ask for handoff?
  - New sector not on neighbor list
  - Neighbor Search Window too Small?
  - BTS in "island mode", wrong PN?
- Why didn't the BTS set up the handoff?
  - Old BTS didn't hear mobile – rev link interf?
  - No resources available on new BTS?
  - T-1 unstable, messages lost
- Why didn't the mobile do the handoff?
  - Couldn't hear BTS, Fwd link interf?

1x Data Tests and Optimization

Good Performance is really Simple!!



- Although there are many phases of optimization activities, good performance is really just compliance with a very simple idea
- One, Two, or Three good signals in handoff
  - Composite Ec/Io > -10 db
- Enough capacity to handle the offered traffic (whether data or voice)
  - No resource problems

In principle, A COW next door can solve almost any CDMA problem!



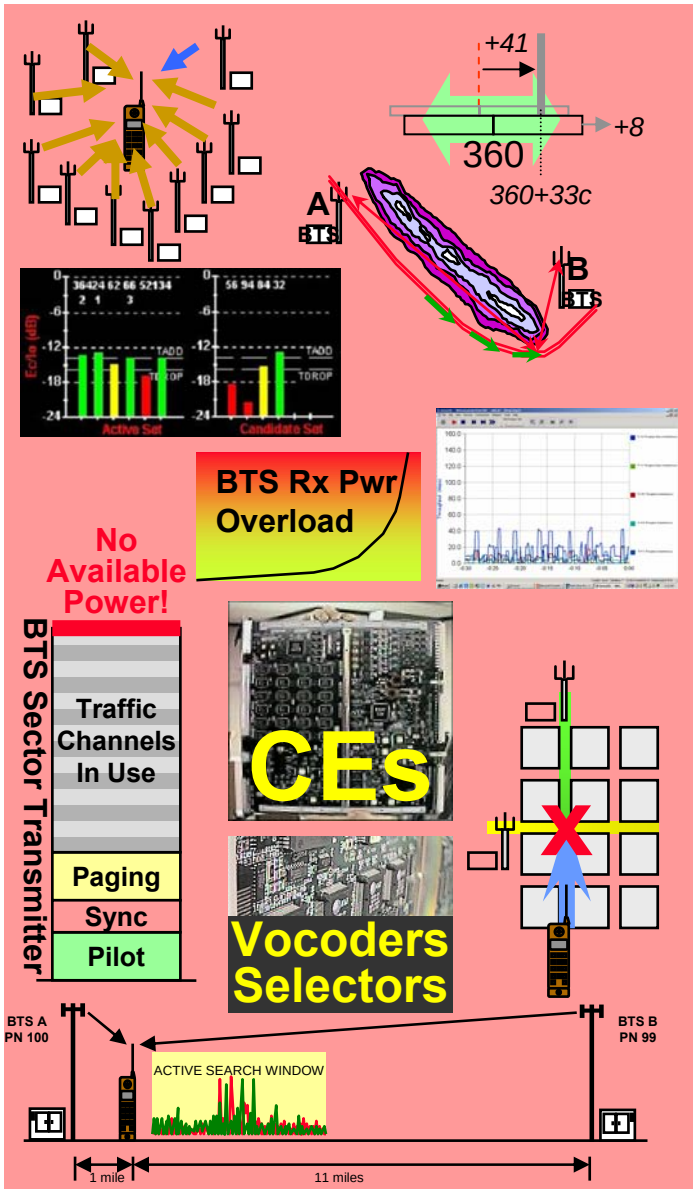
Reality Check:

1. But who has enough regular cells OR cows or money to fix every problem location?!!

2. Problems occur in the areas between cells' dominant coverage. Adding a cow only pushes the problems out to its own boundary with other cells.

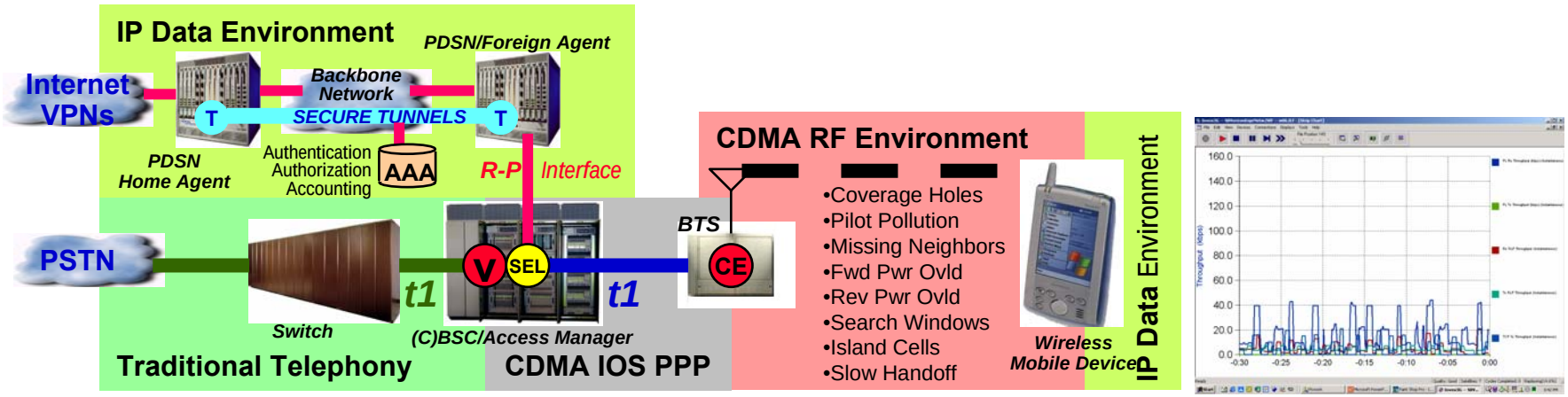
Conclusion: We need to design better, and to use our existing cells more effectively. We need to provide one, two, or three dominant signals everywhere.

Bad Performance Has Many Causes



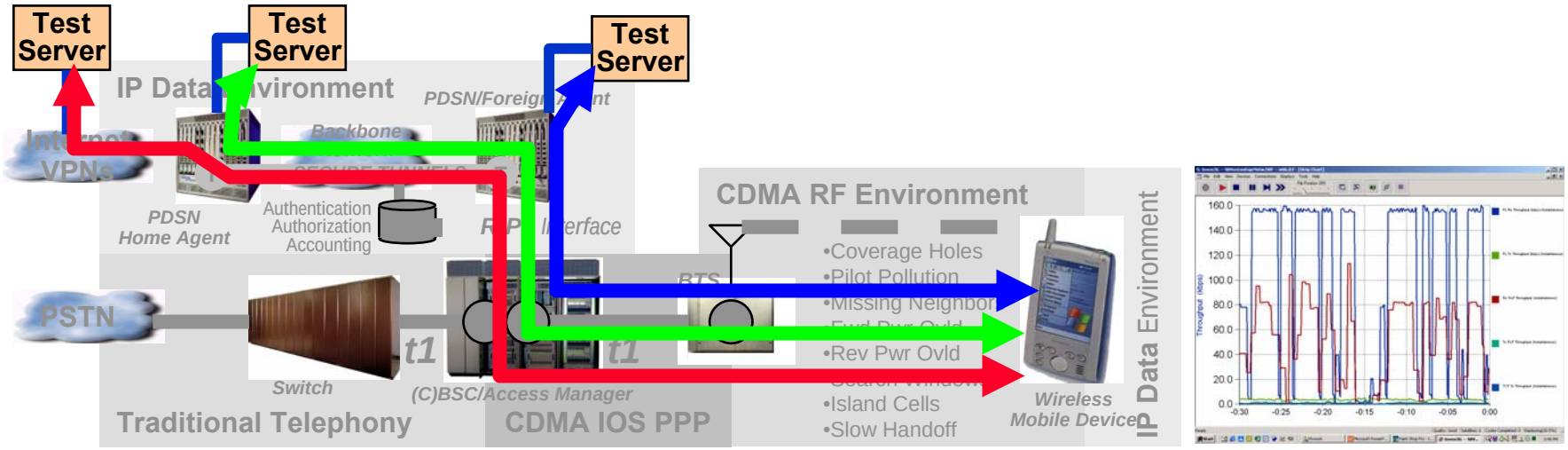
- Weak Signal / Coverage Hole
- Pilot Pollution
  - Excessive Soft Handoff
- Handoff Failures, "Rogue" mobiles
  - Missing Neighbors
  - Search Windows Too Small
  - BTS Resource Overload / No Resources
    - No Forward Power, Channel Elements
    - No available Walsh Codes
    - No space in Packet Pipes
- Pilot "Surprise" ambush; Slow Handoffs
- PN Plan errors
- Slow Data Problems: RF or IP congestion
- Improper cell or reradiator configuration
- Hardware and software failures
- But on analysis, all of these problems' bad effects happen because the simple few-signal ideal CDMA environment isn't possible.

So S L O W ! ! Where's My Data?!!



- Some sessions are tormented by long latency and slow throughput
- Where is the problem? Anywhere between user and distant host:
  - Is the mobile user's data device mis-configured and/or congested?
  - Is the BTS congested, with no power available to produce an SCH?
  - Poor RF environment, causing low rates and packet retransmission?
  - Congestion in the local IP network (PCU, R-P, PDSN FA)?
  - Congestion in the wireless operator's backbone ('OSSN') network?
  - Congestion in the PDSN HA?
  - Congestion in the outside-world internet or Private IP network?
  - Is the distant host congested, with long response times?

Finding Causes of Latency and Low Throughput

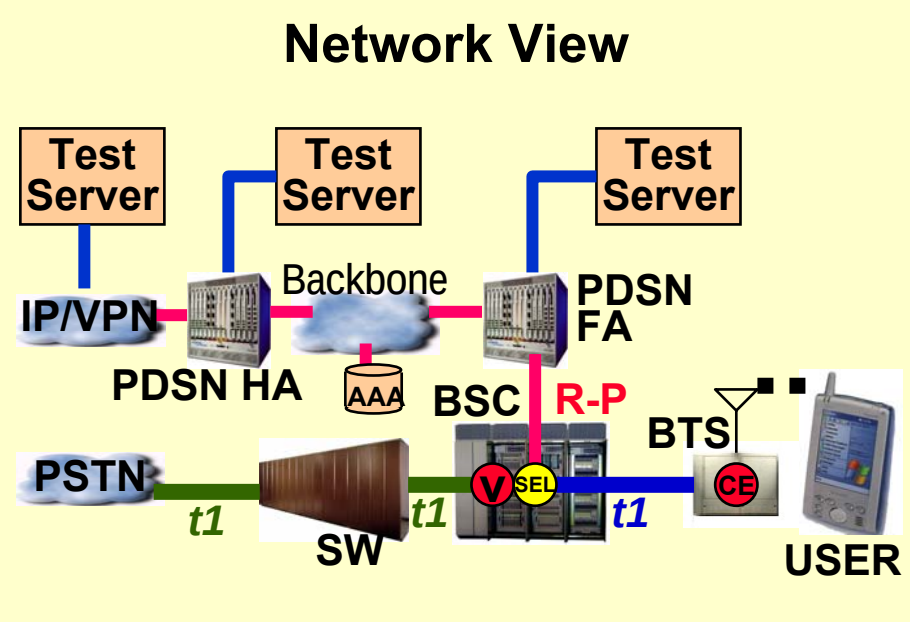


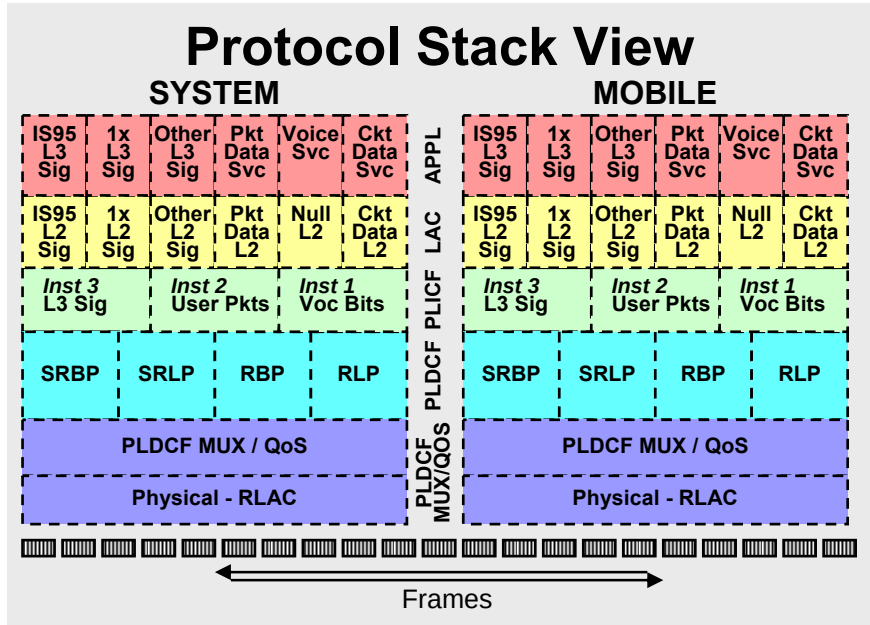
- IP network performance can be measured using test servers
- Problems between mobile a local test server? The problem is local
  - check RF conditions, stats: poor environment, SCH blocking?
  - if the RF is clean, investigate BSC/PCU/R-P/PDSN-FA
- Local results OK, problems accessing test server at PDSN-HA?
  - problem is narrowed to backbone network, or PDSN-HA
- Results OK even through test server at PDSN-HA
  - then the problem is in the public layers beyond.

Overview of Field Tool IP Test Activities

Application	Description	Purpose
Raw Upload	Uploads data with no overhead (no headers, no handshaking beyond the normal TCP handshaking)	Testing uplink throughput
Raw Download	Downloads data with no overhead (no headers, no handshaking beyond the normal TCP handshaking.)	Testing downlink throughput
Raw Loopback	A loopback (data is sent to the remote server which returns the same data) application with no overhead (no headers, no handshaking beyond the normal TCP handshaking.)	Simultaneous exercise of the uplink and downlink
Ping (ICMP ECHO)	Ping does not use the TCP protocol, but rather uses the connectionless and "unreliable" ICMP protocol. Sends small echo request packets to a remote server, which responds with an echo reply.	Determining round-trip-time between the user and the remote server, as well as general link integrity (by counting the number of missing echo reply packets).
HTTP GET	A standard web page "browse" request.	If Raw Download is unavailable, testing downlink throughput; modeling typical customer use.
HTTP POST	A web-based upload (similar to how web-based email sites allow users to upload files as "attachments").	If Raw Upload is unavailable, testing uplink throughput.
FTP GET	A standard FTP file download. Many file downloads on the Internet use FTP.	If Raw Download and HTTP GET are unavailable, testing downlink throughput; modeling typical customer use.
FTP PUT	A FTP file upload. The file is generated by the Invex3G platform and sent to the server.	If Raw Upload and HTTP POST are unavailable, testing uplink throughput
Mail GET (POP3)	Retrieves all the mail for a given mailbox (e-mail address) from an e-mail server. Note: does not delete the e-mail messages from the mailbox.	Modeling typical customer use.
Wait	Waits a specified amount of time.	Testing idle timers, timeouts, etc.

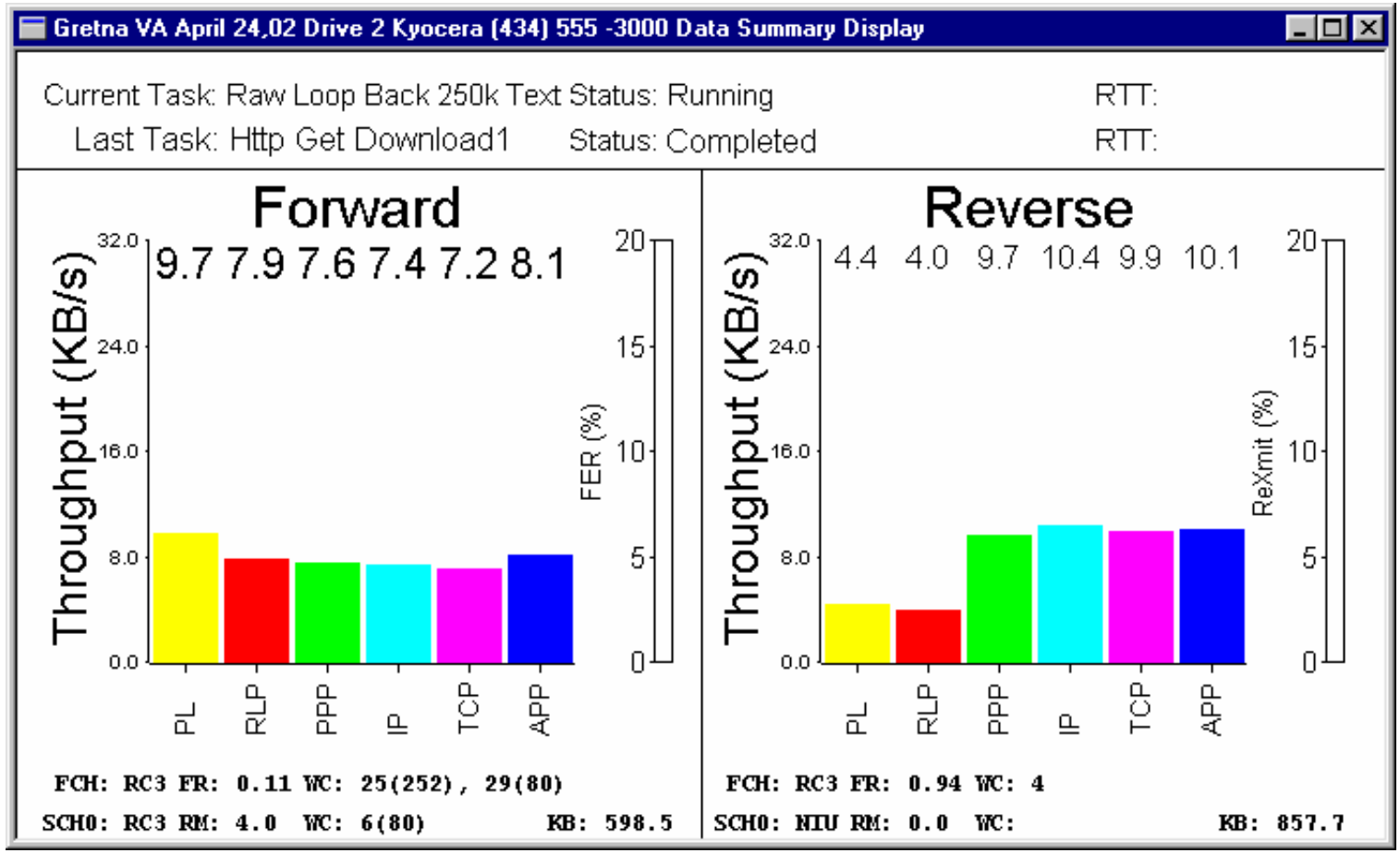
Basic Network Data Test Scenarios





- IP tests can be originated from the mobile side to identify & trap problems
- Test servers can be positioned where needed in the network
  - At PDSN FA, at PDSN HA, or at other end of IP or VPN network
- Test server standard features should be left naturally enabled:
  - Discard/Sync/Null (server throws away data sent to it)
  - Char Gen (server can send randomly generated data to test mobile)
  - Echo (server can loopback all data received from the test mobile)
  - Ping (server will respond to pings sent from the test mobile)

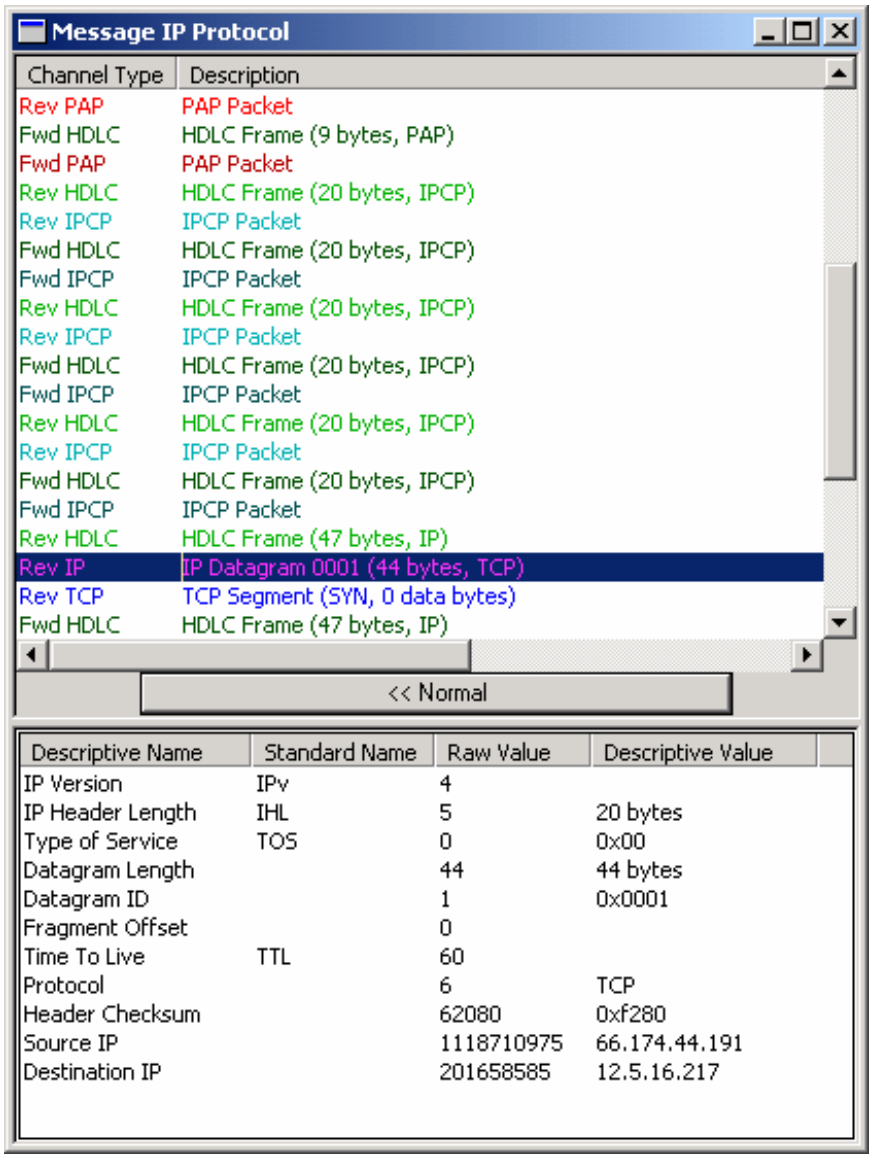
Watching Throughput in Real-Time



- This display shows the relationship between instantaneous throughputs of six protocols at various levels in the stack
  - a useful for identifying real-time problems by their “signatures”

Courtesy of Grayson Wireless from their “Invex3G” data collection tool

Protocol Stack Message Tracing



- Some collection tools can display and track messages between layers of the protocol stack
  - PAP, HDLC, IPCP, TCP, IP
- This allows detailed troubleshooting of connection and TCP/IP transfer problems
  - Capability of seeing packet header contents is useful for identifying and debugging authentication and connection problems

System-Side 1xRTT Tools

Basic Philosophy of System Data

- Each network manufacturer has its own data sets and counters
  - Access failures, TCCFs, blocks, drops, failed handoffs
  - These counters are normally available in 2G-only, 3G-only, and total categories
  - Additional new statistics are available for IP traffic
- The basic philosophy of system data analysis is to analyze and discriminate within the available data
  - Identify and rank existing sectors based on
    - Traffic levels
    - raw failures/blocks/drops
    - percentage failures/blocks/drops
  - Benchmark and track incremental changes
  - Investigate all significant problems uncovered
    - Drive-testing or data testing may be required
- *In-Class activity: view manufacturer documentation and examples*

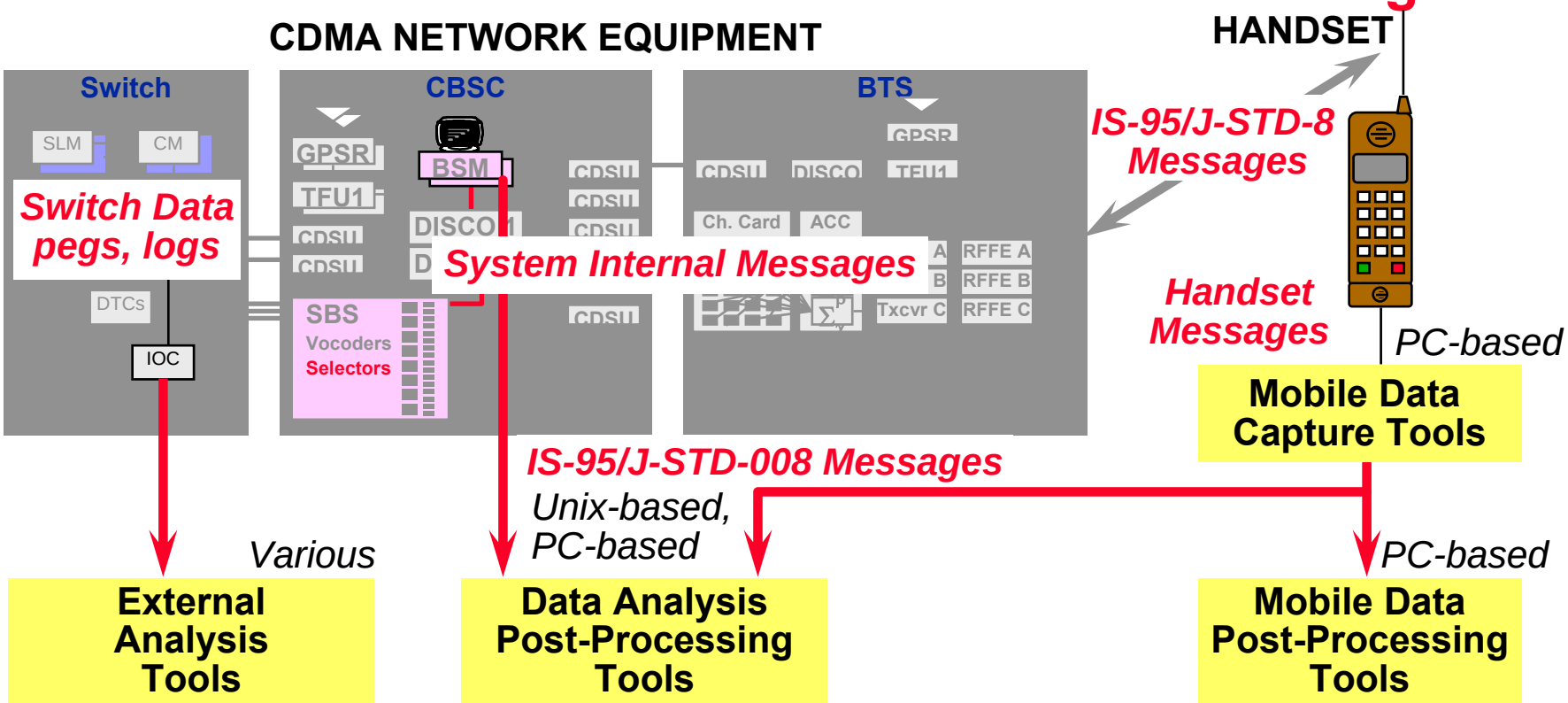
Information on System-Side Statistics

- Lucent
  - Technical Reference: Watchmark Prospect for Lucent, v17.0
- Nortel
  - 411-2131-814 DMS-MTX Operational Measurements Reference Manual version v. 12.02 June, 2001
  - 411-2131-900 DMS-MTX Operational Measurements Quick Reference Guide
- Motorola
  - “Performance Analysis 2.16.0” v O , Motorola Inc., January 2002.
  - “1x network Performance Matrix” v. 0.1, Motorola Inc., April 2001.
  - “CDMA 2000 – 1x Voice and Data – Cellular Application Note” , v. 1.1 – Draft; Motorola Inc.
  - “Impact on CDL and CFC in Version 2.16.0” v.1.4, Part No. 8700SCRP20GCDLCFC-D, Motorola Inc., August 2001
  - “CFC Resolution Document” v. 1.3, Motorola Inc Performance Analysis 2.16.0” v O , Motorola Inc., January 2002

Course 334

Mobile-Side 1xRTT Tools

Sources of CDMA Data and Tools for Processing



- CDMA optimization data flows from three places:
  - Switch
  - CDMA peripherals (CBSC & BTS)
  - Handset
- Each stream of data has a family of software and hardware tools for collection and analysis

CDMA Field Test Tools



Field Collection Tools using Handset Data

- Motorola
- Qualcomm
- Grayson
- Agilent (formerly HP)
- SAFCO
- Comarco
- LCC

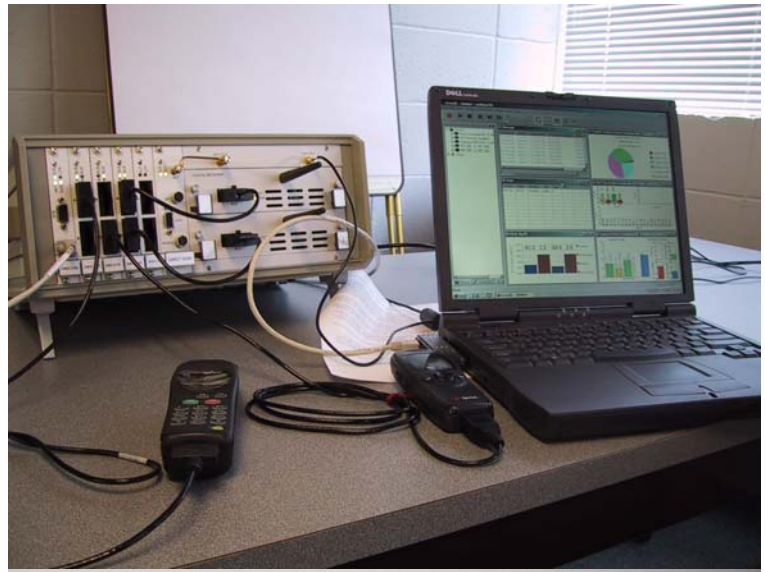
PN Scanners

- Agilent (formerly HP)
- Berkeley Varitronics
- Grayson
- Qualcomm
- Safeco
- Willtech

- There are many commercial CDMA field test tools
- Characteristics of many test tools:
  - capture data from data ports on commercial handsets
  - log data onto PCs using proprietary software
  - can display call parameters, messaging, graphs, and maps
  - store data in formats readable for post-processing analysis
  - small and portable, easy to use in vehicles or even on foot
- A few considerations when selecting test tools:
  - does it allow integration of network and mobile data?
  - Cost, features, convenience, availability, and support
  - new tools are introduced every few months - investigate!

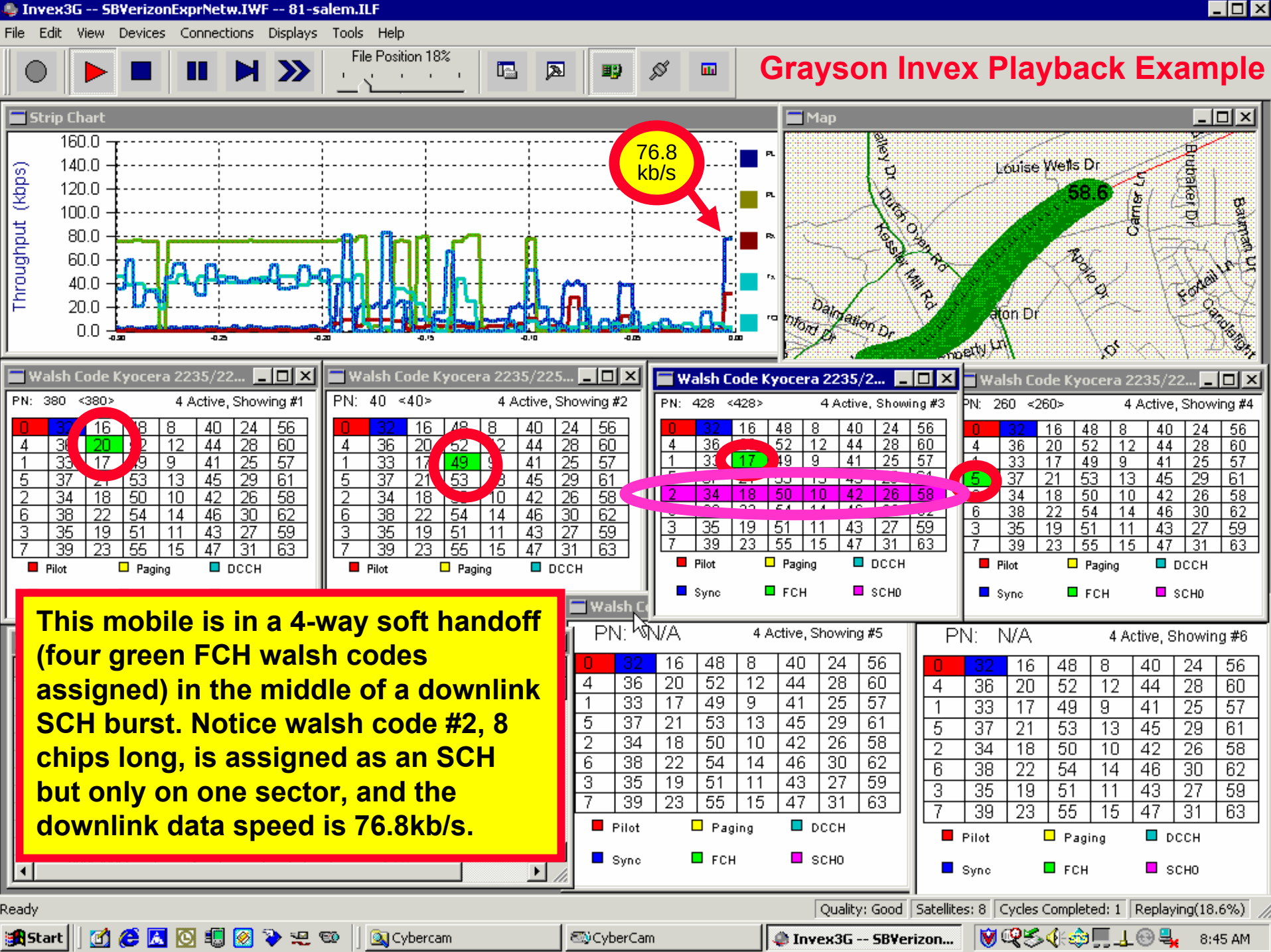
Grayson's new Invex3G Tool

- In 1Q2001 Grayson introduced its new Invex3G tool, with new features
  - 100 MB ethernet connection to PC
  - the eight card slots can hold receivers or dual-phone cards
  - there's also room for two internal PN scanners
  - Multiple Invex units can be cascaded for multi-phone load-test applications
  - Cards are field-swappable - Users can reconfigure the unit in the field for different tasks without factory assistance

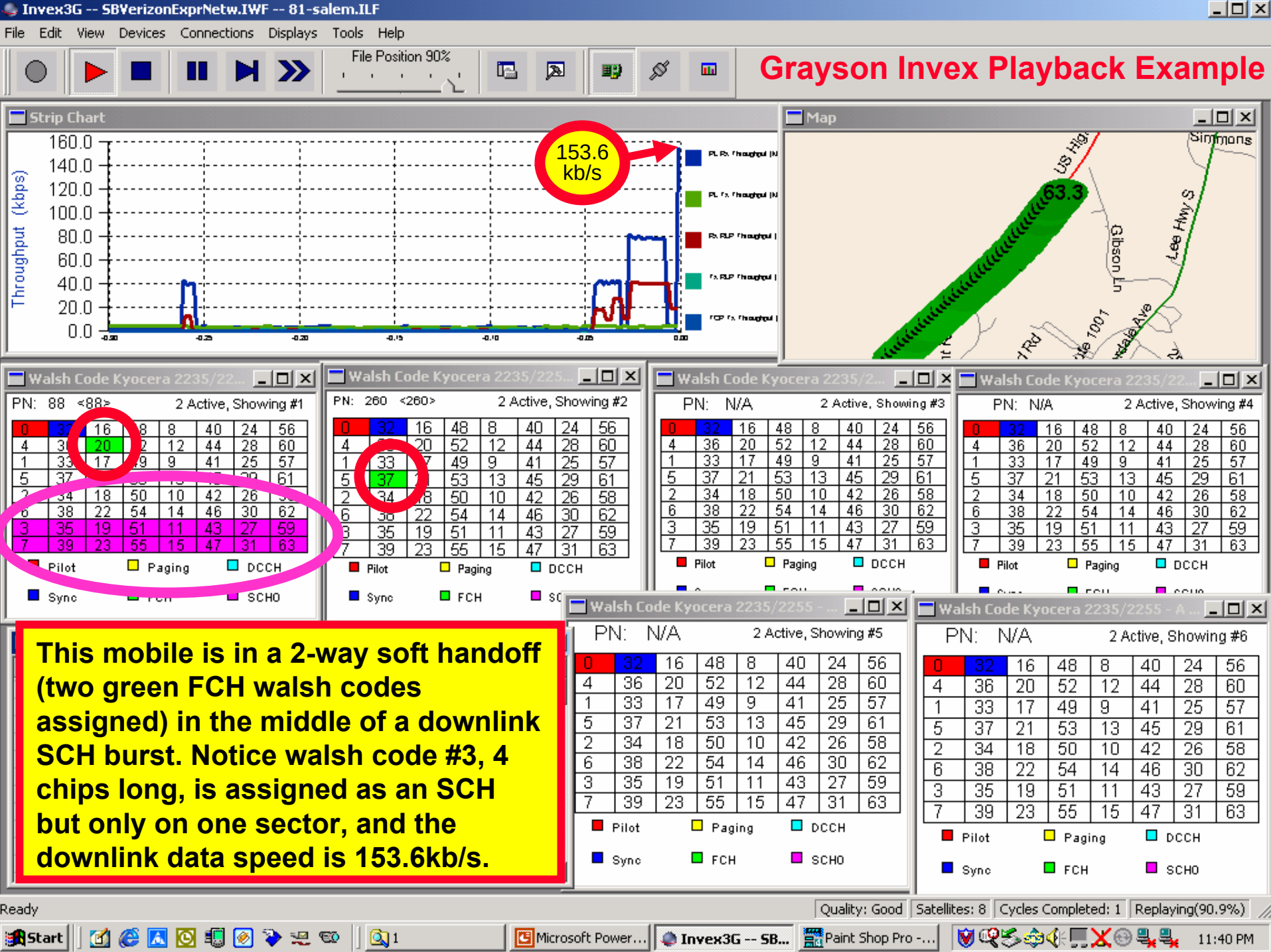


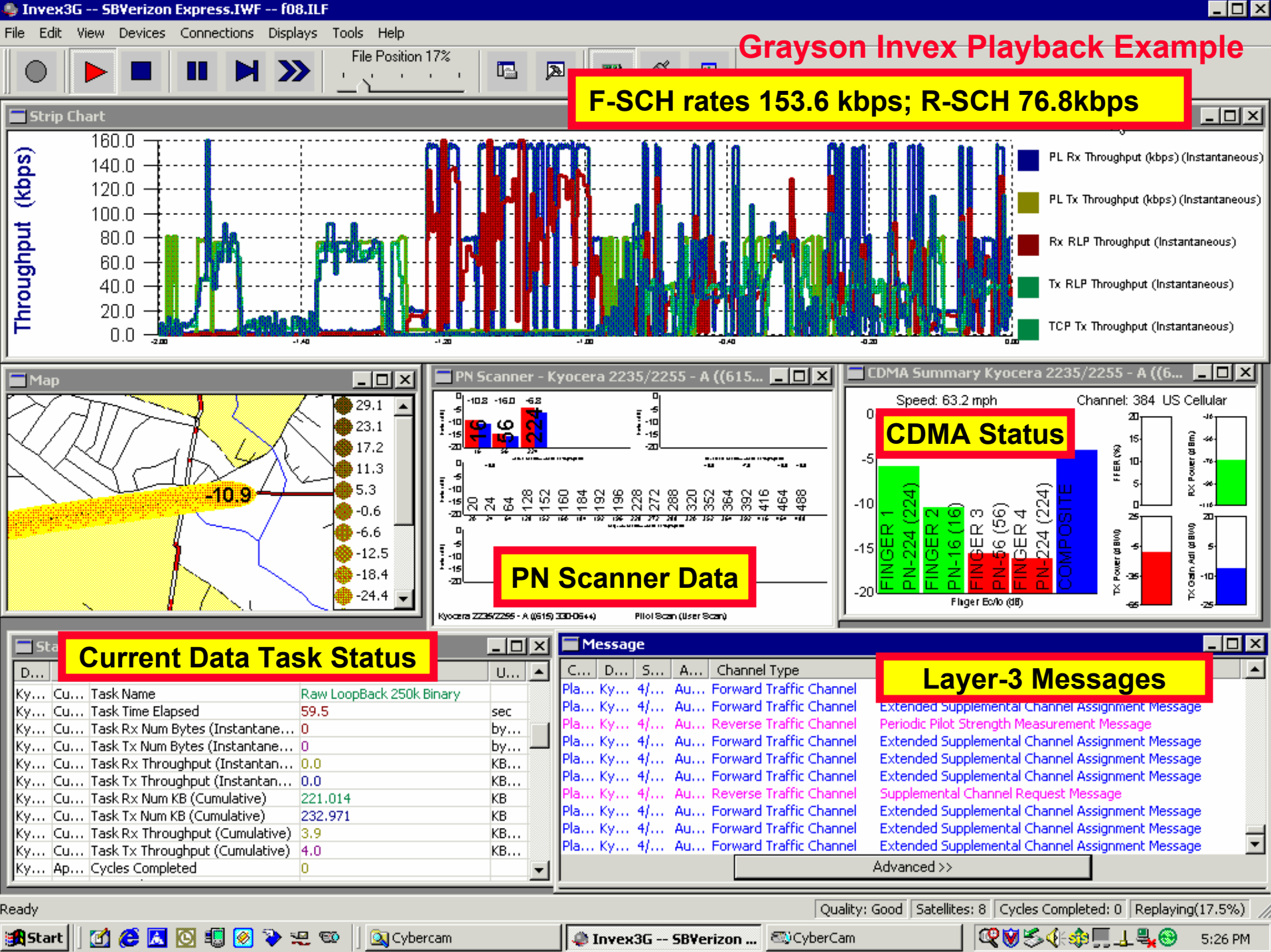


Grayson Invex Playback Example



This mobile is in a 4-way soft handoff (four green FCH walsh codes assigned) in the middle of a downlink SCH burst. Notice walsh code #2, 8 chips long, is assigned as an SCH but only on one sector, and the downlink data speed is 76.8kb/s.


Invex3G -- SBVerizonExprNetw.IWF -- 81-salem.ILF
File Edit View Devices Connections Displays Tools Help
File Position 90%
Grayson Invex Playback Example
Strip Chart
Throughput (kbps)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
153.6 kb/s
Map
63.3
Simmons
Gibson Ln
Lee Hwy S
Walsh Code Kyocera 2235/22...
PN: 88 <88> 2 Active, Showing #1
Walsh Code Kyocera 2235/225...
PN: 260 <260> 2 Active, Showing #2
Walsh Code Kyocera 2235/2...
PN: N/A 2 Active, Showing #3
Walsh Code Kyocera 2235/22...
PN: N/A 2 Active, Showing #4
Pilot
Paging
DCCH
Sync
FCH
SCHO
Walsh Code Kyocera 2235/2255 - ...
PN: N/A 2 Active, Showing #5
Walsh Code Kyocera 2235/2255 - A...
PN: N/A 2 Active, Showing #6
This mobile is in a 2-way soft handoff (two green FCH walsh codes assigned) in the middle of a downlink SCH burst. Notice walsh code #3, 4 chips long, is assigned as an SCH but only on one sector, and the downlink data speed is 153.6kb/s.
Ready
Quality: Good
Satellites: 8
Cycles Completed: 1
Replaying(90.9%)
Start
Microsoft Power...
Invex3G -- SB...
Paint Shop Pro -...
11:40 PM


Invex3G -- SBVerizon Express.IWF -- f08.ILF
File Edit View Devices Connections Displays Tools Help
File Position 17%
Grayson Invex Playback Example
F-SCH rates 153.6 kbps; R-SCH 76.8kbps
Strip Chart
Throughput (kbps)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
PL Rx Throughput (kbps) (Instantaneous)
PL Tx Throughput (kbps) (Instantaneous)
Rx RLP Throughput (Instantaneous)
Tx RLP Throughput (Instantaneous)
TCP Tx Throughput (Instantaneous)
Map
-10.9
29.1
23.1
17.2
11.3
5.3
-0.6
-6.6
-12.5
-18.4
-24.4
PN Scanner - Kyocera 2235/2255 - A ((615...
PN Scanner Data
CDMA Summary Kyocera 2235/2255 - A ((6...
Speed: 63.2 mph
Channel: 384 US Cellular
CDMA Status
FINGER 1 PN-224 (224)
FINGER 2 PN-16 (16)
FINGER 3 PN-56 (56)
FINGER 4 PN-224 (224)
COMPOSITE
Finger Ec/Io (dB)
Current Data Task Status
Task Name Raw LoopBack 250k Binary
Task Time Elapsed 59.5 sec
Task Rx Num Bytes (Instantane... 0 by...
Task Tx Num Bytes (Instantane... 0 by...
Task Rx Throughput (Instantan... 0.0 KB...
Task Tx Throughput (Instantan... 0.0 KB...
Task Rx Num KB (Cumulative) 221.014 KB
Task Tx Num KB (Cumulative) 232.971 KB
Task Rx Throughput (Cumulative) 3.9 KB...
Task Tx Throughput (Cumulative) 4.0 KB...
Cycles Completed 0
Message
Layer-3 Messages
Channel Type
Forward Traffic Channel
Extended Supplemental Channel Assignment Message
Reverse Traffic Channel
Periodic Pilot Strength Measurement Message
Supplemental Channel Request Message
Advanced >>
Ready
Quality: Good
Satellites: 8
Cycles Completed: 0
Replaying(17.5%)
Start
Cybercam
Invex3G -- SBVerizon ...
CyberCam
5:26 PM

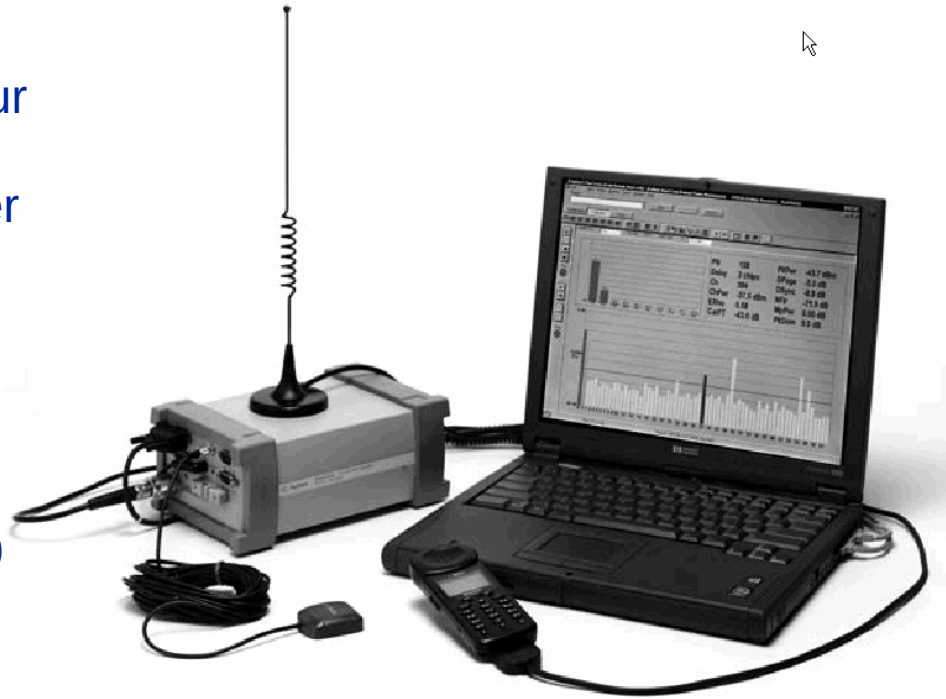
WillTech Tools

- Blue Rose platform can manage multiple phones and collect data
  - Internal processor manages test operations independently for stand-alone operation
  - Internal PCMCIA flash card provides storage
  - An external PC can display collected data during or after data collection



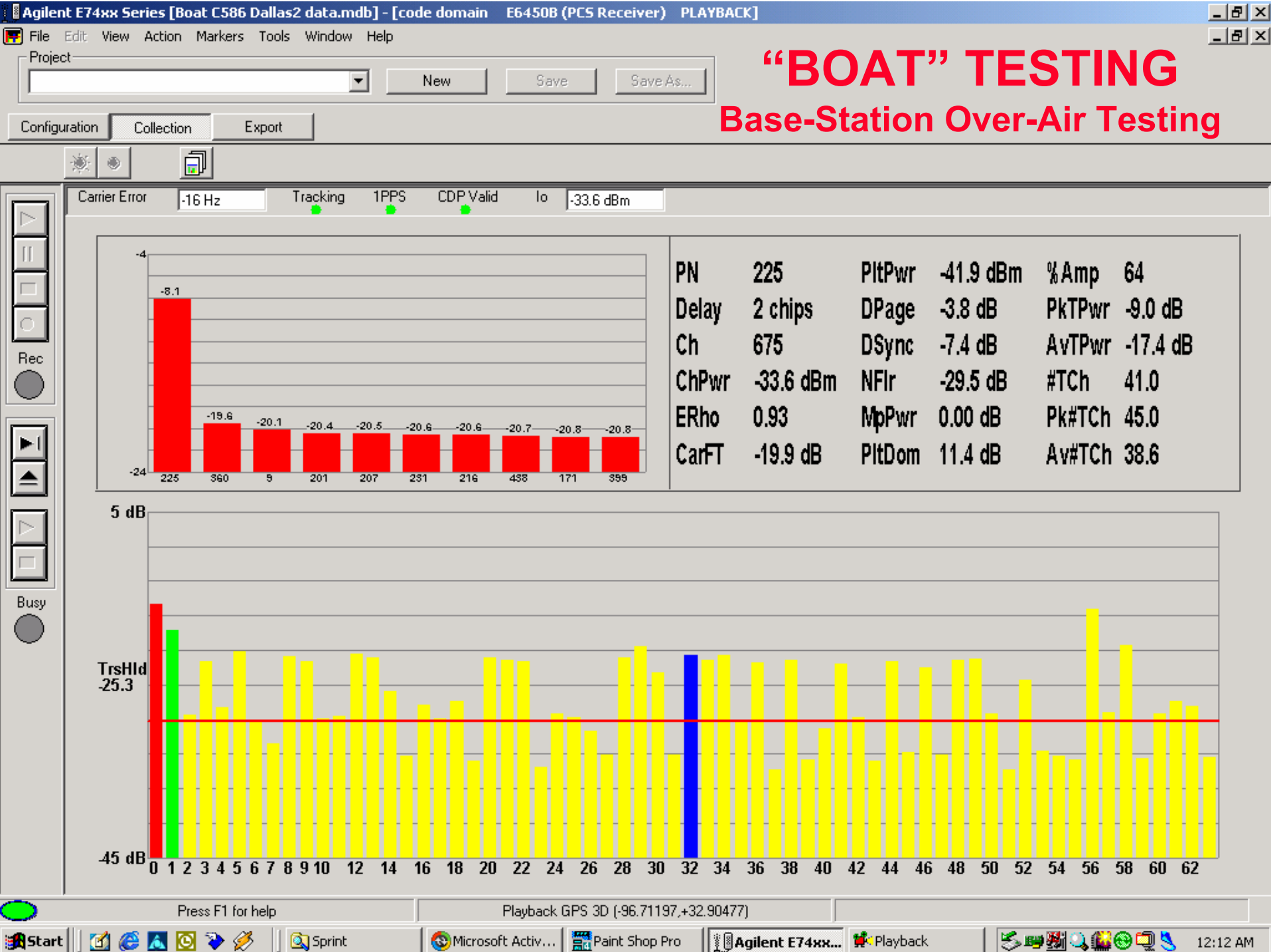
Agilent Drive-Test Tools

- Agilent offers Drive-Test tools
  - Serial interfaces for up to four CDMA phones
  - A very flexible digital receiver with several modes
- PN Scanner
  - Fast, GPS-locked, can scan two carrier frequencies
- Spectrum Analyzer
  - Can scan entire 800 or 1900 mHz. Bands
- Base-Station Over-Air Tester (BOAT)
  - Can display all walsh channel activity on a specific sector
  - Useful for identifying hardware problems, monitoring instantaneous traffic levels, etc.
- Post-Processing tool: OPAS32

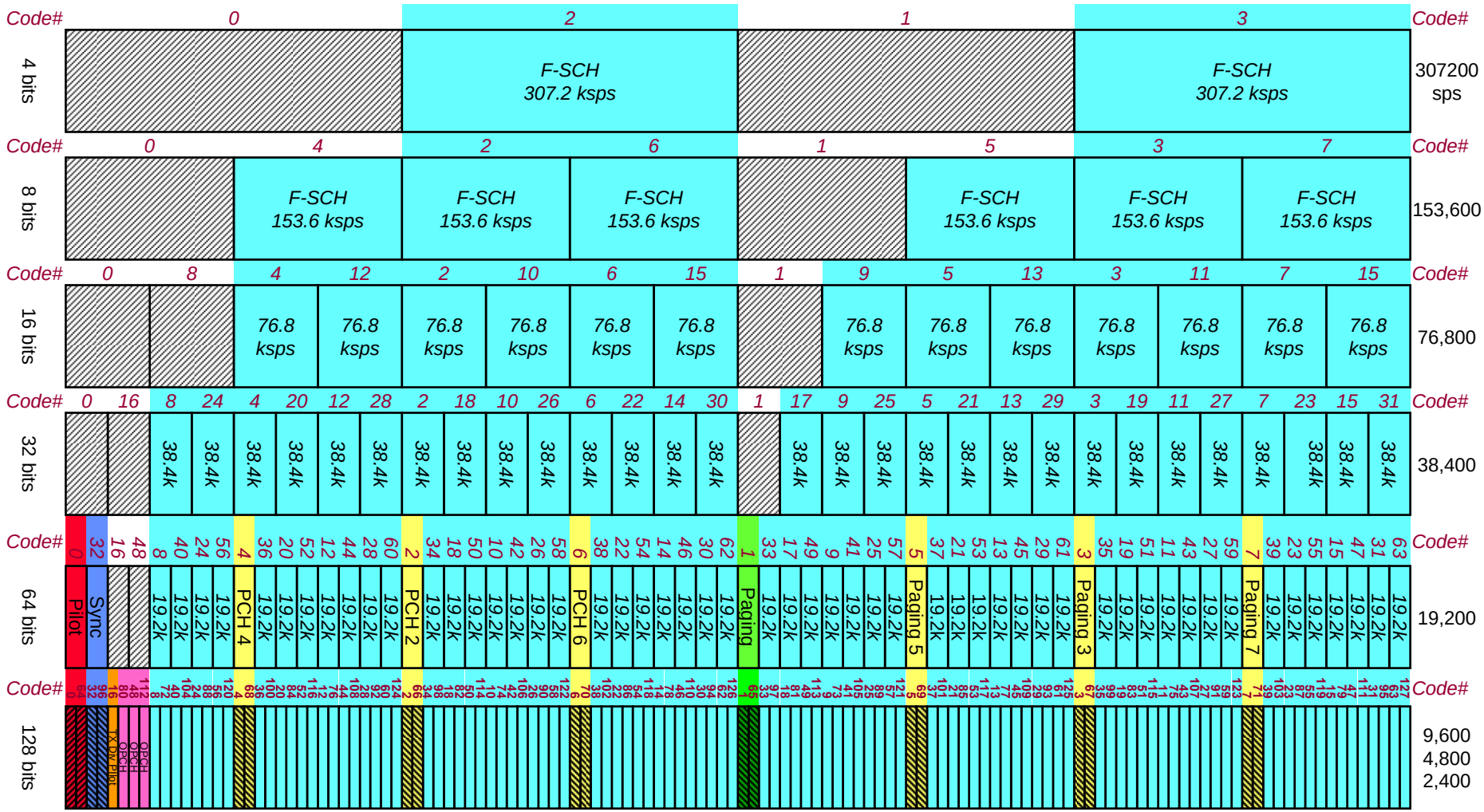


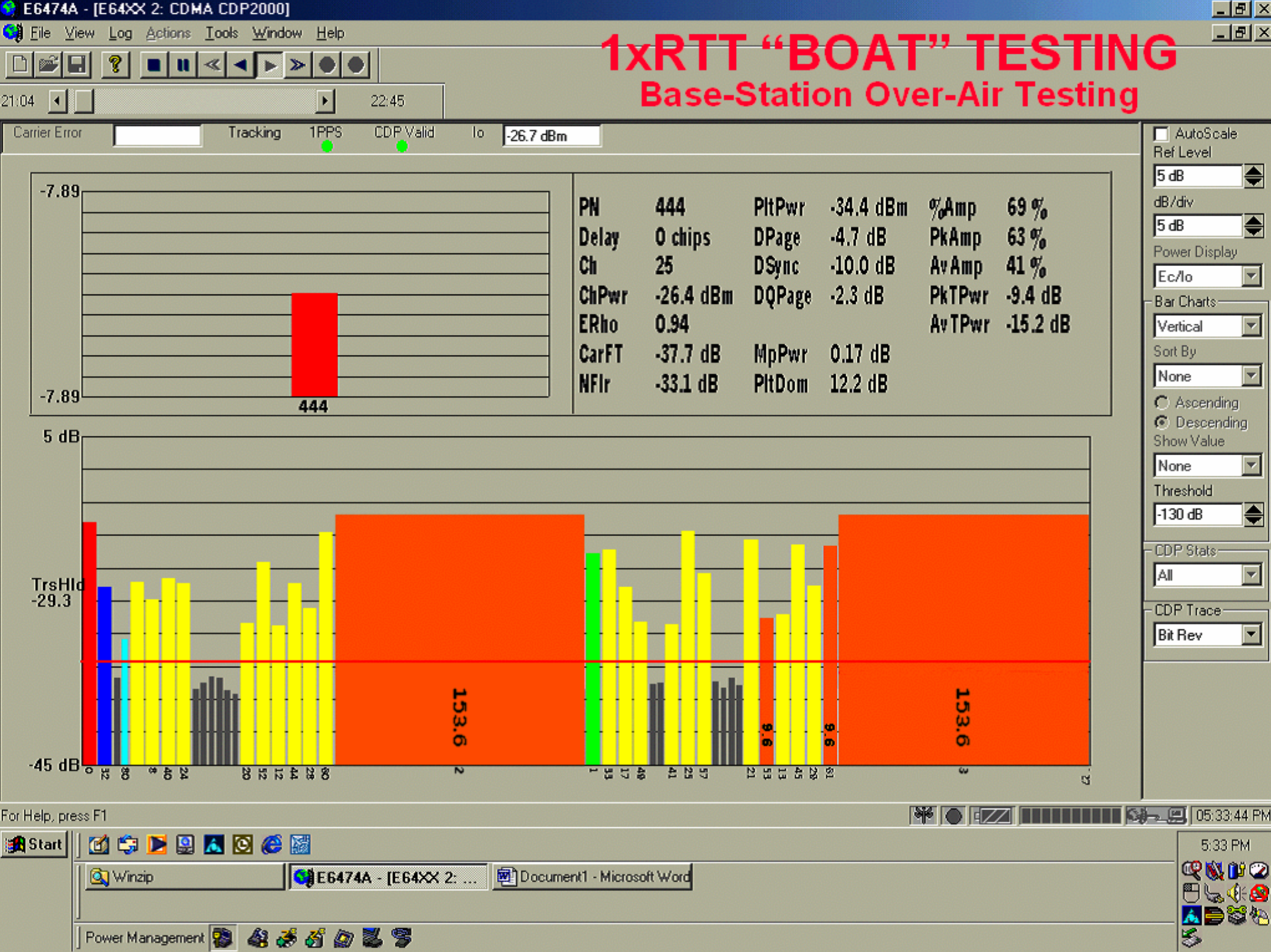
“BOAT” TESTING

Base-Station Over-Air Testing



Walsh Code Utilization in 1xRTT




E6474A - [E64XX 2: CDMA CDP2000]
File View Log Actions Tools Window Help
1xRTT "BOAT" TESTING
Base-Station Over-Air Testing
21:04
22:45
Carrier Error
Tracking
1PPS
CDP Valid
Io
-26.7 dBm
-7.89
-7.89
444
PN 444
Delay 0 chips
Ch 25
ChPwr -26.4 dBm
ERho 0.94
CarFT -37.7 dB
NFlr -33.1 dB
PltPwr -34.4 dBm
DPage -4.7 dB
DSync -10.0 dB
DQPage -2.3 dB
MpPwr 0.17 dB
PltDom 12.2 dB
%Amp 69 %
PkAmp 63 %
AvAmp 41 %
PkTPwr -9.4 dB
AvTPwr -15.2 dB
AutoScale
Ref Level
5 dB
dB/div
5 dB
Power Display
Ec/Io
Bar Charts
Vertical
Sort By
None
Ascending
Descending
Show Value
None
Threshold
-130 dB
CDP Stats
All
CDP Trace
Bit Rev
5 dB
TrsHld
-29.3
-45 dB
153.6
9.6
9.6
153.6
For Help, press F1
05:33:44 PM
Start
Winzip
E6474A - [E64XX 2: ...
Document1 - Microsoft Word
Power Management
5:33 PM

PN Scanners

- Why PN scanners? Because phones can't scan remaining set fast enough, miss transient interfering signals
- **Berkeley Varitronics**
  - high-resolution, GPS-locked
    - full-PN scan speed 26-2/3 ms.
  - 2048 parallel processors for very fast detection of transient interferers
- **Agilent** *(formerly Hewlett-Packard)*
  - high resolution, GPS-locked
    - full-PN scan speed 1.2 sec.
  - Integrated with spectrum analyzer and phone call-processing tool
- **Andrew Network Solutions (formerly Grayson Wireless)**
  - integrated with Invex 3G phone & call-processing data collection tool







Post-Processing Tools

Post-Processing tools display drive-test files for detailed analysis - Faster, more effective than studying data playback with collection tools alone

- Actix Analyzer
  - Imports/analyzes data from almost every brand of drive-test collection tool
- Grayson Interpreter
  - Imports/analyzes data from Grayson Wireless Inspector, Illuminator, and Invex3G
- Agilent OPAS32
  - Imports/analyzes a variety of data
- Nortel RF Optimizer
  - Can merge/analyze drive-test and Nortel CDMA system data
- Wavelink
- Comarco "Workbench" Tool
- Verizon/Airtouch internal tool

