Course 340 Special Edition

1xEV-DO Technology Introduction Rev. 0 and Rev. A

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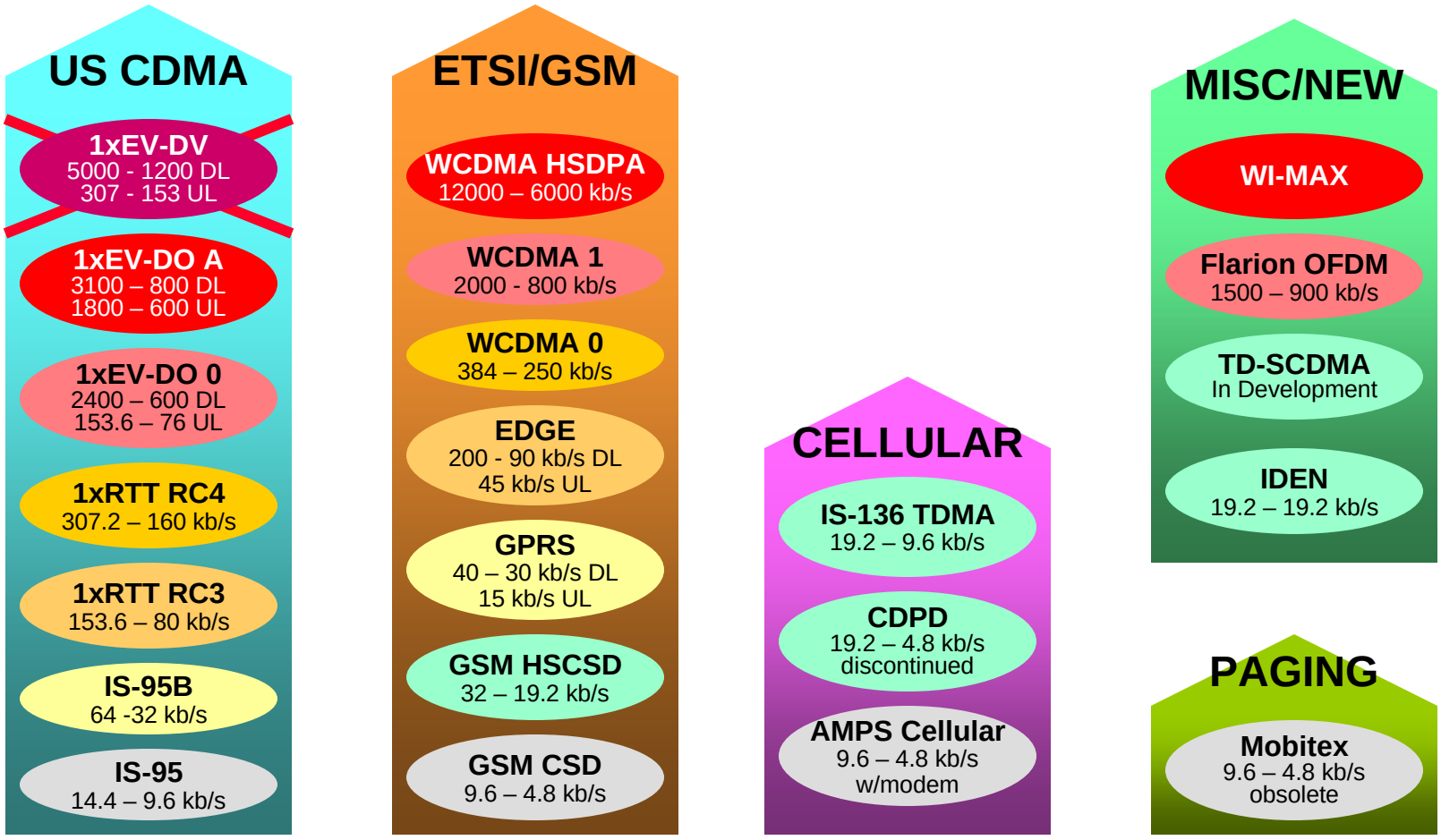
www.howcdmaworks.com/340s.pdf

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Introduction:
How EVDO Fits In the 3G Family

A Quick Survey of Wireless Data Technologies

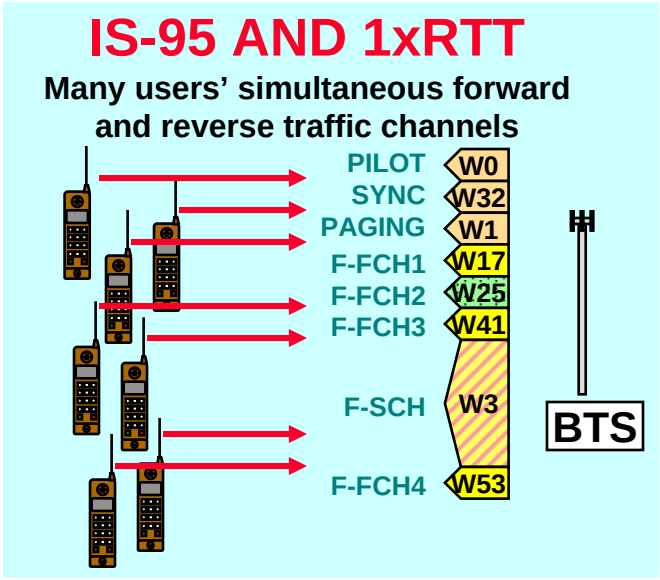


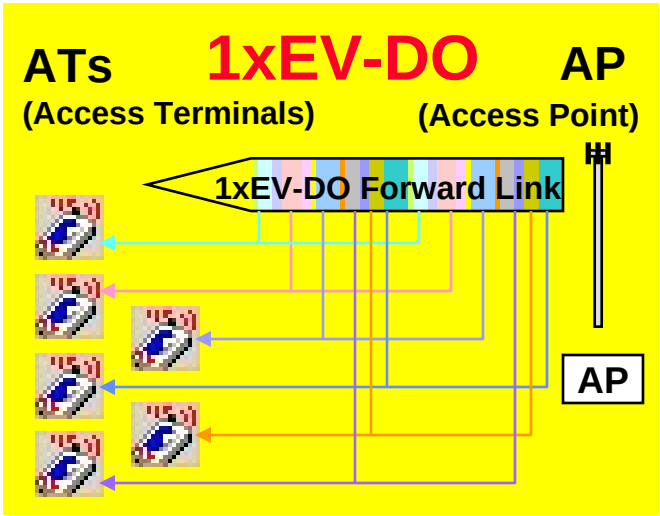
- This summary is a work-in-progress, tracking latest experiences and reports from all the high-tier (provider-network-oriented) 2G and 3G wireless data technologies
- Have actual experiences to share, latest announced details, or corrections to the above? Email to Scott@ScottBaxter.com. Thanks for your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

Channel Structure of 1xEV-DO vs. 1xRTT

CHANNEL STRUCTURE

- IS-95 and 1xRTT
  - many simultaneous users, each with steady forward and reverse traffic channels
  - transmissions arranged, requested, confirmed by layer-3 messages – with some delay……
- 1xEV-DO -- Very Different:
  - Forward Link goes to one user at a time – like TDMA!
  - users are rapidly time-multiplexed, each receives fair share of available sector time
  - instant preference given to user with ideal receiving conditions, to maximize average throughput
  - transmissions arranged and requested via steady MAC-layer walsh streams – very immediate!

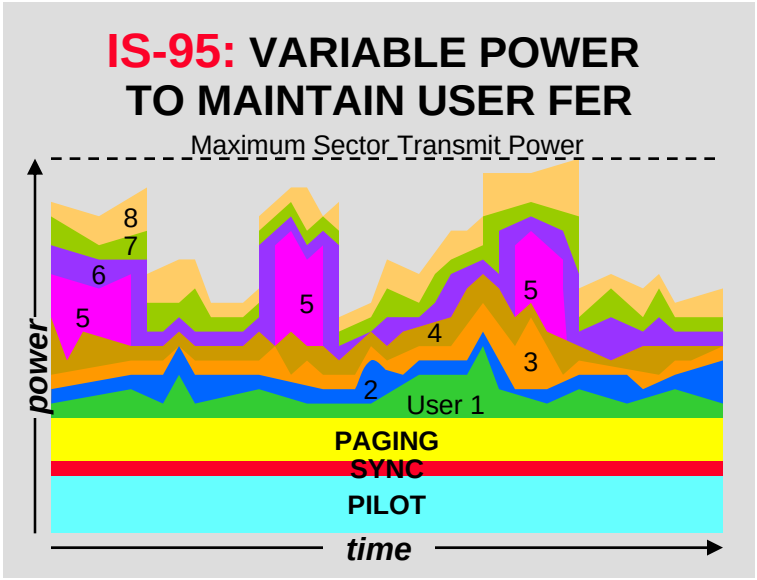


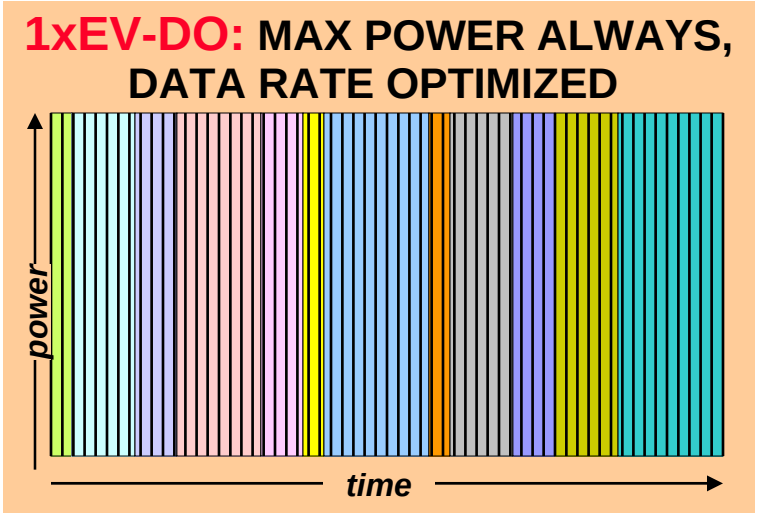


Power Management of 1xEV-DO vs. 1xRTT

POWER MANAGEMENT

- IS-95 and 1xRTT:
  - sectors adjust each user's channel power to maintain a preset target FER
- 1xEV-DO IS-856:
  - sectors always operate at maximum power
  - sector output is time-multiplexed, with only one user served at any instant
  - The transmission data rate is set to the maximum speed the user can receive at that moment





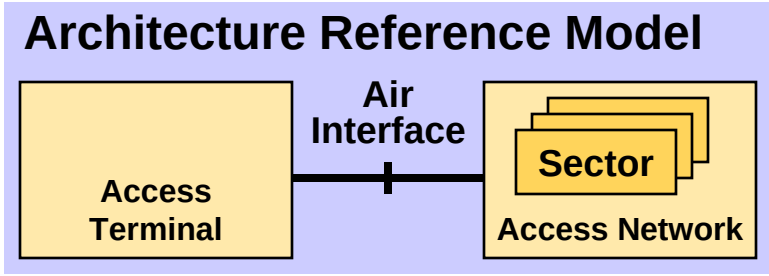
EVDO Standard
And Standards Documents

EVDO Standards

- C.S0024-0_v2.0 Oct., 2000
  - Original EV-DO standard, derived from Qualcomm's "HDR"
- C.S0024-0_v3.0 Dec., 2001
  - Improvements to stability and throughput
- C.S0024-0_v4.0 Oct., 2002
  - Final Rev. 0 standard; improvements in several layers
- C.S0024-A_v1.0 Mar., 2004
  - First Rev. A standard, offering higher speeds on the reverse link and enhancements to speed applications like VOIP and multi-user/multi-media
- C.S0024-A_v2.0 July, 2005
  - More application-driven enhancements
- C.S0024-A_v3.0 Sep., 2006
  - Current Rev. A Standard: More application-driven enhancements
- C.S0024-B_v1.0 May, 2006
  - Advanced version providing up to 4.9 mb/s per carrier and the ability to "gang" multiple carriers for speeds of at least 14 mb/s

Conceptual Framework of the IS-856 Standard

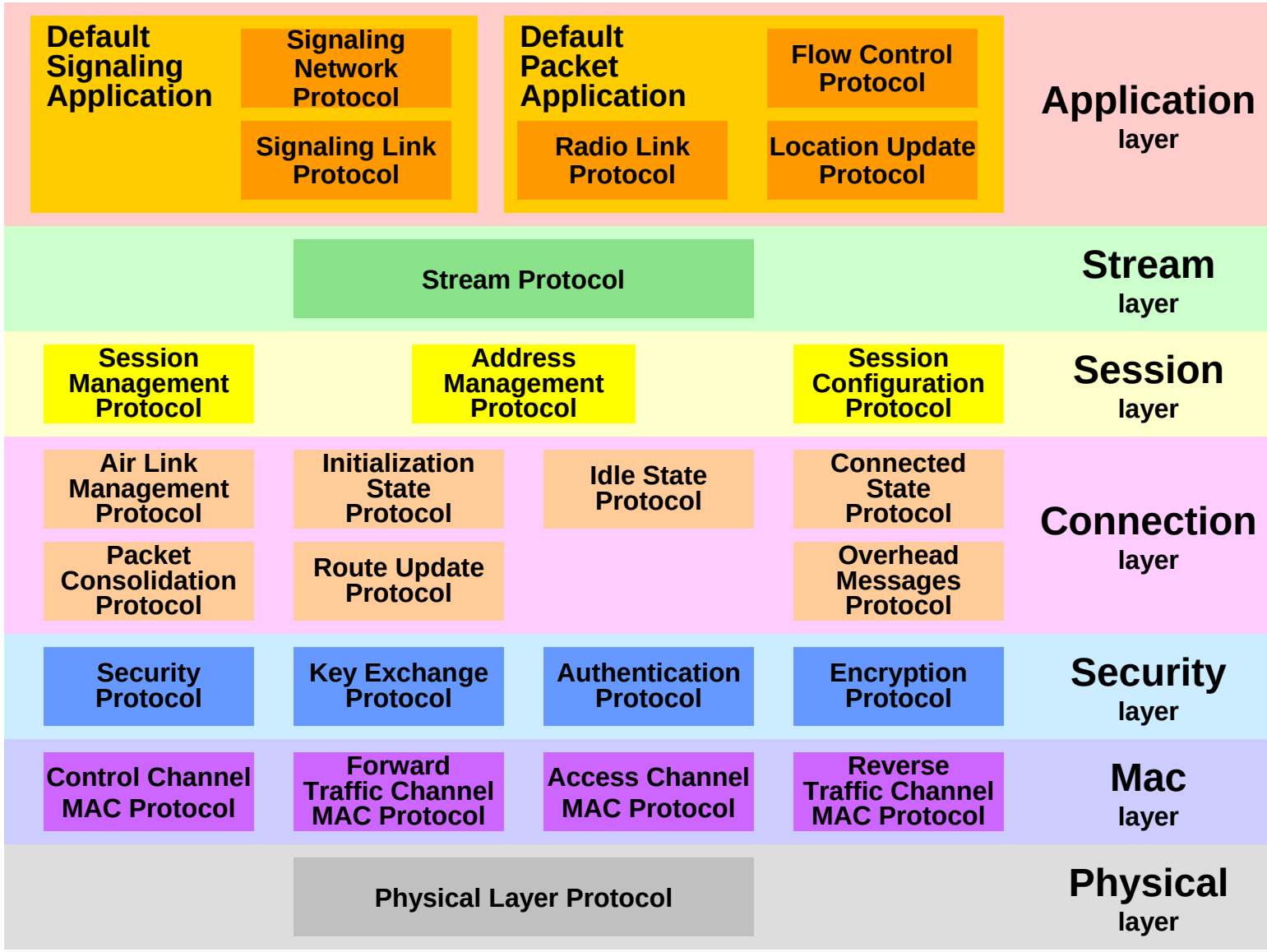
- IS-856 defines the behavior of three main entities:
  - Access Terminal
  - Air Interface
  - Access Network
- The behavior of the system is defined in layers
  - the layers provide a simple, logical foundation for performing functions and applications
  - Specific applications, functions and protocols exist in each layer
  - Each layer is defined in specific chapters of the standard



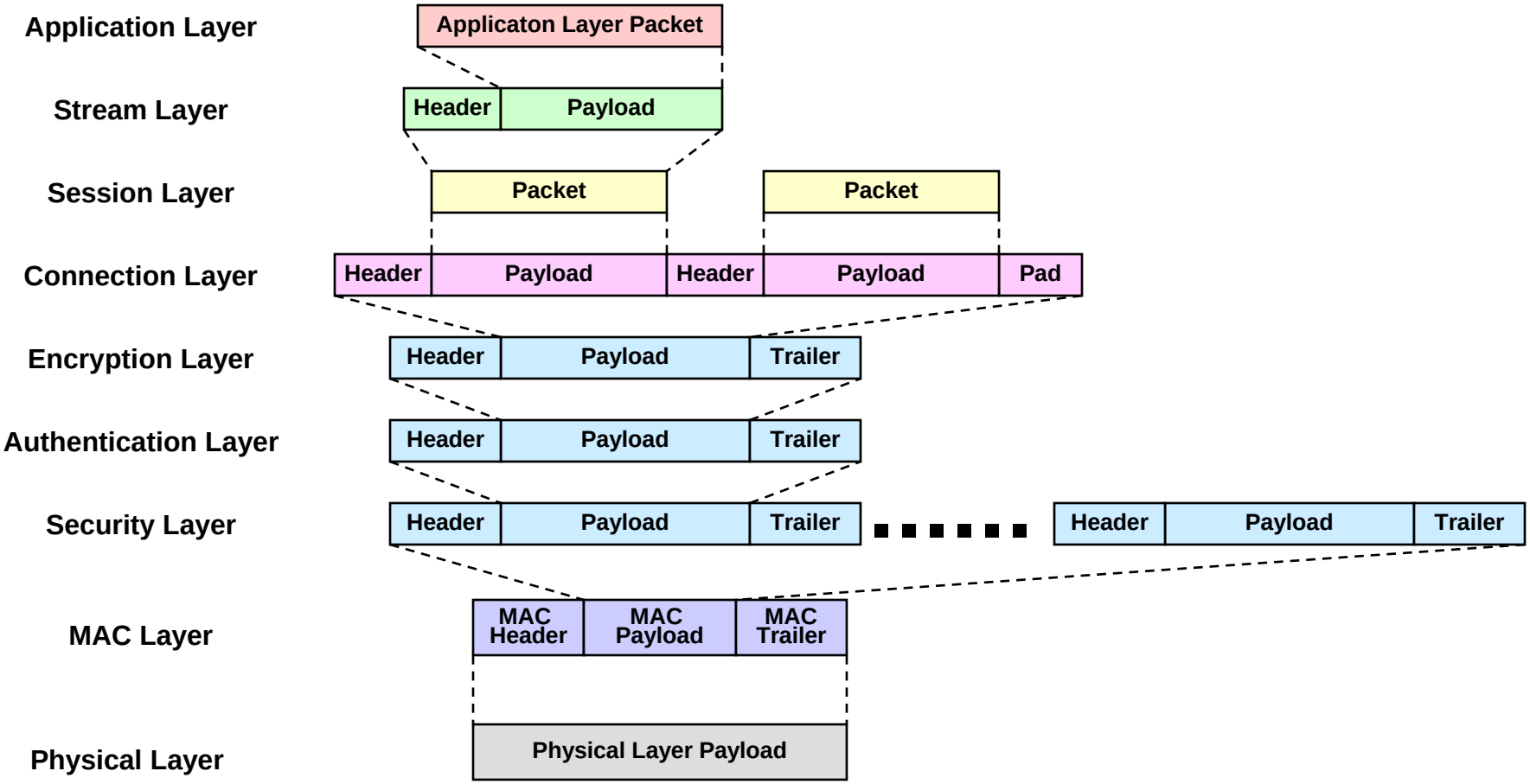
Protocol Architecture

Layer	*Protocol & Function*	*IS-856 Chapter*
Application	•Default Signaling Application •Default Packet Application	2 3
Stream	•Stream 0: Default Signaling •Stream 1, 2, 3: not used by default	4
Session	•Protocol Negotiation •Address Mgt. •Protocol Configuration •State Mtce.	5
Connection	•Air Link Connection Establishment •Air Link Connection Maintenance	6
Security	•Authentication •Encryption	7
Mac	•Defines procedures to transmit and receive over the physical layer	8
Physical	•Channel Structure •Modulation. •Frequency, Power •Encoding.	9

Stack Layers and their Default Protocols



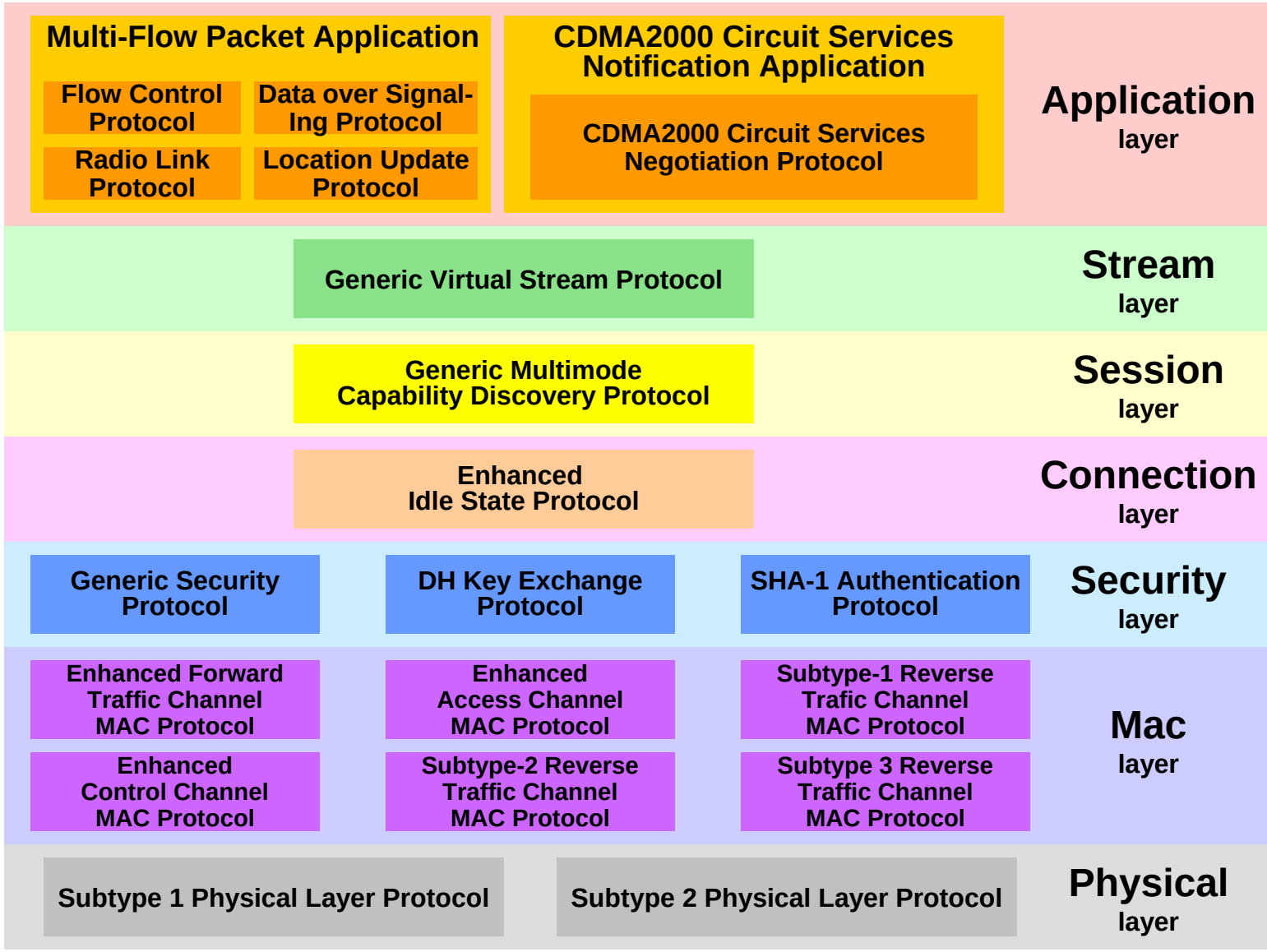
1xEV-DO Protocol Layers and Packet Encapsulation



EV-DO Rev. A Improvements

- Support of enhanced reverse link
  - One channel per mobile station
  - Mobile station is required to transmit at 1.84 Mbps peak rate
  - Shorter frames
  - Higher capacity
- Forward link enhancements
  - – Higher peak data rate of 3.1 Mbps
  - – Smaller packet sizes (128, 256, and 512 bits)
  - – Multi-user packets
- Improved slotted mode
  - Shorter slot cycle for reduced activation time
  - Subsynchronous control channel for enhanced standby time
  - Slots coordinated with need to listen to 1xRTT paging channel
- 1xRTT paging channel content transmitted on EVDO control channel
- Enhanced multi-flow packet data application
- Reverse link MAC enhancements for QoS
- Data Source Control (DSC) for seamless cell selection
- Enhanced Generic Attribute Update protocol

Non-Default Protocols

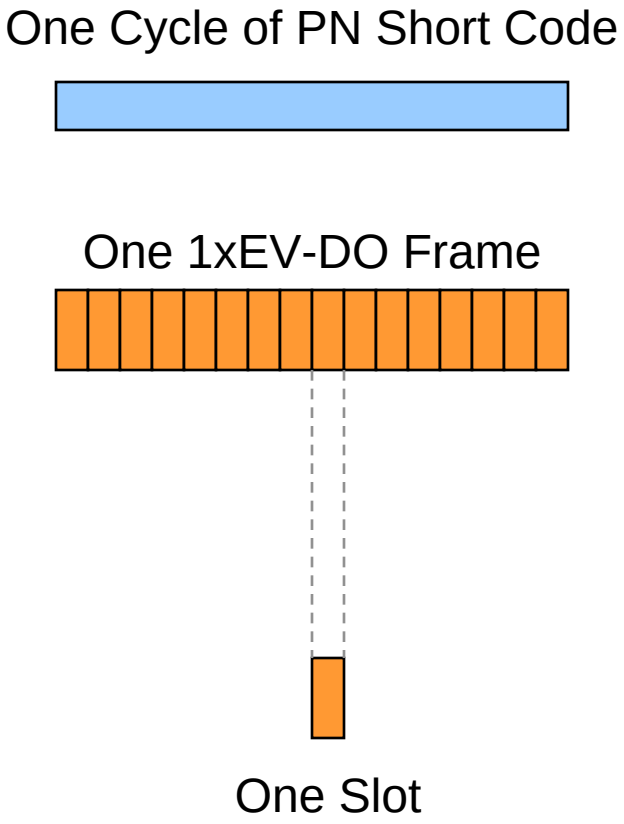


1xEV-DO Physical Layer: Channels in Time and Codes

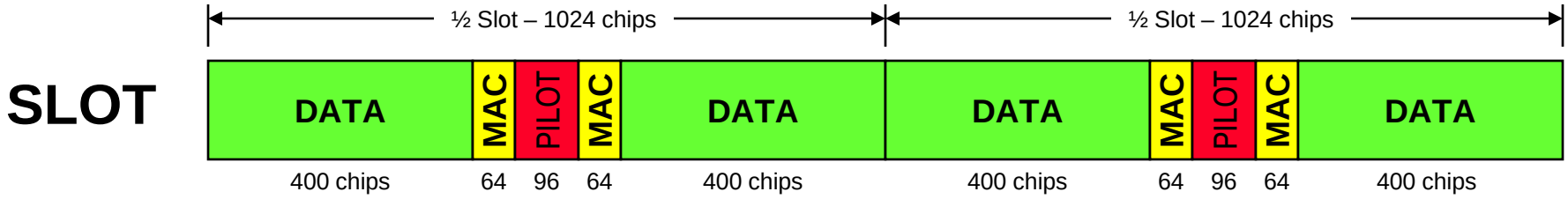
1xEV-DO Transmission Timing

Forward Link

- All members of the CDMA family - IS-95, IS-95B, 1xRTT, 1xEV-DO and 1xEV-DV transmit "Frames"
  - IS-95, IS-95B, 1xRTT frames are usually 20 ms. long
  - 1xEV-DO frames are 26-2/3 ms. long
    - same length as the short PN code
    - each 1xEV-DO frame is divided into 1/16ths, called "slots"
- The Slot is the basic timing unit of 1xEV-DO forward link transmission
  - Each slot is directed toward somebody and holds a subpacket of information for them
  - Some slots are used to carry the control channel for everyone to hear; most slots are intended for individual users or private groups
- Users don't "own" long continuing series of slots like in TDMA or GSM; instead, each slot or small string of slots is dynamically addressed to whoever needs it at the moment

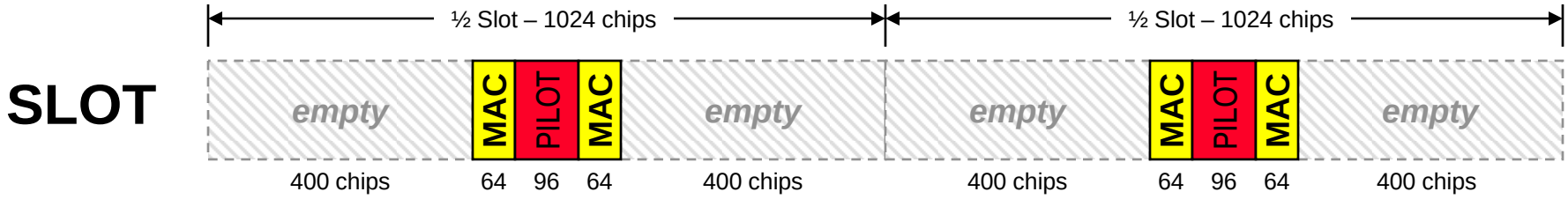


What's In a Forward Link Slot?



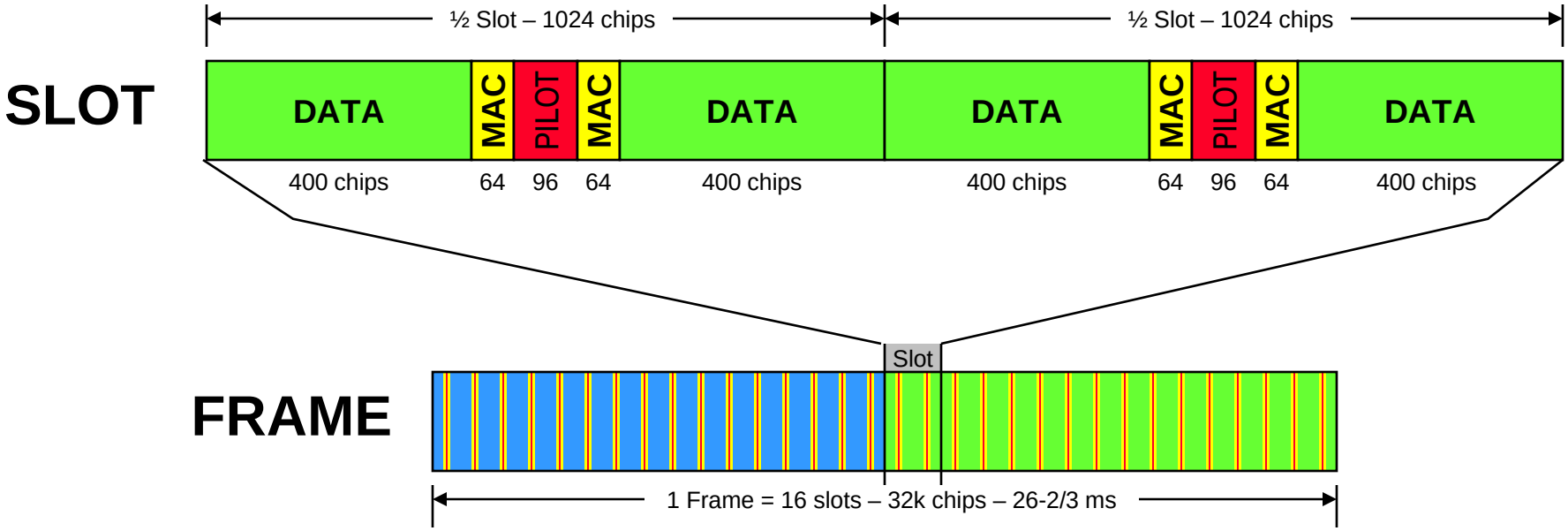
- The main "cargo" in a slot is the **DATA** being sent to a user
- But all users need to get continuous timing and administrative information, even when all the slots are going to somebody else
- Twice in every slot there is regularly-scheduled burst of timing and administrative information for everyone to use
  - MAC (Media Access Control) information such as power control bits
  - a burst of pure Pilot
    - allows new mobiles to acquire the cell and decide to use it
    - keeps existing user mobiles exactly on sector time
    - mobiles use it to decide which sector should send them their next forward link packet

What if there's No Data to Send?



- Sometimes there may be no data waiting to be sent on a sector's forward link
  - When there's no data to transmit on a slot, transmitting can be suspended during the data portions of that slot
  - But---the MAC and PILOT must be transmitted!!
  - New and existing mobiles on this sector and surrounding sectors need to monitor the relative strength of all the sectors and decide which one to use next, so they need the pilot
  - Mobiles TRANSMITTING data to the sector on the reverse link need power control bits
  - So MAC and PILOT are always transmitted, even in an empty slot

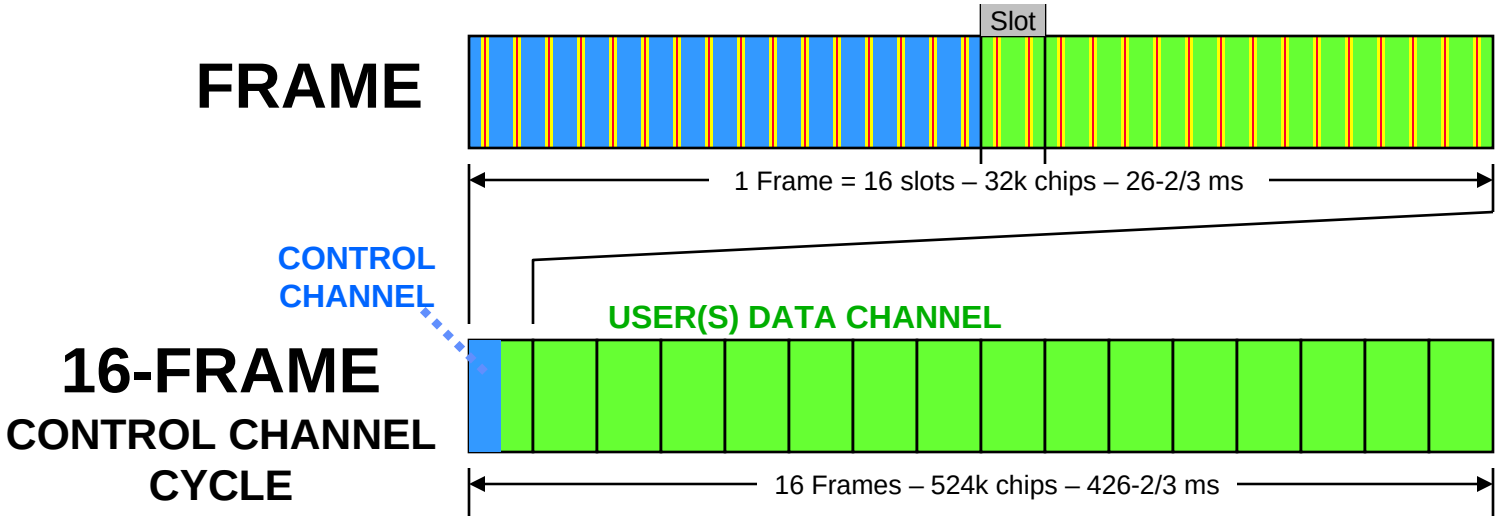
Forward Link Slots and Frames



- Two Half-Slots make a Slot
- 16 Slots make a frame

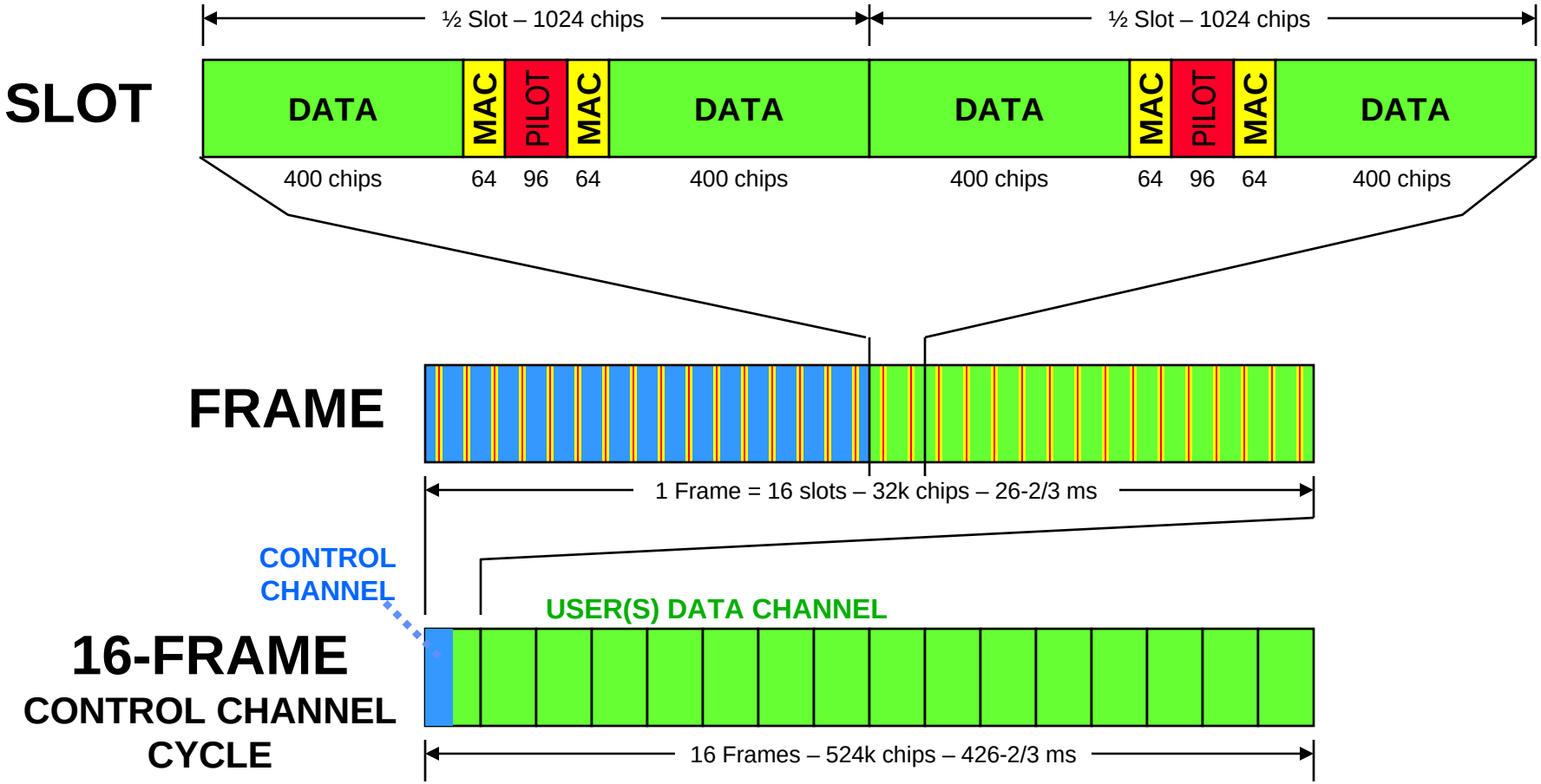
Forward Link Frames and Control Channel Cycles

- A Control Channel Cycle is 16 frames (that's 426-2/3 ms, about 1/2 second)
- The first half of the first frame has all of its slots reserved for possible use carrying Control Channel packets
- The last half of the first frame, and all of the remaining 15 frames, have their slots available for ordinary use transmitting subpackets to users



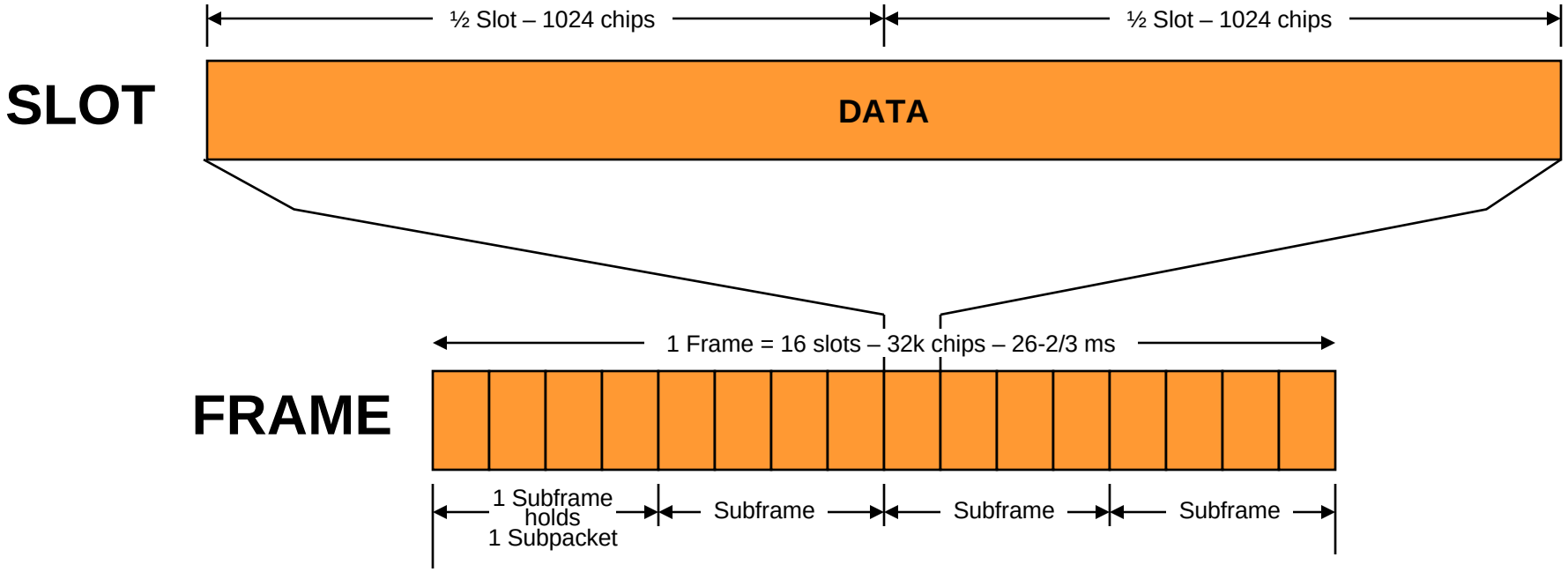
That's a lot of slots!
16 x 16 = 256

Forward Link Frame and Slot Structure: "Big Picture" Summary



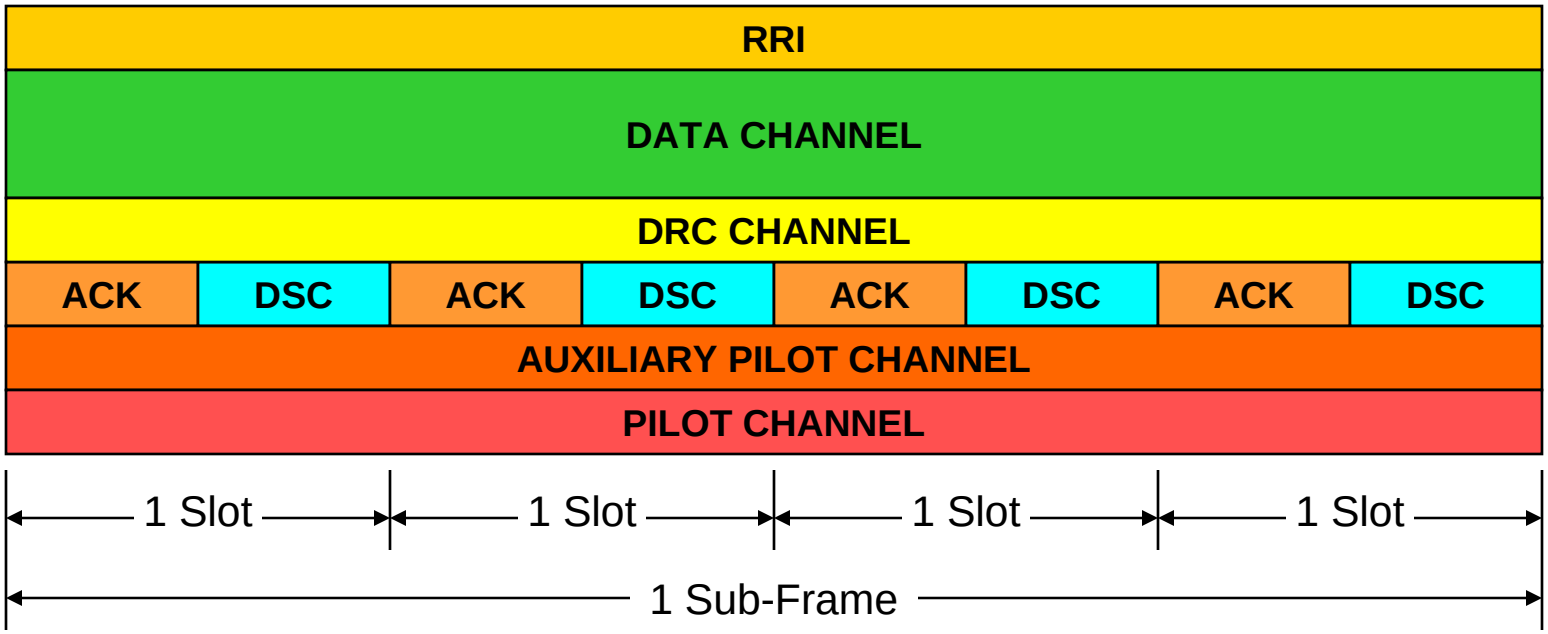
- Slots make Frames and Frames make Control Channel Cycles!

Reverse Link Frame and Slot Structure: "Big Picture" Summary



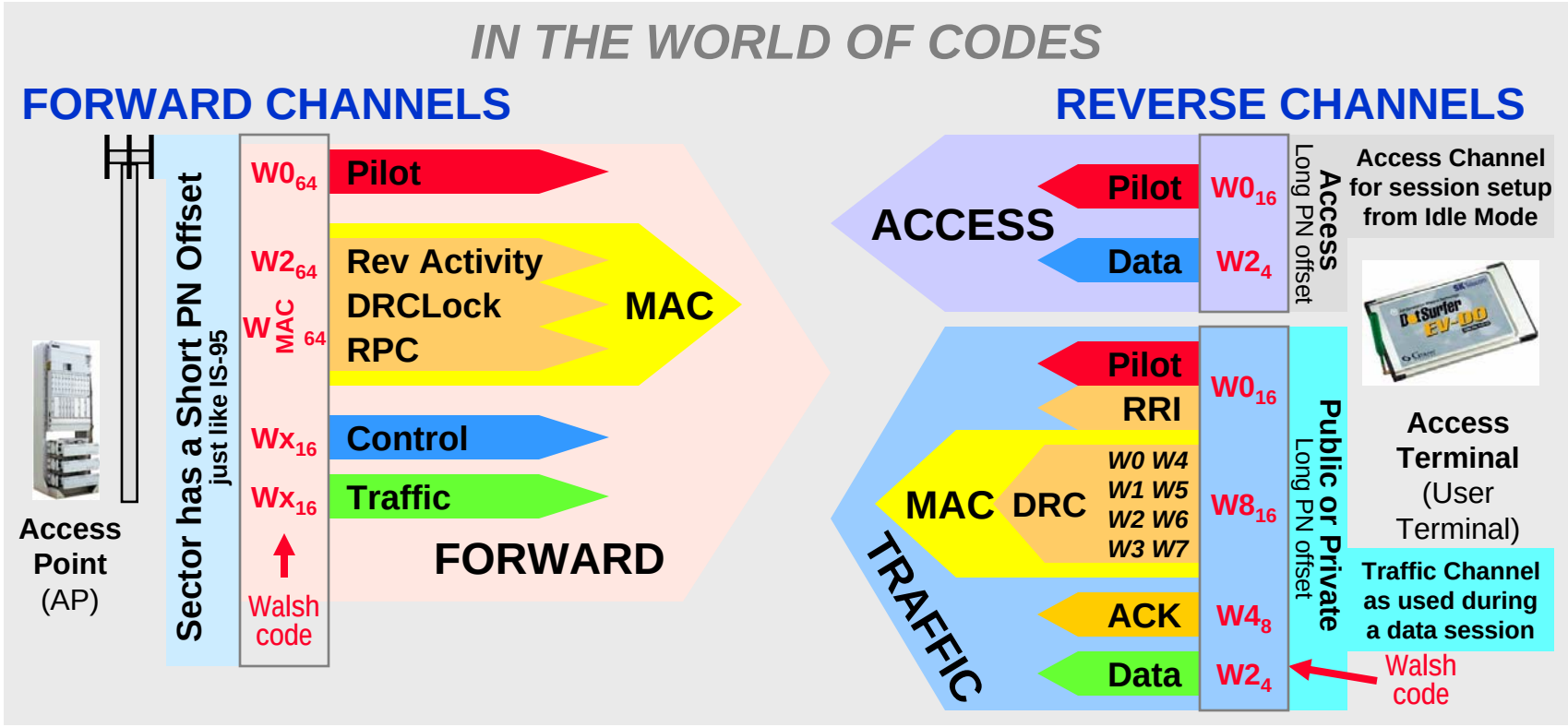
- Reverse Link frames are the same length as forward link frames
- The mobile does not include separate MAC and Pilot bursts
  - Its MAC and pilot functions are carried inside its signal by simultaneous walsh codes
- There is no need for slots for dedicated control purposes since the mobile can transmit on the access channel whenever it needs

Rev. A Reverse Channel Sub-Frame Structure



- The mobile transmits sub-packets occupying four reverse link slots, called a reverse link “sub-frame”.
- If multiple subpackets are required to deliver a packet, the additional subpackets are spaced in every third subframe until done

The 1xEV-DO Rev. 0 Channels

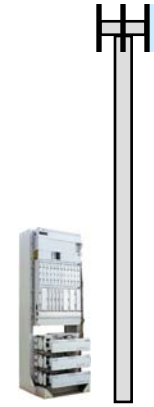


- These channels are NOT CONTINUOUS like IS-95 or 1xRTT!
  - They are made up of SLOTS carrying data subpackets to individual users or control channel subpackets for everyone to monitor
  - Regardless of who "owns" a SLOT, the slot also carries two small generic bursts containing PILOT and MAC information everyone can monitor

Functions of Rev. 0 Forward Channels



FORWARD CHANNELS



Access Point (AP)

Sector has a Short PN Offset

$W0_{64}$ **Pilot**

$W2_{64}$ **Rev Activity**

$W_{MAC\ 64}$ **DRCLock**, **RPC** — **MAC**

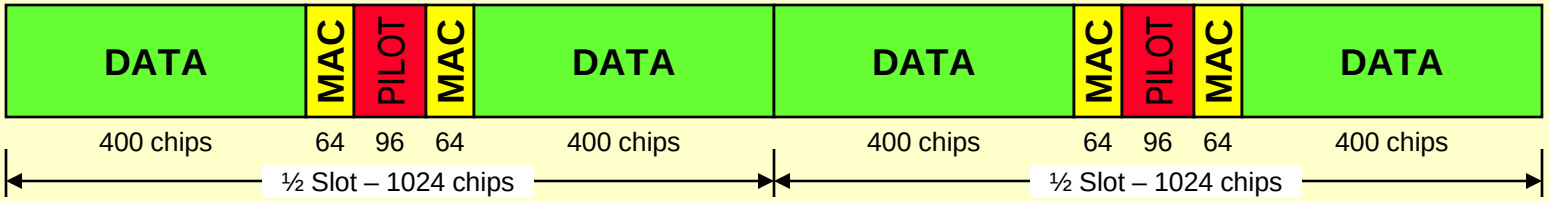
Wx_{16} **Control**

Wx_{16} **Traffic**

- Access terminals watch the **Pilot** to select the strongest sector and choose burst speeds
- The Reverse Activity Channel tells ATs If the reverse link loading is too high, requiring rate reduction
- Each AT with open connection has a MAC channel including DRCLock and RPC (Reverse Power Control) muxed using the same MAC index 5-63.
- Traffic channels carry user data to one user at a time
- The Control channel carries overhead messages for idle ATs but can also carry user traffic

IN THE WORLD OF TIME

Forward Link Slot Structure (16 slots in a 26-2/3 ms. frame)



Functions of Rev. 0 Reverse Channels



•The **Pilot** is used as a preamble during access probes

•**Data** channel during access carries mobile requests

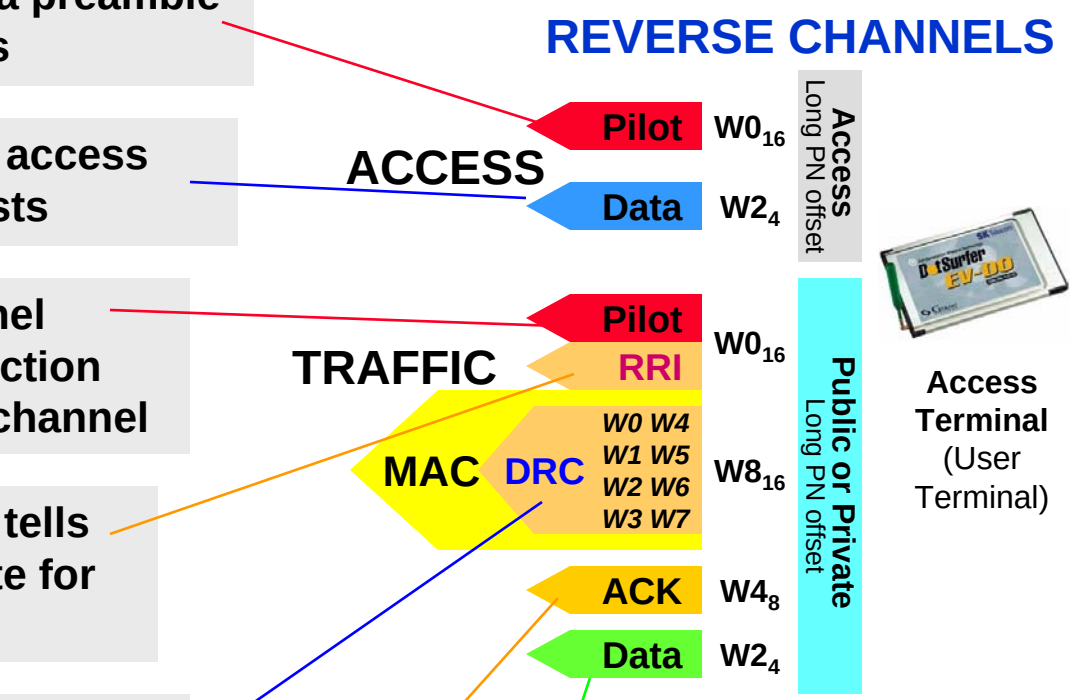
•**Pilot** during traffic channel allows synchronous detection and also carries the RRI channel

•**RRI reverse rate indicator** tells the AP the AT's desired rate for reverse link data channel

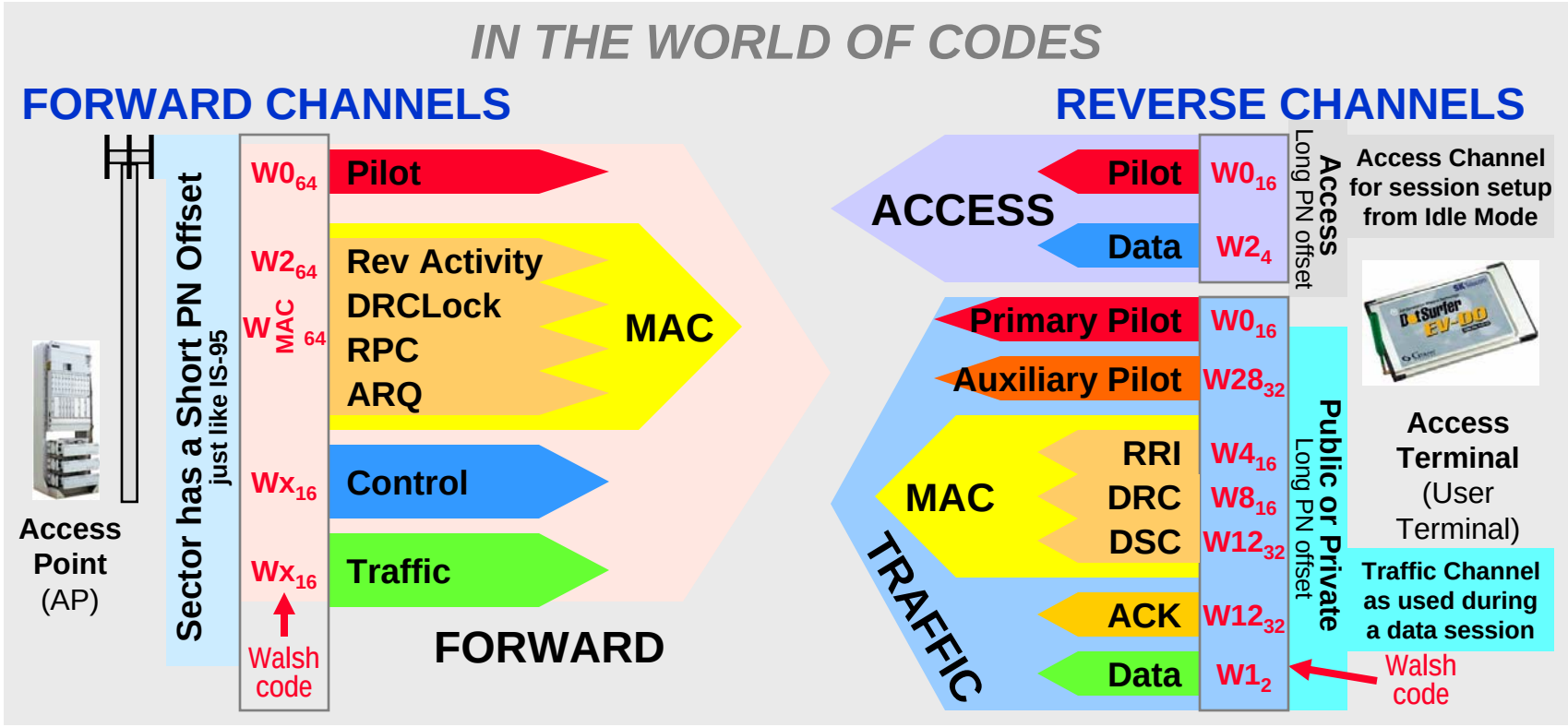
•**DRC Data Rate Control** channel asks a specific sector to transmit to the AT at a specific rate

•**ACK** channel allows AT to signal successful reception of a packet

•**DATA** channel during traffic carries the AT's traffic bits



EV-DO Rev. A Channels

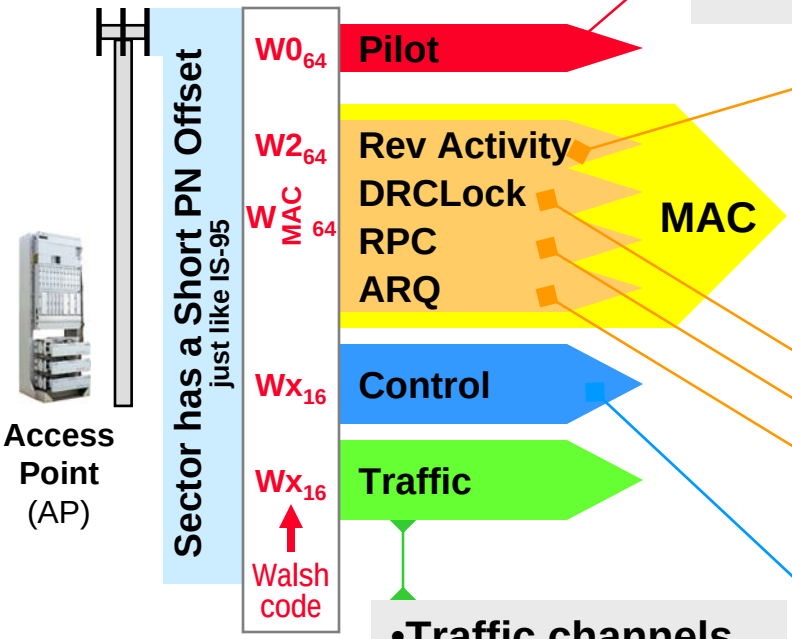


- The channels are not continuous like ordinary 1xRTT CDMA
- Notice the differences between the MAC channels and the Rev. 0 MAC channels – these are the heart of the Rev. 0/A differences

Functions of Rev. A Forward Channels

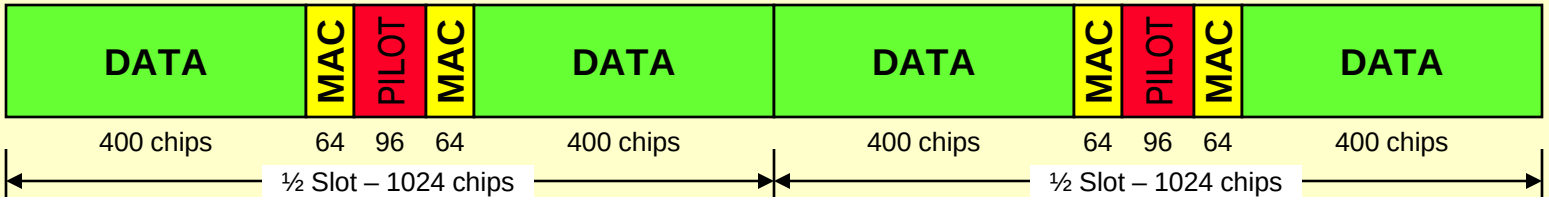


FORWARD CHANNELS



- Access terminals watch the Pilot to select the strongest sector and choose burst speeds
- The Reverse Activity Channel tells ATs If the reverse link loading is too high, requiring rate reduction
- Each connected AT has MAC channel:
  - DRCLock indication if sector busy
  - RPC (Reverse Power Control)
  - ARQ to halt reverse link subpackets as soon as complete packet is recovered
- Traffic channels carry user data to one user at a time
- The Control channel carries overhead messages for idle ATs but can also carry user traffic

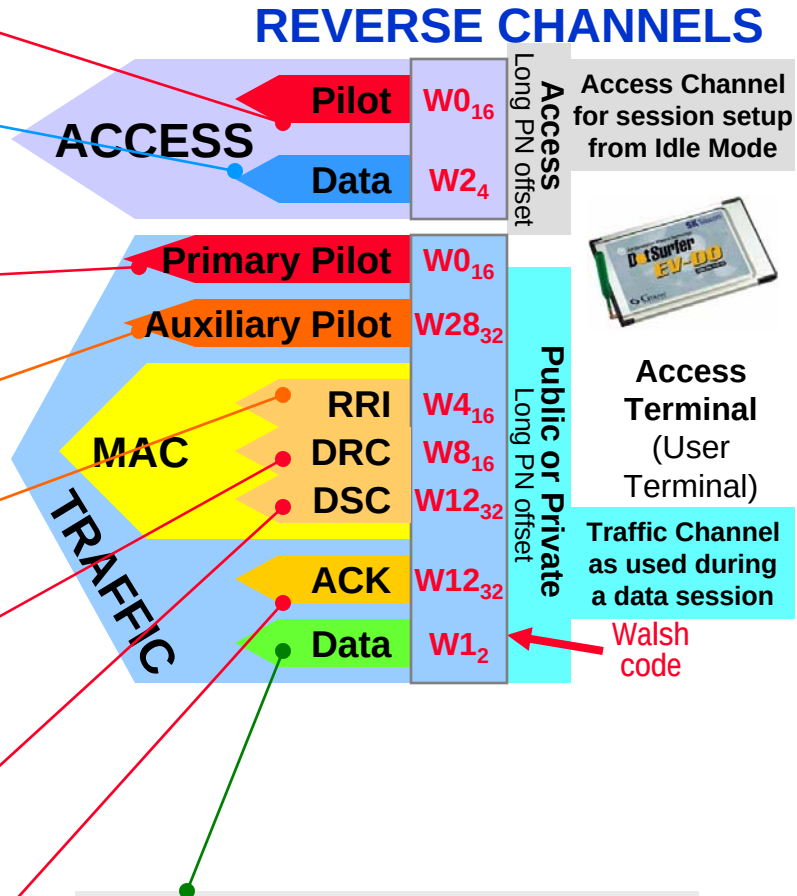
Forward Link Slot Structure (16 slots in a 26-2/3 ms. frame)



Functions of Rev. A Reverse Channels



- The Pilot is used as a preamble during access probes
- Data channel during access carries mobile requests
- Primary Pilot on traffic channel allows synchronous detection and also carries the RRI channel
- Auxiliary Pilot on traffic channel allows synchronous detection during high data rates
- RRI reverse rate indicator tells AP what rate is being sent by AT
- DRC Data Rate Control channel tells desired downlink speed
- DSC Data Source Control channel tells which sector will send burst
- ACK channel allows AT to signal successful reception of a packet
- DATA channel during traffic carries the AT's traffic bits





The Rev. 0 MAC Index

MACIndex	MAC Channel Use	Preamble Use
0 and 1	Not Used	Not Used
2	Not Used	76.8 kbps CCH
3	Not Used	38.4 kbps CCH
4	RA Channel	Not Used
5-63	Available for RPC and DRCLock Channel Transmissions	Available for Forward Traffic Channel Transmissions

- Each active user on a sector is assigned a unique 7-bit MAC index (64 MACs possible)
- Each data packet begins with a preamble, using the MAC index of the intended recipient
- Five values of MAC indices are reserved for “multi-user” packets
  - packets intended for reception by a group
    - for example, control channels
  - mobiles may have individual MAC indices AND be simultaneously in various groups
  - this “trick” keeps payload size low even for transmissions to groups

MACIndex	Walsh Code	Phase
0	0	I
2	1	I
4	2	I
6	3	I
8	4	I
10	5	I
12	6	I
14	7	I
16	8	I
18	9	I
20	10	I
22	11	I
24	12	I
26	13	I
28	14	I
30	15	I

MACIndex	Walsh Code	Phase
32	16	I
34	17	I
36	18	I
38	19	I
40	20	I
42	21	I
44	22	I
46	23	I
48	24	I
50	25	I
52	26	I
54	27	I
56	28	I
58	29	I
60	30	I
62	31	I

MACIndex	Walsh Code	Phase
1	32	Q
3	33	Q
5	34	Q
7	35	Q
9	36	Q
11	37	Q
13	38	Q
15	39	Q
17	40	Q
19	41	Q
21	42	Q
23	43	Q
25	44	Q
27	45	Q
29	46	Q
31	47	Q

MACIndex	Walsh Code	Phase
33	48	Q
35	49	Q
37	50	Q
39	51	Q
41	52	Q
43	53	Q
45	54	Q
47	55	Q
49	56	Q
51	57	Q
53	58	Q
55	59	Q
57	60	Q
59	61	Q
61	62	Q
63	63	Q

Rev. A MAC Index Values and Their Uses

MAC INDEX	MAC CHANNEL USE	PREAMBLE USE	PREAMBLE LENGTH
0, 1	Not Used	Not Used	N/A
2	Not Used	Control 76.8 kbps	512
3	Not Used	Control 38.4 kbps	1024
4	RA Channel	Not Used	N/A
5	RPC, DRC LOCK, ARQ	Fwd TC if no Bcst	Variable
64 and 65	Not Used	Not Used	N/A
66	Not Used	Multi-User 128, 256, 512, 1024	256
67	Not Used	Multi-User 2048	128
68	Not Used	Multi-user 3072	64
60	Not Used	Multi-User 4096	64
70	Not Used	Mujlti-User 5120	64
71	Not Used	Control 19.2, 38.4, 76.8	1024
6-63 and 72-127	RPC, DRC LOCK, ARQ	Fwd TC, Single User	Variable

- 114 MAC indices are available for regular single-user packets
- 3 MAC indices are earmarked for control channel packets
- 5 MAC indices are reserved for mult-user packets
- 1 MAC index is reserved for broadcast packets, or single-users
- 4 MAC indices are not used due to conflicts with multiplexing patterns

Rev. A MAC Index and I/Q Channel Contents

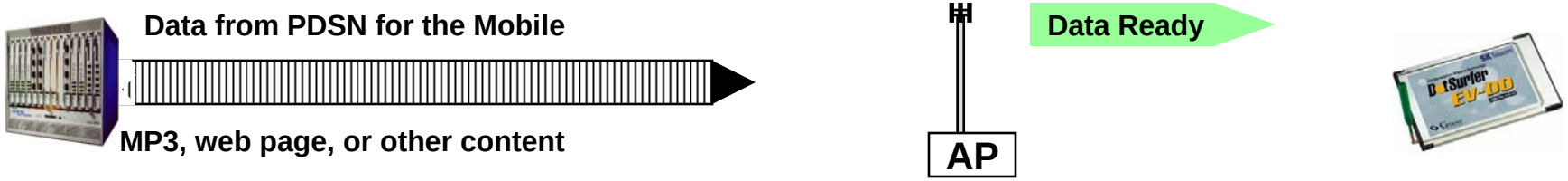
		(T-FrameOffset) mod 4 =3		(T-FrameOffset) mod 4 ≠3	
MAC INDEX	128-ary Walsh Function	I-branch	Q-branch	I-branch	Q-branch
0	Not Used				
1	Not Used				
2	Not Used				
3	Not Used				
4	2	RA		RA	
5	34	DRC LOCK	RPC	ARQ P	ARQ H or L
6	3	RPC	DRC LOCK	ARQ H or L	ARQ P
7	35	DRC LOCK	RPC	ARQ P	ARQ H or L
8	4	RPC	DRC LOCK	ARQ H or L	ARQ P
9	36	DRC LOCK	RPC	ARQ P	ARQ H or L
10	5	RPC	DRC LOCK	ARQ H or L	ARQ P
11	37	DRC LOCK	RPC	ARQ P	ARQ H or L
12	6	RPC	DRC LOCK	ARQ H or L	ARQ P
13	38	DRC LOCK	RPC	ARQ P	ARQ H or L
14	7	RPC	DRC LOCK	ARQ H or L	ARQ P
15	39	DRC LOCK	RPC	ARQ P	ARQ H or L
16	8	RPC	DRC LOCK	ARQ H or L	ARQ P
17	40	DRC LOCK	RPC	ARQ P	ARQ H or L
18	9	RPC	DRC LOCK	ARQ H or L	ARQ P
19	41	DRC LOCK	RPC	ARQ P	ARQ H or L
20	10	RPC	DRC LOCK	ARQ H or L	ARQ P
21	42	DRC LOCK	RPC	ARQ P	ARQ H or L
22	11	RPC	DRC LOCK	ARQ H or L	ARQ P
23	43	DRC LOCK	RPC	ARQ P	ARQ H or L
24	12	RPC	DRC LOCK	ARQ H or L	ARQ P
25	44	DRC LOCK	RPC	ARQ P	ARQ H or L
26	13	RPC	DRC LOCK	ARQ H or L	ARQ P
27	45	DRC LOCK	RPC	ARQ P	ARQ H or L
28	14	RPC	DRC LOCK	ARQ H or L	ARQ P
29	46	DRC LOCK	RPC	ARQ P	ARQ H or L
30	15	RPC	DRC LOCK	ARQ H or L	ARQ P
31	47	DRC LOCK	RPC	ARQ P	ARQ H or L
32	16	RPC	DRC LOCK	ARQ H or L	ARQ P
33	48	DRC LOCK	RPC	ARQ P	ARQ H or L
34	17	RPC	DRC LOCK	ARQ H or L	ARQ P
35	49	DRC LOCK	RPC	ARQ P	ARQ H or L
36	18	RPC	DRC LOCK	ARQ H or L	ARQ P
37	50	DRC LOCK	RPC	ARQ P	ARQ H or L
38	19	RPC	DRC LOCK	ARQ H or L	ARQ P
39	51	DRC LOCK	RPC	ARQ P	ARQ H or L
40	20	RPC	DRC LOCK	ARQ H or L	ARQ P
41	52	DRC LOCK	RPC	ARQ P	ARQ H or L

		(T-FrameOffset) mod 4 =3		(T-FrameOffset) mod 4 ≠3	
MAC INDEX	128-ary Walsh Function	I-branch	Q-branch	I-branch	Q-branch
42	21	RPC	DRC LOCK	ARQ H or L	ARQ P
43	53	DRC LOCK	RPC	ARQ P	ARQ H or L
44	22	RPC	DRC LOCK	ARQ H or L	ARQ P
45	54	DRC LOCK	RPC	ARQ P	ARQ H or L
46	23	RPC	DRC LOCK	ARQ H or L	ARQ P
47	55	DRC LOCK	RPC	ARQ P	ARQ H or L
48	24	RPC	DRC LOCK	ARQ H or L	ARQ P
49	56	DRC LOCK	RPC	ARQ P	ARQ H or L
50	25	RPC	DRC LOCK	ARQ H or L	ARQ P
51	57	DRC LOCK	RPC	ARQ P	ARQ H or L
52	26	RPC	DRC LOCK	ARQ H or L	ARQ P
53	58	DRC LOCK	RPC	ARQ P	ARQ H or L
54	27	RPC	DRC LOCK	ARQ H or L	ARQ P
55	59	DRC LOCK	RPC	ARQ P	ARQ H or L
56	28	RPC	DRC LOCK	ARQ H or L	ARQ P
57	60	DRC LOCK	RPC	ARQ P	ARQ H or L
58	29	RPC	DRC LOCK	ARQ H or L	ARQ P
59	61	DRC LOCK	RPC	ARQ P	ARQ H or L
60	30	RPC	DRC LOCK	ARQ H or L	ARQ P
61	62	DRC LOCK	RPC	ARQ P	ARQ H or L
62	31	RPC	DRC LOCK	ARQ H or L	ARQ P
63	63	DRC LOCK	RPC	ARQ P	ARQ H or L
64	Not Used				
65	Not Used				
66	Not Used				
67	Not Used				
68	Not Used				
69	Not Used				
70	Not Used				
71	Not Used				
72	68	RPC	DRC LOCK	ARQ H or L	ARQ P
73	100	DRC LOCK	RPC	ARQ P	ARQ H or L
74	69	RPC	DRC LOCK	ARQ H or L	ARQ P
75	101	DRC LOCK	RPC	ARQ P	ARQ H or L
76	70	RPC	DRC LOCK	ARQ H or L	ARQ P
77	102	DRC LOCK	RPC	ARQ P	ARQ H or L
78	71	RPC	DRC LOCK	ARQ H or L	ARQ P
79	103	DRC LOCK	RPC	ARQ P	ARQ H or L
80	72	RPC	DRC LOCK	ARQ H or L	ARQ P
81	104	DRC LOCK	RPC	ARQ P	ARQ H or L
82	73	RPC	DRC LOCK	ARQ H or L	ARQ P
83	105	DRC LOCK	RPC	ARQ P	ARQ H or L
84	74	RPC	DRC LOCK	ARQ H or L	ARQ P

		(T-FrameOffset) mod 4 =3		(T-FrameOffset) mod 4 ≠3	
MAC INDEX	128-ary Walsh Function	I-branch	Q-branch	I-branch	Q-branch
85	106	DRC LOCK	RPC	ARQ P	ARQ H or L
86	75	RPC	DRC LOCK	ARQ H or L	ARQ P
87	107	DRC LOCK	RPC	ARQ P	ARQ H or L
88	76	RPC	DRC LOCK	ARQ H or L	ARQ P
89	108	DRC LOCK	RPC	ARQ P	ARQ H or L
90	77	RPC	DRC LOCK	ARQ H or L	ARQ P
91	109	DRC LOCK	RPC	ARQ P	ARQ H or L
92	78	RPC	DRC LOCK	ARQ H or L	ARQ P
93	110	DRC LOCK	RPC	ARQ P	ARQ H or L
94	79	RPC	DRC LOCK	ARQ H or L	ARQ P
95	111	DRC LOCK	RPC	ARQ P	ARQ H or L
96	80	RPC	DRC LOCK	ARQ H or L	ARQ P
97	112	DRC LOCK	RPC	ARQ P	ARQ H or L
98	81	RPC	DRC LOCK	ARQ H or L	ARQ P
99	113	DRC LOCK	RPC	ARQ P	ARQ H or L
100	82	RPC	DRC LOCK	ARQ H or L	ARQ P
101	114	DRC LOCK	RPC	ARQ P	ARQ H or L
102	83	RPC	DRC LOCK	ARQ H or L	ARQ P
103	115	DRC LOCK	RPC	ARQ P	ARQ H or L
104	84	RPC	DRC LOCK	ARQ H or L	ARQ P
105	116	DRC LOCK	RPC	ARQ P	ARQ H or L
106	85	RPC	DRC LOCK	ARQ H or L	ARQ P
107	117	DRC LOCK	RPC	ARQ P	ARQ H or L
108	86	RPC	DRC LOCK	ARQ H or L	ARQ P
109	118	DRC LOCK	RPC	ARQ P	ARQ H or L
110	87	RPC	DRC LOCK	ARQ H or L	ARQ P
111	119	DRC LOCK	RPC	ARQ P	ARQ H or L
112	88	RPC	DRC LOCK	ARQ H or L	ARQ P
113	120	DRC LOCK	RPC	ARQ P	ARQ H or L
114	89	RPC	DRC LOCK	ARQ H or L	ARQ P
115	121	DRC LOCK	RPC	ARQ P	ARQ H or L
116	90	RPC	DRC LOCK	ARQ H or L	ARQ P
117	122	DRC LOCK	RPC	ARQ P	ARQ H or L
118	91	RPC	DRC LOCK	ARQ H or L	ARQ P
119	123	DRC LOCK	RPC	ARQ P	ARQ H or L
120	92	RPC	DRC LOCK	ARQ H or L	ARQ P
121	124	DRC LOCK	RPC	ARQ P	ARQ H or L
122	93	RPC	DRC LOCK	ARQ H or L	ARQ P
123	125	DRC LOCK	RPC	ARQ P	ARQ H or L
124	94	RPC	DRC LOCK	ARQ H or L	ARQ P
125	126	DRC LOCK	RPC	ARQ P	ARQ H or L
126	95	RPC	DRC LOCK	ARQ H or L	ARQ P
127	127	DRC LOCK	RPC	ARQ P	ARQ H or L

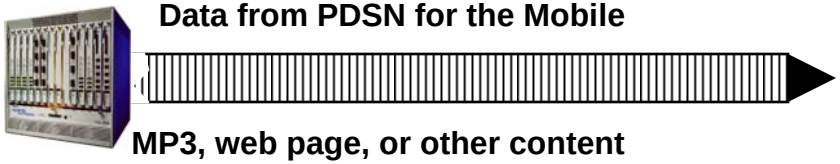
Forward Link Data Transmission During an Established Connection

Transmission of a Packet over EV-DO



A user has initiated a1xEV-DO data session on their AT, accessing a favorite website.
The requested page has just been received by the PDSN.
The PDSN and Radio Network Controller send a "Data Ready" message to let the AT know it has data waiting.

Transmission of a Packet over EV-DO





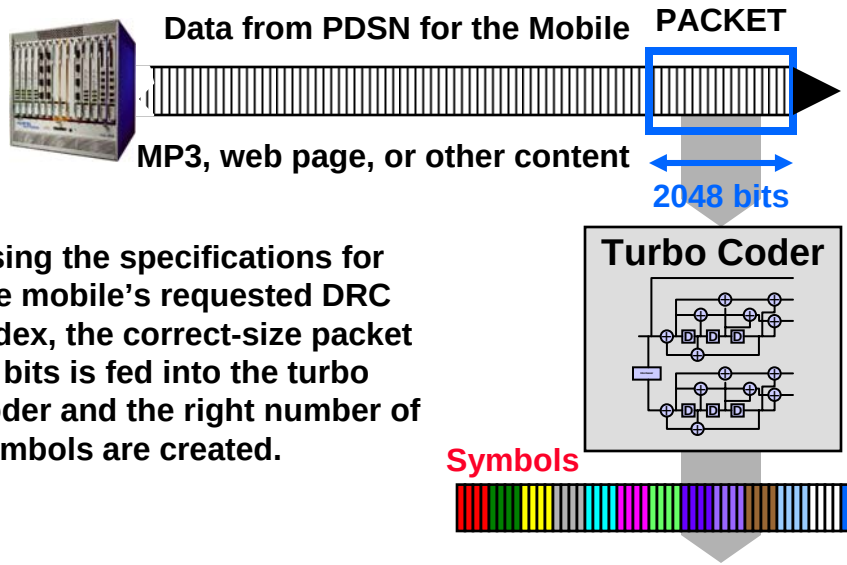
A user has initiated a1xEV-DO data session on their AT, accessing a favorite website.
The requested page has just been received by the PDSN.
The PDSN and Radio Network Controller send a "Data Ready" message to let the AT know it has data waiting.

The AT quickly determines which of its active sectors is the strongest. On the AT's DRC channel it asks that sector to send it a packet at speed "DRC Index 5".

The mobile's choice, DRC Index 5, determines everything:
The raw bit speed is 307.2 kb/s.
The packet will have 2048 bits.
There will be 4 subpackets (in slots 4 apart).
The first subpacket will begin with a 128 chip preamble.

DRC Index	Slots	Modu-lation	Preamble Chips	Payload Bits	Raw kb/s	C/I db
0x0	n/a	QPSK	n/a	0	null rate	n/a
0x1	16	QPSK	1024	1024	38.4	-11.5
0x2	8	QPSK	512	1024	76.8	-9.2
0x3	4	QPSK	256	1024	153.6	-6.5
0x4	2	QPSK	128	1024	307.2	-5
0x5	4	QPSK	128	2048	307.2	-3.5
0x6	1	QPSK	64	1024	614.4	-3.5
0x7	2	QPSK	64	2048	614.4	-0.5
0x8	2	QPSK	64	3072	921.6	+2.2
0x9	1	QPSK	64	2048	1,228.8	+3.9
0xa	2	16QAM	64	4096	1,228.8	+4.0
0xb	1	8PSK	64	3072	1,843.2	+8.0
0xc	1	16QAM	64	4096	2,457.6	+10.3
0xd	2	16QAM	64	5120	1,536.0	in Rev. A
0xe	1	16QAM	64	5120	3,072.0	in Rev. A

Transmission of a Packet over EV-DO

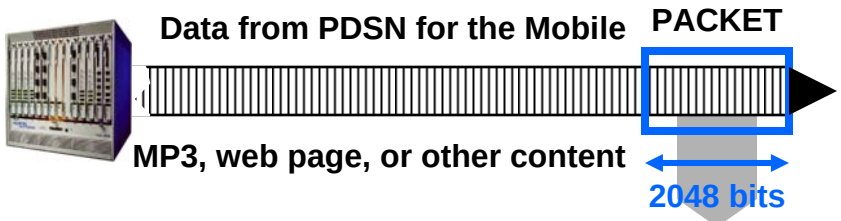




Using the specifications for the mobile's requested DRC index, the correct-size packet of bits is fed into the turbo coder and the right number of symbols are created.

DRC Index	Slots	Modu-lation	Preamble Chips	Payload Bits	Raw kb/s	C/I db
0x0	n/a	QPSK	n/a	0	null rate	n/a
0x1	16	QPSK	1024	1024	38.4	-11.5
0x2	8	QPSK	512	1024	76.8	-9.2
0x3	4	QPSK	256	1024	153.6	-6.5
0x4	2	QPSK	128	1024	307.2	-3.5
0x5	4	QPSK	128	2048	307.2	**-3.5**
0x6	1	QPSK	64	1024	614.4	-0.6
0x7	2	QPSK	64	2048	614.4	-0.5
0x8	2	QPSK	64	3072	921.6	+2.2
0x9	1	QPSK	64	2048	1,228.8	+3.9
0xa	2	16QAM	64	4096	1,228.8	+4.0
0xb	1	8PSK	64	3072	1,843.2	+8.0
0xc	1	16QAM	64	4096	2,457.6	+10.3
0xd	2	16QAM	64	5120	1,536.0	in Rev. A
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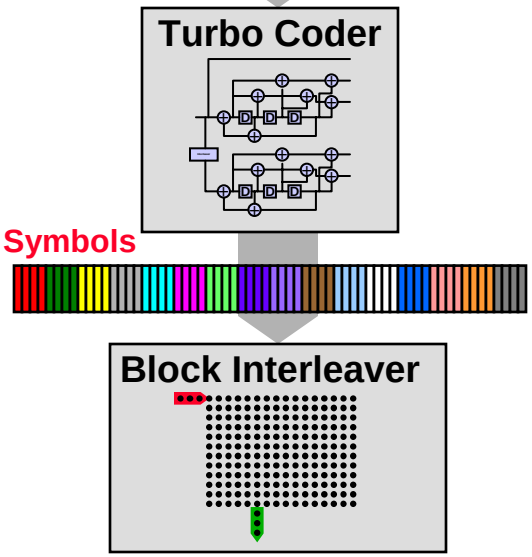
Transmission of a Packet over EV-DO





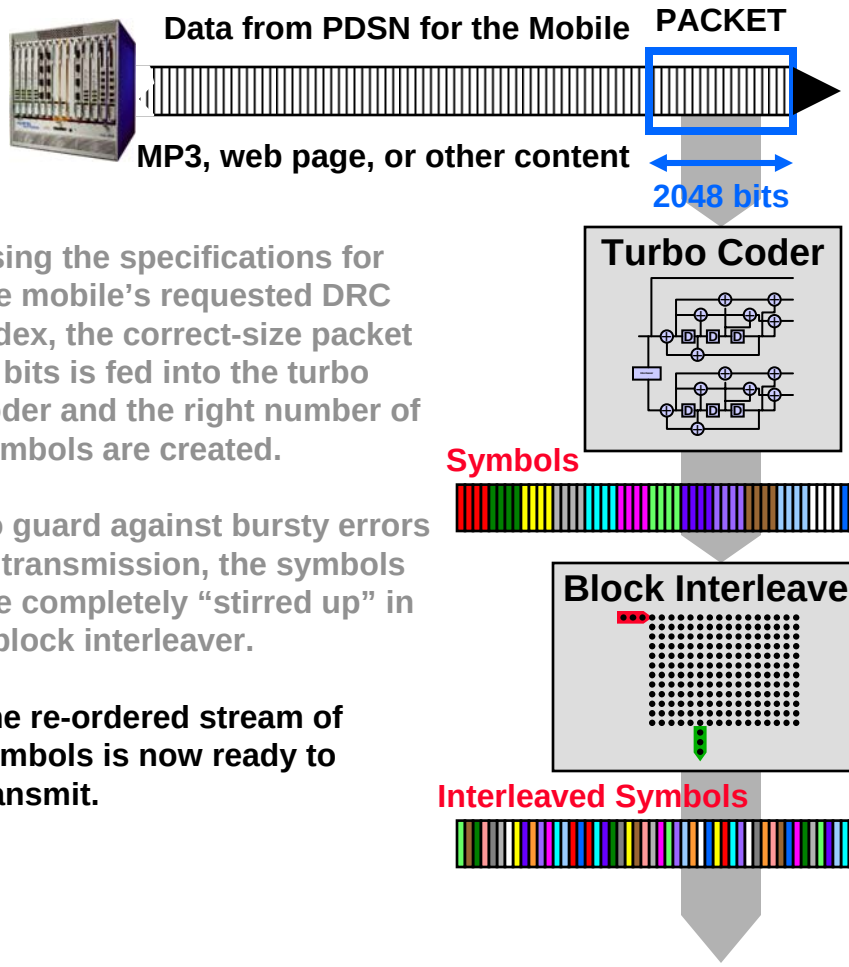
Using the specifications for the mobile's requested DRC index, the correct-size packet of bits is fed into the turbo coder and the right number of symbols are created.

To guard against bursty errors in transmission, the symbols are completely "stirred up" in a block interleaver.



DRC Index	Slots	Modu-lation	Preamble Chips	Payload Bits	Raw kb/s	C/I db
0x0	n/a	QPSK	n/a	0	null rate	n/a
0x1	16	QPSK	1024	1024	38.4	-11.5
0x2	8	QPSK	512	1024	76.8	-9.2
0x3	4	QPSK	256	1024	153.6	-6.5
0x4	2	QPSK	128	1024	307.2	-3.5
0x5	4	QPSK	128	2048	307.2	**-3.5**
0x6	1	QPSK	64	1024	614.4	-0.6
0x7	2	QPSK	64	2048	614.4	-0.5
0x8	2	QPSK	64	3072	921.6	+2.2
0x9	1	QPSK	64	2048	1,228.8	+3.9
0xa	2	16QAM	64	4096	1,228.8	+4.0
0xb	1	8PSK	64	3072	1,843.2	+8.0
0xc	1	16QAM	64	4096	2,457.6	+10.3
0xd	2	16QAM	64	5120	1,536.0	in Rev. A
0xe	1	16QAM	64	5120	3,072.0	in Rev. A

Transmission of a Packet over EV-DO





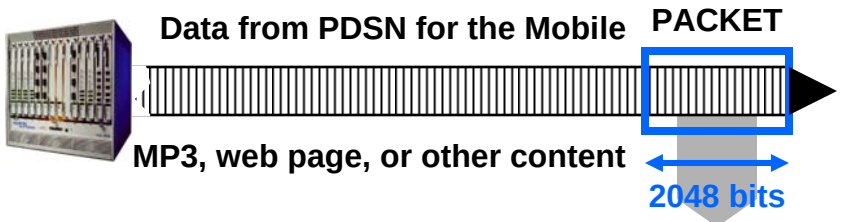
Using the specifications for the mobile's requested DRC index, the correct-size packet of bits is fed into the turbo coder and the right number of symbols are created.

To guard against bursty errors in transmission, the symbols are completely "stirred up" in a block interleaver.

The re-ordered stream of symbols is now ready to transmit.

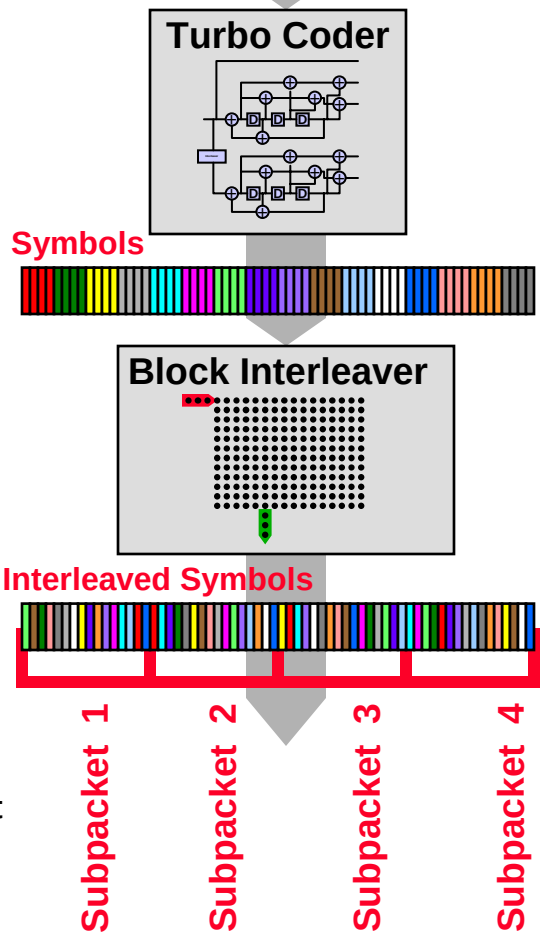
DRC Index	Slots	Modu-lation	Preamble Chips	Payload Bits	Raw kb/s	C/I db
0x0	n/a	QPSK	n/a	0	null rate	n/a
0x1	16	QPSK	1024	1024	38.4	-11.5
0x2	8	QPSK	512	1024	76.8	-9.2
0x3	4	QPSK	256	1024	153.6	-6.5
0x4	2	QPSK	128	1024	307.2	-3.5
0x5	4	QPSK	128	2048	307.2	**-3.5**
0x6	1	QPSK	64	1024	614.4	-0.6
0x7	2	QPSK	64	2048	614.4	-0.5
0x8	2	QPSK	64	3072	921.6	+2.2
0x9	1	QPSK	64	2048	1,228.8	+3.9
0xa	2	16QAM	64	4096	1,228.8	+4.0
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0xd	2	16QAM	64	5120	1,536.0	in Rev. A
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Transmission of a Packet over EV-DO



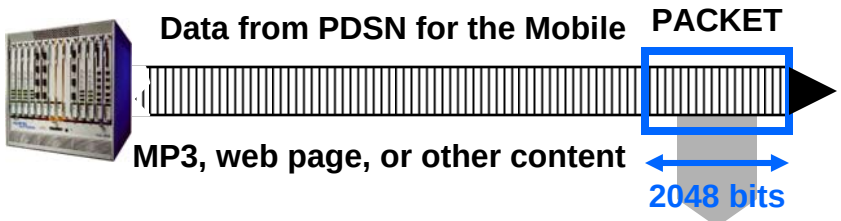


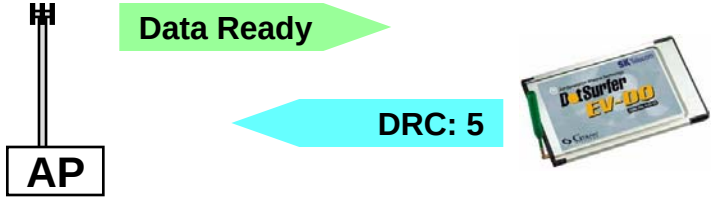
Using the specifications for the mobile's requested DRC index, the correct-size packet of bits is fed into the turbo coder and the right number of symbols are created.
To guard against bursty errors in transmission, the symbols are completely "stirred up" in a block interleaver.
The re-ordered stream of symbols is now ready to transmit. **The symbols are divided into the correct number of subpackets, which will occupy the same number of transmission slots, spaced four apart.**
It's up to the AP to decide when it will start transmitting the stream, taking into account any other pending subpackets for other users, and "proportional fairness".



DRC Index	Slots	Modu-lation	Preamble Chips	Payload Bits	Raw kb/s	C/I db
0x0	n/a	QPSK	n/a	0	null rate	n/a
0x1	16	QPSK	1024	1024	38.4	-11.5
0x2	8	QPSK	512	1024	76.8	-9.2
0x3	4	QPSK	256	1024	153.6	-6.5
0x4	2	QPSK	128	1024	307.2	-3.5
0x5	4	QPSK	128	2048	307.2	**-3.5**
0x6	1	QPSK	64	1024	614.4	-0.6
0x7	2	QPSK	64	2048	614.4	-0.5
0x8	2	QPSK	64	3072	921.6	+2.2
0x9	1	QPSK	64	2048	1,228.8	+3.9
0xa	2	16QAM	64	4096	1,228.8	+4.0
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Transmission of a Packet over EV-DO



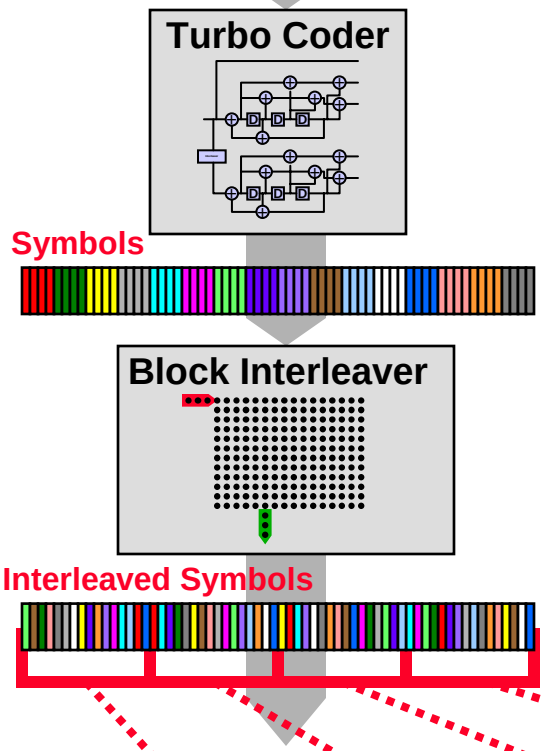


When the AP is ready, the first subpacket is actually transmitted in a slot.

The first subpacket begins with a preamble carrying the user's MAC index, so the user knows this is the start of its sequence of subpackets, and how many subpackets are in the sequence..

The user keeps collecting subpackets until either:

1) it has been able to reverse-turbo decode the packet contents early, or
2) the whole schedule of subpackets has been transmitted.



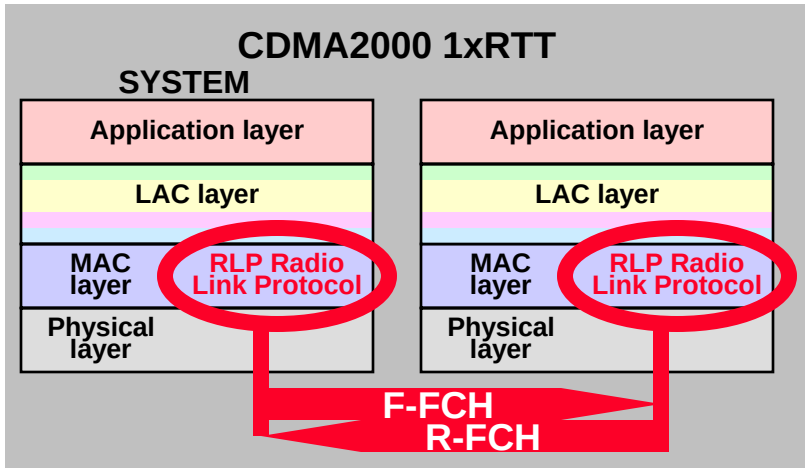
DRC Index	Slots	Modu-lation	Preamble Chips	Payload Bits	Raw kb/s	C/I db
0x0	n/a	QPSK	n/a	0	null rate	n/a
0x1	16	QPSK	1024	1024	38.4	-11.5
0x2	8	QPSK	512	1024	76.8	-9.2
0x3	4	QPSK	256	1024	153.6	-6.5
0x4	2	QPSK	128	1024	307.2	-3.5
0x5	4	QPSK	128	2048	307.2	**-3.5**
0x6	1	QPSK	64	1024	614.4	-0.6
0x7	2	QPSK	64	2048	614.4	-0.5
0x8	2	QPSK	64	3072	921.6	+2.2
0x9	1	QPSK	64	2048	1,228.8	+3.9
0xa	2	16QAM	64	4096	1,228.8	+4.0
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0xc	1	16QAM	64	4096	2,457.6	+10.3
0xd	2	16QAM	64	5120	1,536.0	in Rev. A
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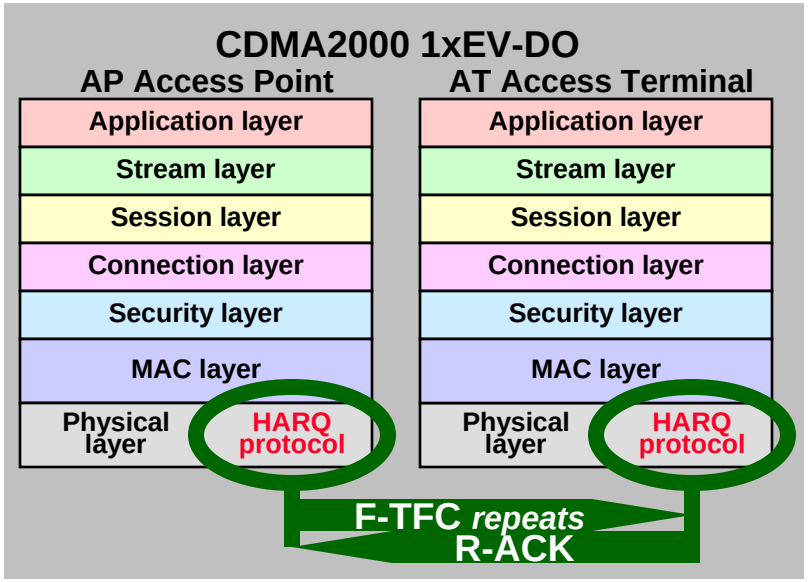


SLOTS

Hybrid ARQ:
Hybrid Repeat-Request Protocol

The Hybrid ARQ Process





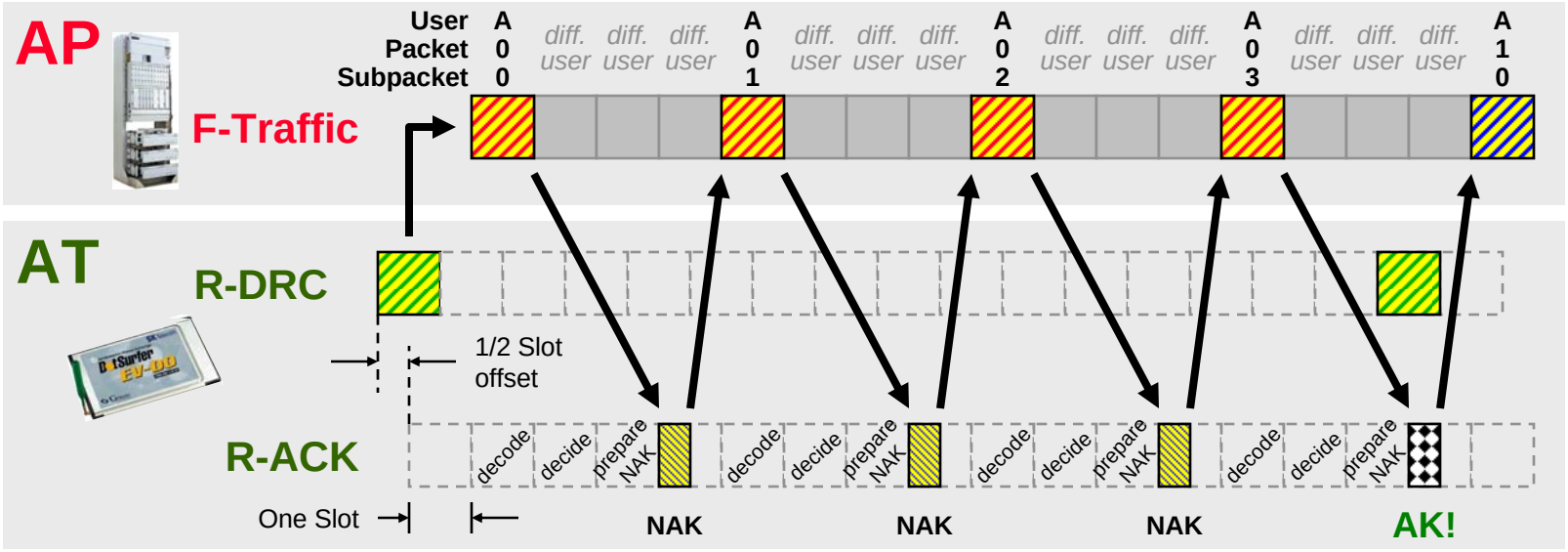
- In 1xRTT, retransmission protocols typically work at the link layer
  - Radio Link Protocol (RLP)
    - communicates using signaling packets
    - lost data packets aren't recognized and are discarded at the decoder
- This method is slow and wasteful!

- In 1xEV-DO, RLP functions are replicated at the physical layer
  - HARQ Hybrid Repeat Request Protocol
    - fast physical layer ACK bits
    - Chase Combining of multiple repeats
    - unneeded repeats pre-empted by positive ACK
- This method is fast and efficient!

The Hybrid ARQ Process

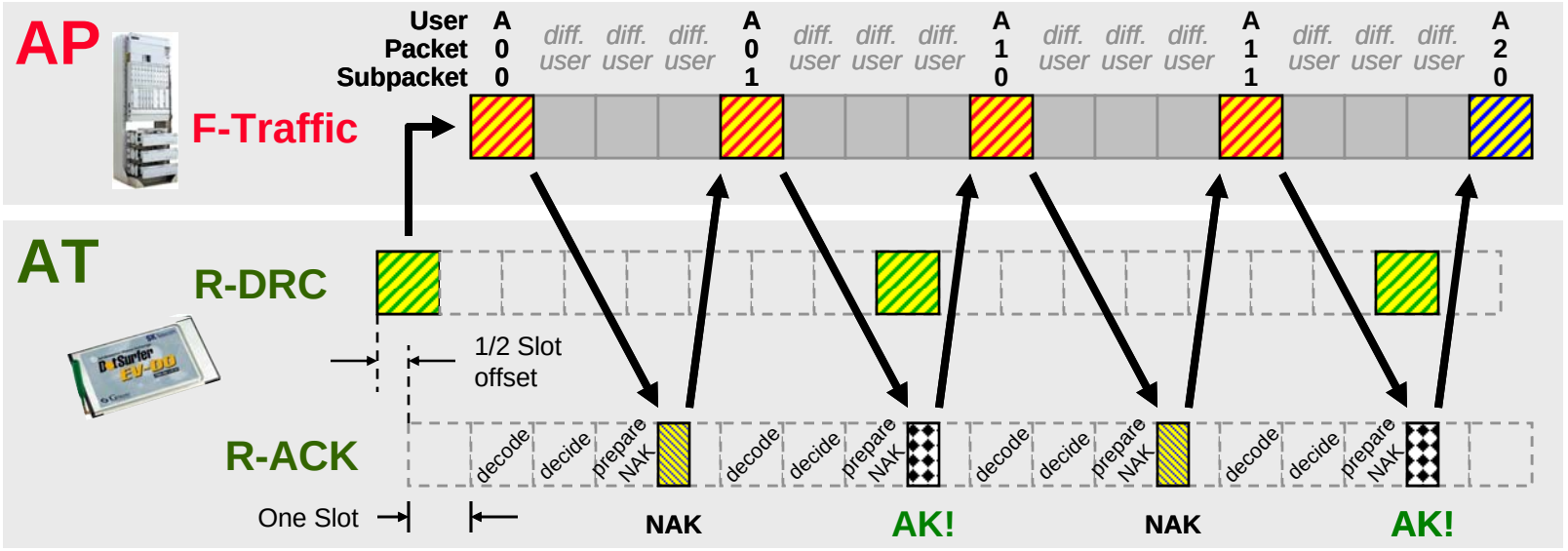
- Each physical layer data packet is encoded into subpackets
  - as long as the receiver does not send back an acknowledgment, the transmitter keeps sending more subpackets, up to the maximum of the current configuration
  - The identity of the subpackets is known by the receiver, so it can combine the subpackets for better decoding
- each additional subpacket in essence contributes additional signal power to aid in the detection of its parent packet
  - it's hard to predict the exact power necessary for successful decoding in systems without HARQ
    - the channel changes rapidly during transmission
    - various estimation errors (noise, bias, etc.)
    - exact needed SNR is stochastic, even on a static channel!
- In effect, HARQ sends progressively more energy until there is just enough and the packet is successfully decoded

Forward Link Multislot ARQ, Normal Termination



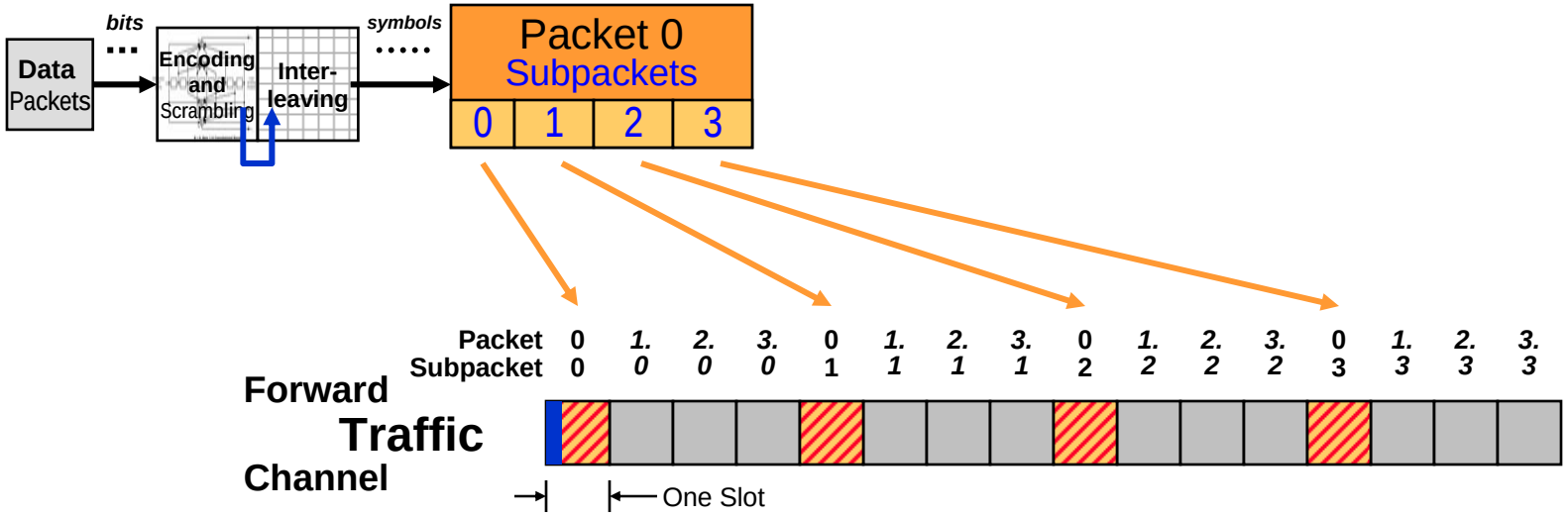
- AT selects sector, sends request for data
- AP starts sending next packet, one subpacket at a time
- After each subpacket, AT either NAKs or AKs on ACK channel
- In this example,
  - AP transmits all 4 scheduled subpackets of packet #0 before the AT is finally able to decode correctly and send AK
  - then the AP can begin packet #1, first subpacket

Forward Link Multislot ARQ, Early Termination



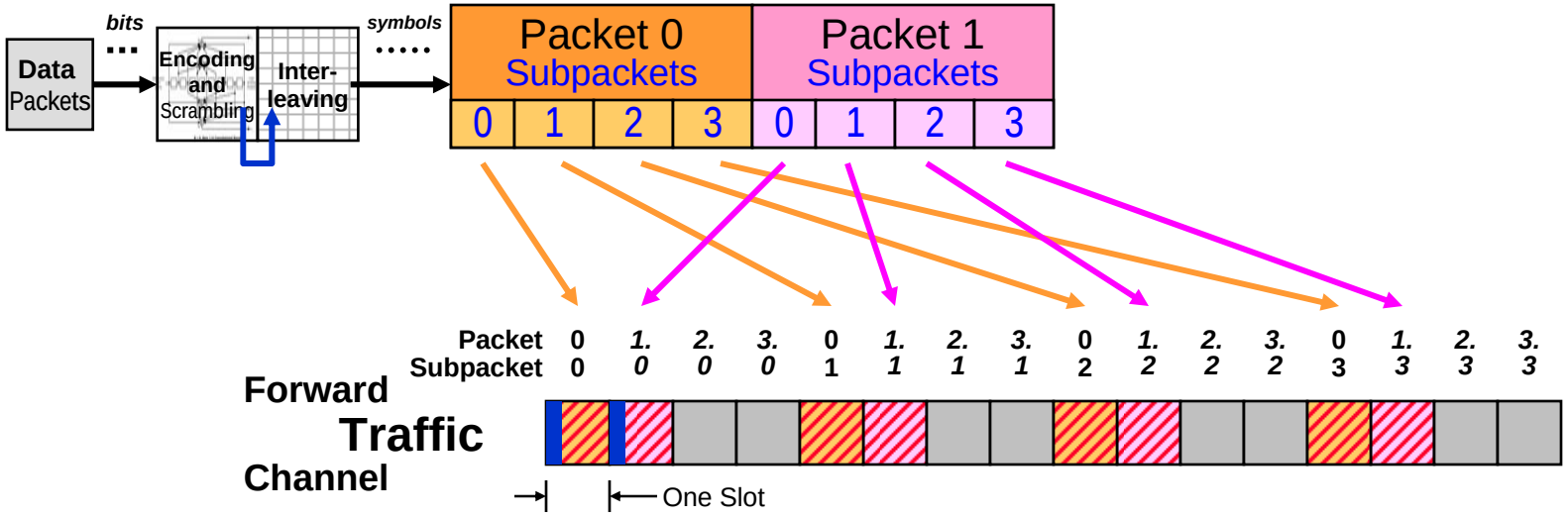
- AT selects sector, sends request for data
- AP starts sending next packet, one subpacket at a time
- After each subpacket, AT either NAKs or AKs on ACK channel
- In this example,
  - AT is able to successfully decode packet #0 after receiving only the first two subpackets
  - AT sends ACK. AP now continues with first subpacket of packet #1

Multiple ARQ Instances



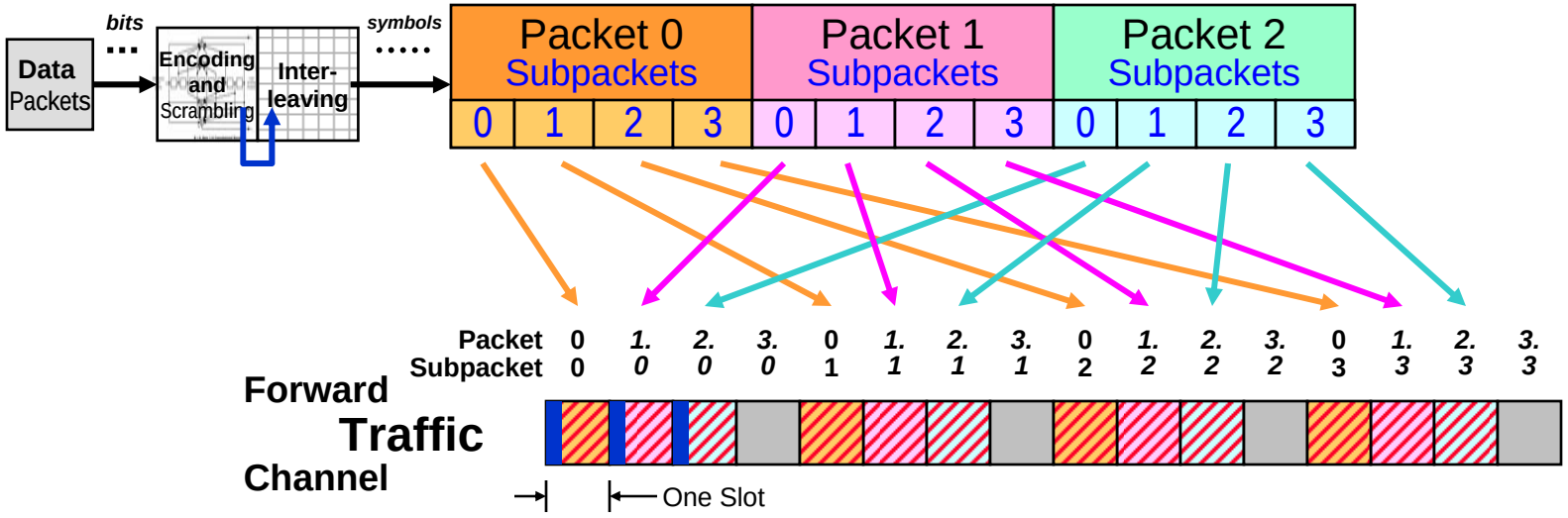
- Definition: Number of ARQ Instances
  - the maximum number of packets that may be in transit simultaneously
  - sometimes also called “the number of ARQ channels”
- This figure and the preceding page appear to show 4 ARQ instances
- Packets in the different ARQ instances
  - may be for the same user (the most common situation)
  - may be for different users (determined by QOS and scheduling)
- Destination mobile knows its packets by their preamble

Multiple ARQ Instances



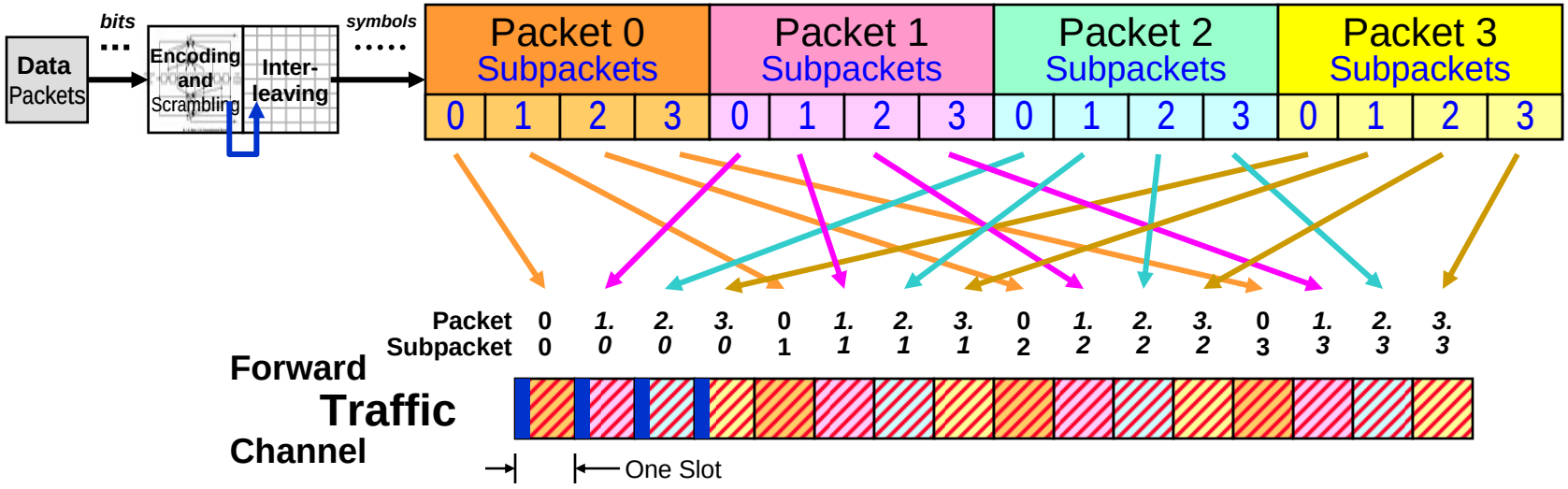
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Link Rates and Packet/Subpacket Formats

FORWARD LINK

DRC Index	Slots	Modu-lation	Preamble Chips	Payload Bits	Raw kb/s	C/I db
0x0	n/a	QPSK	n/a	0	null rate	n/a
0x1	16	QPSK	1024	1024	38.4	-11.5
0x2	8	QPSK	512	1024	76.8	-9.2
0x3	4	QPSK	256	1024	153.6	-6.5
0x4	2	QPSK	128	1024	307.2	-3.5
0x5	4	QPSK	128	2048	307.2	-3.5
0x6	1	QPSK	64	1024	614.4	-0.6
0x7	2	QPSK	64	2048	614.4	-0.5
0x8	2	QPSK	64	3072	921.6	+2.2
0x9	1	QPSK	64	2048	1,228.8	+3.9
0xa	2	16QAM	64	4096	1,228.8	+4.0
0xb	1	8PSK	64	3072	1,843.2	+8.0
0xc	1	16QAM	64	4096	2,457.6	+10.3
0xd	2	16QAM	64	5120	1,536.0	+8.3
0xe	1	16QAM	64	5120	3,072.0	+11.3

REVERSE LINK

Payload Bits	Modu-lation	Effective Rate kbps after:				Code Rate (repetition) after			
		4 slots	8 slots	12 slots	16 slots	4 slots	8 slots	12 slots	16 slots
128	B4	19.2	9.6	6.4	4.8	1/5	1/5	1/5	1/5
256	B4	38	19.2	12.8	9.6	1/5	1/5	1/5	1/5
512	B4	76	38.4	25.6	19.2	1/4	1/5	1/5	1/5
768	B4	115	57.6	38.4	28.8	3/8	1/5	1/5	1/5
1024	B4	153	76.8	51.2	38.4	1/2	1/4	1/5	1/5
1536	Q4	230	115	76.8	57.6	3/8	1/5	1/5	1/5
2048	Q4	307	153	102.4	76.8	1/2	1/4	1/5	1/5
3072	Q2	461	230	153.6	115.2	3/8	1/5	1/5	1/5
4096	Q2	614	307	204.8	153.6	1/2	1/4	1/5	1/5
6144	Q4Q2	921	461	307	230.4	1/2	1/4	1/5	1/5
8192	Q4Q2	1228	614	409	307.2	2/3	1/3	2/9	1/5
12288	E4E2	1843	921	614	460.8	2/3	1/3	1/3	1/3

- The 1xEV-DO Rev. A reverse link has seven available modes offering higher speeds than available in Rev. 0
  - Modulation formats are hybrids defined in the standard
- The 1xEV-DO Rev. A forward has two available modes offering higher speeds than available in Rev. 0.

Basics of EV-DO Operation

Sessions and Connections

- A Session is a state shared by an Access Terminal and the network.
  - Negotiated protocols and configurations are remembered by both sides as the basis for their communication.
  - An access terminal must already have a session underway in order to communicate with the network
    - The only exception is the setup communications made possible on the access channel for the purpose of initially setting up a session
- A Connection is a particular state of the air link in which the access terminal is assigned a forward traffic channel, reverse traffic channel, and associated MAC channels.
- During one ongoing session, the terminal and network may open and close their connection many times.

EV-DO Terminal Identifiers

- In CDMA, mobiles are identified by the familiar IMSI and ESN. These are permanent quantities stored in the mobile.
- EV-DO terminals have hardware addresses which can be queried by the system, but connections are coordinated by the use of Access Terminal Identifiers (ATIs)
- There are four types of ATIs:
  - ’00’ BATI Broadcast Access Terminal Identifier
  - ’01’ MATI Multicast Access Terminal Identifier
  - ’02’ UATI Unicast Access Terminal Identifier
    - Requested by the mobile at session setup and assigned by the system. Updated when crossing various boundaries
  - ’03’ RATI Random Access Terminal Identifier
    - Used by the mobile during initial access
- From the view of the SLP protocol, ATIs simply define connection endpoints.

Channels and Layer-3 Messages in 1xEV-DO Call Processing

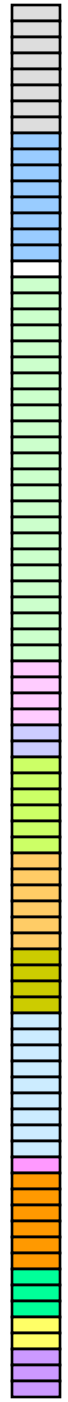
Dissecting a Layer-3 Message

- Most EV-DO basic packet flow and bursts are managed by layer-2 bursts
- Layer-3 messages are used to set up and control sessions, connections, location updating, and other higher-level tasks
- Messages include many fields of binary data
- The first byte of each message identifies message type: this allows the recipient to parse the contents
- To ensure no messages are missed, all 1xEV-DO messages bear serial numbers and important messages contain a bit requesting acknowledgment
- Messages not promptly acknowledged are retransmitted several times. If not acknowledged, the sender may release the call

EXAMPLE:
TRAFFIC CHANNEL ASSIGNMENT MESSAGE

Field	Length (in bits)
MESSAGE ID	*8*
MESSAGE SEQUENCE	*8*
CHANNEL INCLUDED	*1*
CHANNEL	*0 or 24*
FRAME OFFSET	*4*
DRC LENGTH	*2*
DRC CHANNEL GAIN	*6*
ACK CHANNEL GAIN	*6*
NUM PILOTS	*4*
NUMPILOTS occurrences of this block:	
PILOT PN	*9*
SOFTER HANDOFF	*1*
MAC INDEX	*6*
DRC COVER	*3*
RAB LENGTH	*2*
RAB OFFSET	*3*

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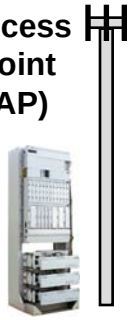
Message Vocabulary: Acquisition & Idle States

Pilot Channel

No Messages

Access Network (AN)

Access Point (AP)



Access Terminal (AN)



Pilot Channel

No Messages

Control Channel

- ACAck
- Access Parameters
- Broadcast Reverse Rate Limit
- Connection Deny
- Data Ready
- Hardware ID Request
- Keep Alive Request
- Keep Alive Response
- Location Request
- Location Assignment
- Redirect
- Session Close
- **Sync**
- **SectorParameters**
- **Page**
- **Quick Config**
- Xoff Response
- Xon Response
- Traffic Channel Assignment
- UATI Assignment

Access Channel

- Connection Request
- Data Ready ACK
- Hardware ID Response
- Keep Alive Request
- Keep Alive Response
- Location Complete
- Location Notification
- Route Update
- Session Close
- UATI Request
- UATI Complete
- Xoff Request
- Xon Request

Message Vocabulary: Connected State

Forward Traffic Channel

Access Point (AP)



- ANKey Complete
- Attribute Override
- Configuration Complete
- Configuration Request
- Configuration Response
- Configuration Start
- Connection Close
- Data Ready
- Hardware ID Request
- Keep Alive Request
- Keep Alive Response
- Key Request
- Location Assignment
- Location Request
- Nak
- Neighbor List
- Redirect
- Reset
- Reset ACK
- Reset Report
- RTC ACK
- Session Close
- Traffic Channel Assignment
- UATI Assignment
- Unicast Reverse Rate Limit
- Xoff Response
- Xon Response

Reverse Traffic Channel

Access Terminal (AN)



- ATKey Complete
- Attribute Override Response
- Configuration Complete
- Configuration Request
- Configuration Response
- Connection Close
- Data Ready ACK
- Fixed Mode Enable
- Fixed Mode X Off
- Hardware ID Response
- Keep Alive Request
- Keep Alive Response
- Key Response
- Location Complete
- Location Notification
- Nak
- Redirect
- Reset
- Reset ACK
- Route Update
- Session Close
- Traffic Channel Complete
- UATI Complete
- Xoff Request
- Xon Request

Message			Sent on Channels								
Name	ID	Inst.	CC	Syn	SS	AC	FTC	RTC	SLP	Addressing	Pri.
ACAck	0x00	1	CC						Best Effort	Unicast	10
Access Parameters	0x01	1	CC						Best Effort	Broadcast	30
ANKey Complete	0x02	1					FTC		Reliable	Unicast	40
ATKey Complete	0x03	1						RTC	Reliable	Unicast	40
Attribute Override	0x05	1					FTC		Best Effort	Unicast	40
Attribute Override Response	0x06	1						RTC	Best Effort	Unicast	40
Broadcast Reverse Rate Limit	0x01	1	CC						Best Effort	Broadcast	40
Configuration Complete	0x00	1					FTC	RTC	Reliable	Unicast	40
Configuration Request	0x50	24					FTC	RTC	Reliable	Unicast	40
Configuration Response	0x51	24					FTC	RTC	Reliable	Unicast	40
Configuration Start	0x01	1					FTC		Best Effort	Unicast	40
ConnectionClose	0x00	1					FTC	RTC	Best Effort	Unicast	40
ConnectionDeny	0x02	1	CC						Best Effort	Unicast	40
ConnectionRequest	0x01	1				AC			Best Effort	Unicast	40
DataReady	0x0b	1	CC				FTC		Best Effort	Unicast	40
DataReadyACK	0x0c	1				AC		RTC	Best Effort	Unicast	40
Fixed Mode Enable	0x00	1						RTC	Best Effort	Unicast	40
Fixed Mode X off	0x01	1						RTC	Best Effort	Unicast	40
Hardware ID Request	0x03	2	CC				FTC		Best Effort	Unicast	40
Hardware ID Response	0x04	1				AC		RTC	Rel, Best Eff	Unicast	40
Keep Alive Request	0x02	1	CC			AC	FTC	RTC	Best Effort	Unicast	40
Keep Alive Response	0x03	1	CC			AC	FTC	RTC	Best Effort	Unicast	40
Key Request	0x00	1					FTC		Reliable	Unicast	40
Key Response	0x01	1						RTC	Reliable	Unicast	40
Location Assignment	0x05	1	CC				FTC		Best Effort	Unicast	40
Location Complete	0x06	1				AC		RTC	Rel, Best Eff	Unicast	40
Location Request	0x03	1	CC				FTC		Best Effort	Unicast	40
Location Notification	0x04	1				AC		RTC	Rel, Best Eff	Unicast	40
Nak	0x00	1					FTC	RTC	Best Effort	Unicast	50
Neighbor List	0x00	1					FTC		Reliable	Unicast	40
Page	0x00	1			SS				Best Effort	Unicast	20
Quick Config	0x00	1			SS				Best Effort	Broadcast	10
Redirect	0x00	1	CC				FTC	RTC	Best Effort	Bcst, Unicst	40
Reset	0x00	2					FTC	RTC	Best Effort	Unicast	40
Reset ACK	0x01	2					FTC	RTC	Best Effort	Unicast	40
Reset Report	0x03	1					FTC		Reliable	Unicast	40
Route Update	0x00	1				AC		RTC	Rel, Best Eff	Unicast	20
RTCAck	0x00	1					FTC		Reliable	Unicast	10
SectorParameters	0x01	1	CC	SYN	SS				Best Effort	Broadcast	30
Session Close	0x01	1	CC			AC	FTC	RTC	Best Effort	Unicast	40
Sync	'00'	1	CC	SYN	SS				Best Effort	Broadcast	30
Traffic Channel Assignment	0x01	1	CC				FTC		Rel, Best Eff	Unicast	20
Traffic Channel Complete	0x02	1						RTC	Reliable	Unicast	40
UATI Assignment	0x01	1	CC				FTC		Best Effort	Unicast	10
UATI Complete	0x02	1				AC		RTC	Rel, Best Eff	Unicast	10
UATI Request	0x00	1				AC			Best Effort	Unicast	10
Unicast Reverse Rate Limit	0x02	1					FTC		Reliable	Unicast	40
Xoff Request	0x09	1				AC		RTC	Best Effort	Unicast	40
Xoff Response	0x0a	1	CC				FTC		Best Effort	Unicast	40
Xon Request	0x07	1				AC		RTC	Best Effort	Unicast	40
Xon Response	0x08	1	CC				FTC		Best Effort	Unicast	40

All the Messages of 1xEV-DO Rev. 0

- In 1xEV-DO, most call processing events are driven by messages
- The MAC channels in both directions are used to carry messages or specific Walsh Masks to convey commands and selection options
- Messages have priority and delivery protocols
- Each message has a channel or channels on which it may be sent
- The structure of all the 1xEV-DO messages is defined in IS-856

Name	ID	CC	SYN	SS	AC	FTC	RTC	SLP	Addressing	Priority
Access Parameters	0x01	CC						Best	Broadcast	30
ANKeyComplete	0x02					FTC		REL	Unicast	40
Application Data	N/A	CC			AC	FTC	RTC	Best	Unicast	=data
ATKeyComplete	0x03						RTC	REL	Unicast	40
Attribute Override	0x05					FTC		Best	Unicast	40
Attribute Override Response	0x06						RTC	Best	Unicast	40
Attribute Update Accept	0x53					FTC	RTC	REL	Unicast	40
Attribute Update Reject	0x54					FTC		REL	Unicast	40
Attribute Update Request	0x52					FTC	RTC	REL	Unicast	40
Broadcast Reverse Rate Limit	0x01	CC						Best	Unicast	40
Configuration Complete	0x00					FTC	RTC	REL	Unicast	40
Configuration Request	0x50					FTC	RTC	REL	Unicast	40
Configuration Response	0x51					FTC	RTC	REL	Unicast	40
Configuration Start	0x01					FTC		Best	Unicast	40
Connection Close	0x00					FTC	RTC	Best	Unicast	40
Connection Deny	0x02	CC						Best	Unicast	40
Connection Failure Report	0x02						RTC	Best	Unicast	40
Connection Failure Report ACK	0x02					FTC		Best	Unicast	40
Connection Request	0x01				AC			Best	Unicast	40
Data Over Signaling	0x14	CC			AC	FTC		Best	Unicast	20-50
Data Over Signaling ACK	0x15	CC			AC	FTC	RTC	Best	Unicast	40
Data Ready	0x0b	CC				FTC		Best	Unicast	40
Data Ready ACK	0x0c				AC		RTC	Best	Unicast	40
Delete Personality	0x07	CC				FTC		REL,Best	Unicast	40
Fixed Mode Enable	0x00						RTC	Best	Unicast	40
Fixed Mode Xoff	0x01						RTC	Best	Unicast	40
Fwd Reservation Ack	0x24				AC		RTC	Best	Unicast	40
Fwd Reservation Off	0x22	CC				FTC		Best	Unicast	40
Fwd Reservation On	0x23	CC				FTC		Best	Unicast	40
Grant	0x03	CC				FTC		Best	Unicast	50
Hardware ID Request	0x03	CC				FTC		Best	Unicast	40
Hardware ID Response	0x04				AC		RTC	REL, Best	Unicast	40
Keep Alive Request	0x02	CC			AC	FTC	RTC	Best	Unicast	40
Keep Alive Response	0x03	CC			AC	FTC	RTC	Best	Unicast	40
Key Request	0x00					FTC		REL	Unicast	40
Key Response	0x01						RTC	REL	Unicast	40
Location Assignment	0x05	CC				FTC		Best	Unicast	40
Location Complete	0x06				AC		RTC	REL, Best	Unicast	40
Location Notification	0x04				AC		RTC	REL, Best	Unicast	40
Location Request	0x03	CC				FTC		Best	Unicast	40
Lock Configuration	0x03					FTC		Best	Unicast	40
Lock Configuration ACK	0x04						RTC	Best	Unicast	40

Rev. A Layer-3 Messages Part 1

Name	ID	CC	SYN	SS	AC	FTC	RTC	SLP	Addressing	Priority
Nak	0x02					FTC	RTC	Best	Unicast	50
Neighbor List	0x04					FTC		Best	Unicast	40
Page	0x00	CC	SYN					Bestl	Unicast	20
Quick Config	0x00	CC	SYN					Best	Broadcast	10
Redirect	0x00	CC				FTC		Best	Unicast,Broadcast	40
Request	0x01						RTC	Best	Unicast	50
Reservation Accept	0x18	CC			AC	FTC	RTC	Best	Unicast	40
Reservation Off Request	0x17				AC		RTC	Best	Unicast	40
Reservation On Request	0x16				AC		RTC	Best	Unicast	40
Reservation Reject	0x19	CC				FTC		Best	Unicast	40
Reset	0x00					FTC		Best	Unicast	40
Reset ACK	0x01						RTC	Best	Unicast	40
Reset Report	0x03					FTC		Best	Unicast	40
Reset RX Complete	0x0f					FTC	RTC	REL	Unicast	50
Reset RX Indication	0x01					FTC	RTC	REL	Unicast	50
Reset TX Complete	0x0e					FTC	RTC	REL	Unicast	50
Reset TX Indication	0x00					FTC	RTC	REL	Unicast	50
Reset TX Indication ACK	0x0d					FTC	RTC	REL	Unicast	50
Rev Reservation Off	0x1b	CC				FTC		Best	Unicast	40
Rev Reservation On	0x1a	CC				FTC		Best	Unicast	40
Route Update	0x00				AC		RTC	REL, Best	Unicast	20
Route Update Request	0x07	CC				FTC		Best	Unicast	40
RTC Ack	0x00					FTC		Best	Unicast	10
Sector Parameters	0x01	CC	SYN					Best	Broadcast	30
Session Close	0x01	CC			AC	FTC	RTC	Best	Unicast	40
Soft Configuration Complete	0x02					FTC		REL	Unicast	40
Storage BLOB Assignment	0x12	CC				FTC		Best	Unicast	40
Storage BLOB Complete	0x13				AC		RTC	Best	Unicast	40
Storage BLOB Notification	0x11	CC				FTC		Best	Unicast	40
Storage BLOB Request	0x10	CC				FTC		Best	Unicast	40
Sync	00	CC	SYN					Best	Broadcast	30
Traffic Channel Assignment	0x01	CC				FTC		REL, Best	Unicast	20
Traffic Channel Complete	0x02						RTC	Best	Unicast	40
UATI Assignment	0x01	CC				FTC		Best	Unicast	10
UATI Complete	0x02				AC		RTC	REL, Best	Unicast	10
UATI Request	0x00				AC		RTC	Best	Unicast	10
Unicast Reverse Rate Limit	0x02					FTC		Best	Unicast	40
Unlock Configuration	0x05					FTC		Best	Unicast	40
Unlock Configuration ACK	0x06						RTC	Best	Unicast	40
Xoff Request	0x09				AC		RTC	Best	Unicast	40
Xoff Response	0x0a	CC				FTC		Best	Unicast	40
Xon Request	0x07				AC		RTC	Best	Unicast	40
Xon Response	0x08	CC				FTC		Best	Unicast	40

Rev. A Layer-3 Messages Part 2

Protocol Type			Protocol Subtype		Page
Name	ID	Len	Name	ID	
Physical Layer	0x00	7	Default Physical Layer	0x0000	12-1
		7	Subtype 1 Physical Layer	0x0001	12-1
		7	Subtype 2 Physical Layer	0x0002	13-1
Control Channel MAC	0x01	7	Default Control Channel MAC	0x0000	10-4
		7	Enhanced Control Channel MAC	0x0001	10-16
Access Channel MAC	0x02	7	Default Access Channel MAC	0x0000	10-16
		7	Enhanced Access Channel MAC	0x0001	10-50
Forward Traffic Channel MAC	0x03	7	Default Forward Traffic Channel MAC	0x0000	10-79
		7	Enhanced Forward Traffic Channel MAC	0x0001	10-96
Reverse Traffic Channel MAC	0x04	7	Default Reverse Traffic Channel MAC	0x0000	10-131
		7	Subtype 1 Reverse Traffic Channel MAC	0x0001	10-149
		7	Subtype 2 Reverse Traffic Channel MAC	0x0002	10-169
		7	Subtype 3 Reverse Traffic Channel MAC	0x0003	10-223
Key Exchange	0x05	7	Default Key Exchange	0x0000	9-12
		7	DH Key Exchange	0x0001	9-16
Authentication	0x06	7	Default Authentication	0x0000	9-36
		7	SHA-1 Authentication	0x0001	9-40
Encryption	0x07	7	Default Encryption	0x0000	9-47
Security	0x08	7	Default Security	0x0000	9-3
		7	Generic Security	0x0001	9-7
Packet Consolidation	0x09	7	Default Packet Consolidation	0x0000	8-138
Air-Link Management	0x0a	7	Default Air-Link Management	0x0000	8-5
Initialization State	0x0b	7	Default Initialization State	0x0000	8-21
Idle State	0x0c	7	Default Idle State	0x0000	8-29
		7	Enhanced Idle State	0x0001	8-45
Connected State	0x0d	7	Default Connected State	0x0000	8-68
Route Update	0x0e	7	Default Route Update	0x0000	8-77
Overhead Messages	0x0f	7	Overhead Messages	0x0000	8-148
Session Management	0x10	7	Default Session Management	0x0000	7-3
Address Management	0x11	7	Default Address Management	0x0000	7-17
Session Configuration	0x12	7	Default Session Configuration	0x0000	7-41
Multimode Capability Discovery	0x1b	7	Generic Multimedia Capability Discovery	0x0001	7-79
Stream	0x13	7	Default Stream	0x0000	6-3
Virtual Stream	0x19	7	Generic Virtual Stream	0x0001	6-9
Stream 0 Application	0x14	7	Default Signaling Application	0x0000	2-1
Stream 1 Application	0x15	7	Default Packet Application bound to the radio network	0x0001	3-1
		7	Default Packet Application bound to the service network	0x0002	3-1
		7	Multi-flow Packet Application bound to the radio networik	0x0004	4-1
		7	Multi-flow Packet Application bound to the service network	0x0005	4-1
Stream 2 Application	0x16	7	Default Packet Application bound to the radio network	0x0001	3-1
		7	Default Packet Application bound to the service network	0x0001	3-1
		7	Multi-flow Packet Application bound to the radio networik	0x0004	4-1
		7	Mujlti-flow Packet Application bound to the service network	0x0005	4-1
Stream 3 Application	0x17	7	Default Packet Application bound to the radio network	0x0001	3-1
		7	Default Packet Application bound to the service network	0x0002	3-1
		7	Mujlti-flow Packet Application bound to the radio network	0x0004	4-1
		7	Multi-flow Packet Appllication bound to the service network	0x0005	4-1

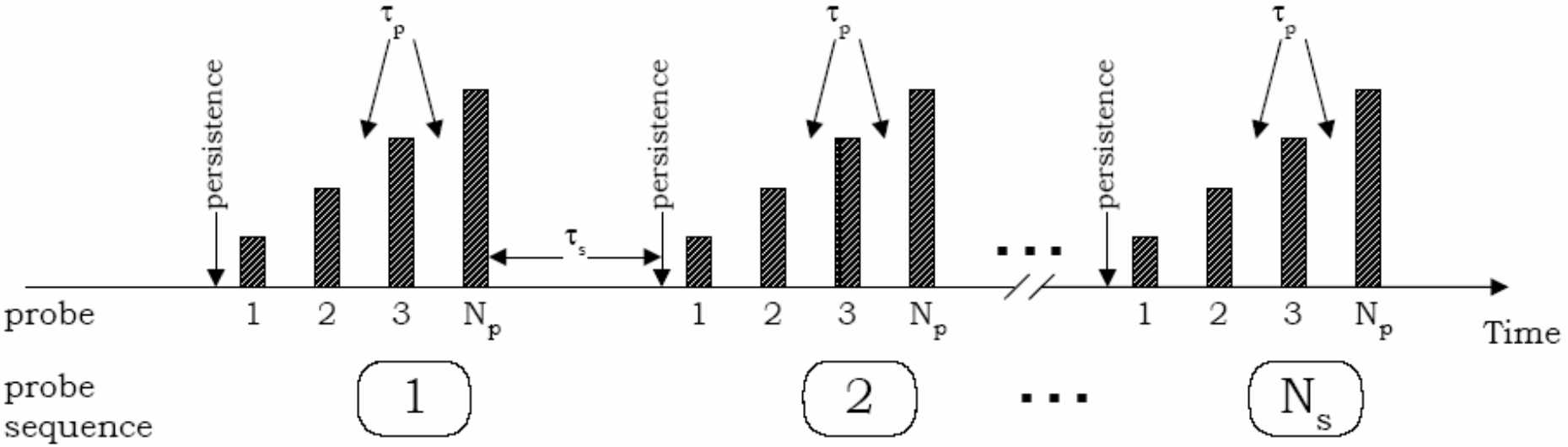
EV-DO Rev. A Protocols and Subtypes

Access Procedures

Access Channel Transmission

- The access channel is an uncoordinated, public channel where mobiles compete for the sector's attention despite risks of uncertain signal-to-noise ratio and even collision with transmissions of other users
- This situation is much like the access channel in IS-95 and CDMA2000, although transmissions are shorter
- A transmission by a mobile is called a "probe", first sent at
  - A power level calculated by the mobile from its receive power
  - A time delayed by a randomly computed number of slots
- If a mobile does not hear an acknowledgment within a prescribed time, it knows the system did not hear its probe.
- A second probe is sent at an incrementally higher power, and only after waiting a randomly computed number of slots
- If unsuccessful, probing continues for as many probes and as many sequences of additional probes as parameters allow

Access Channel MAC Protocol



- Probes allowed to start at intervals of AccessCycleDuration
- PreambleLength frames of pilot only on I channel, followed by
- CapsuleLengthMax frames of data on Q channel
- Probes shall avoid falling on ReverseLinkSilence Duration period, which occurs starting on ReverseLinkSilenceInterval times.
  - Typical values RLSD, RLSI currently 0 on most systems
- ATI used is

Access Channel and Reverse Traffic Channel Long Code Masks

ACCESS CHANNEL LONG CODE MASK

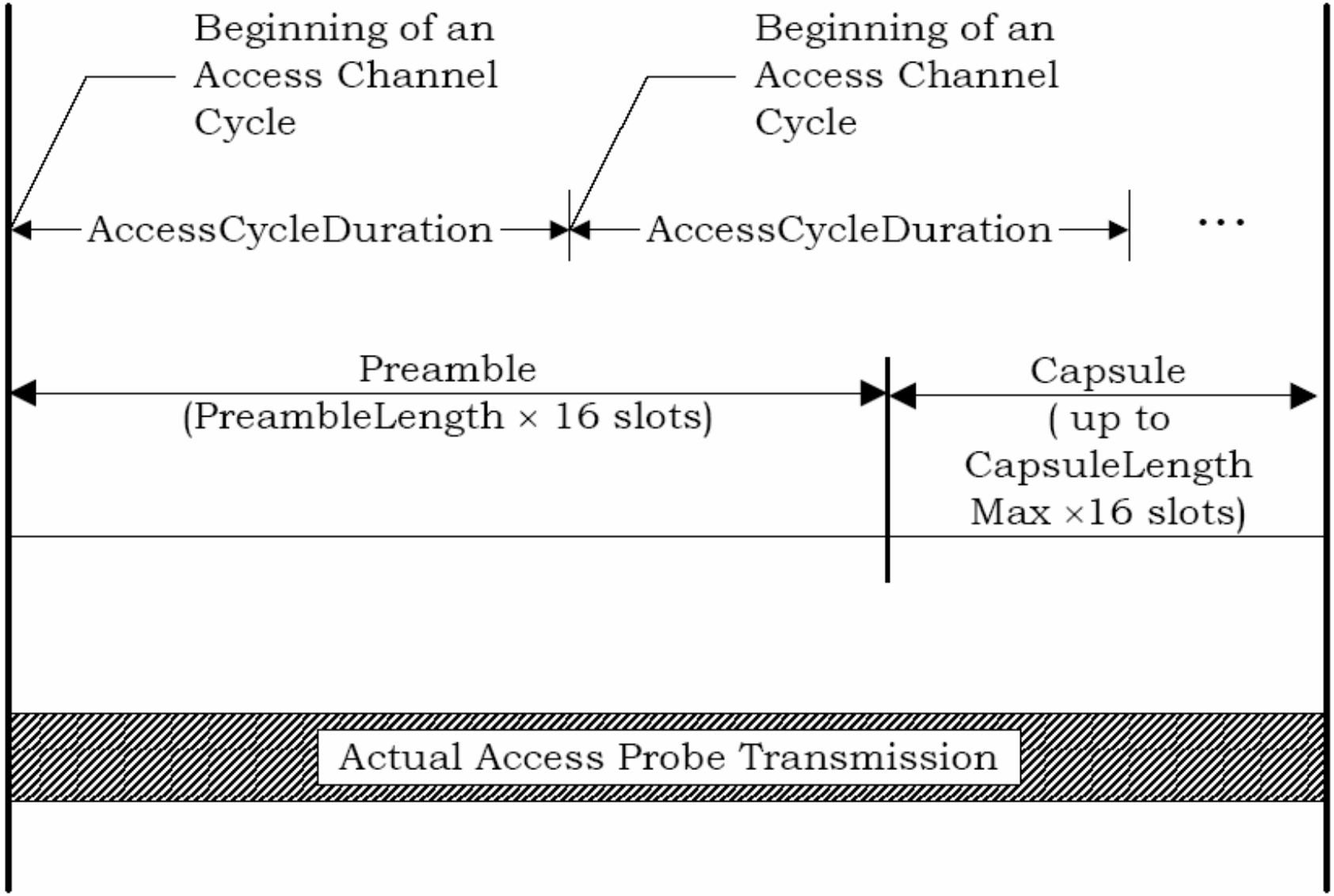
BIT	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MI_{ACMAC}	1	1	Access Cycle Number								Permuted (Color Code | Sector ID)																															

REVERSE TRAFFIC CHANNEL LONG CODE MASK

BIT	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MI_{RTCMAC}	1	1	1	1	1	1	1	1	1	1	Permuted (ATI_{LCM})																															

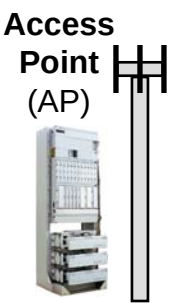
- A sector's access channel is public. Its long code mask includes the sector ID and color code, as well as the Access Cycle Number.
  - This ensures uniqueness so that the sector hears only mobiles intending to transmit to it, and not mobiles on other sectors
- During traffic channel operation, a mobile uses a long code mask unique to it
  - long code offset is determined by the mobile's permuted ATI

Structure of an Access Probe



An EV-DO Connection

EV-DO Connection



TRAFFIC
CONTROL
MAC
PILOT

CONNECTION ROUTE UPDATE
CONNECTION REQUEST
MAC ACK
TRAFFIC CHANNEL ASSIGNMENT
MAC RTC ACK
TRAFFIC CHANNEL COMPLETE
XON REQUEST
NULL MESSAGE
NEIGHBOR LIST
XON RESPONSE
ROUTE UPDATE

TRANSITION TO DORMANT

NULL MESSAGE
TRAFFIC CHANNEL ASSIGNMENT
TRAFFIC CHANNEL COMPLETE
NEIGHBOR LIST

ACCESS
PILOT
RRI
DRC
ACK
DATA
TRAFFIC

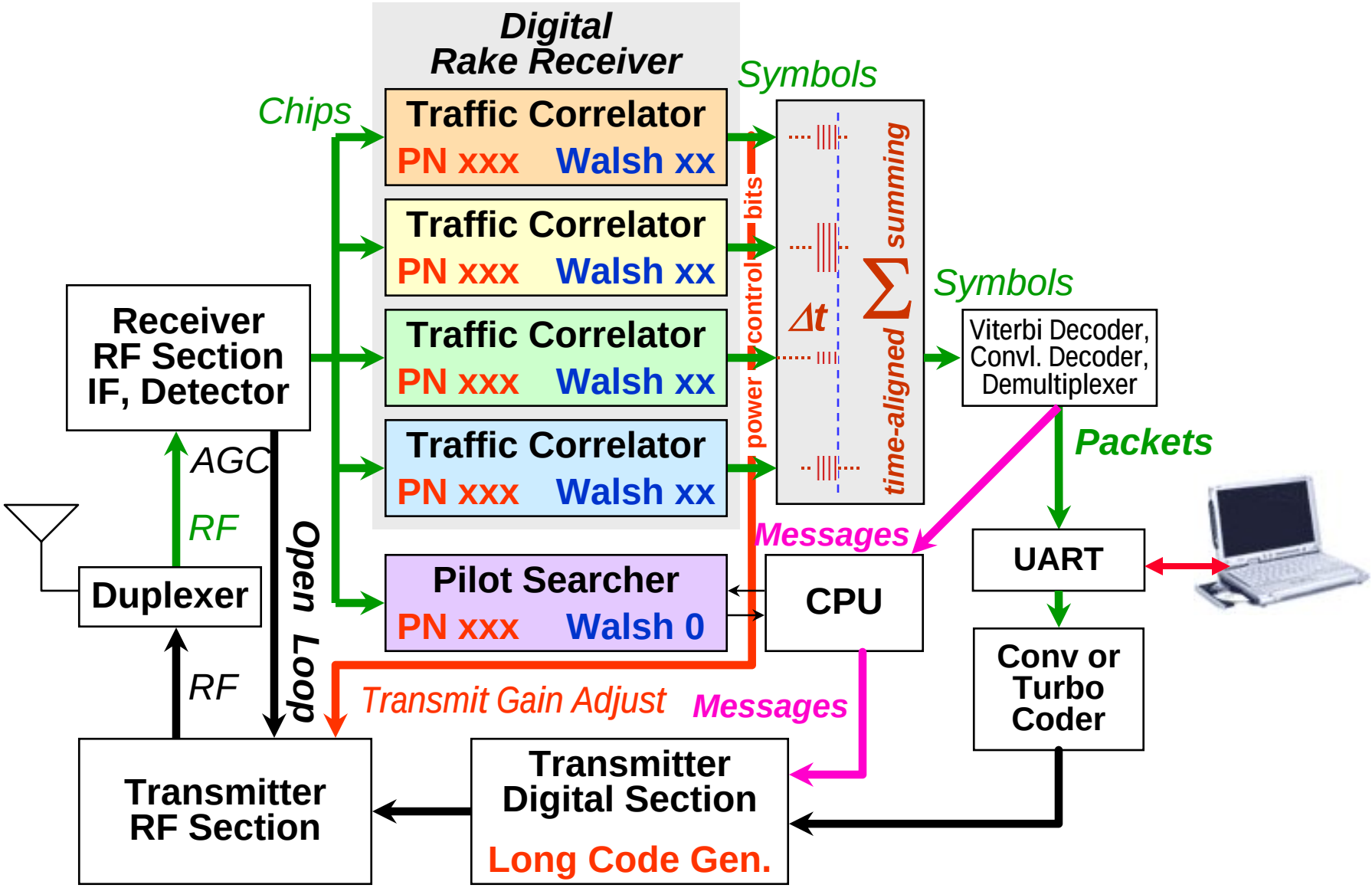
Access
Terminal
(AT)



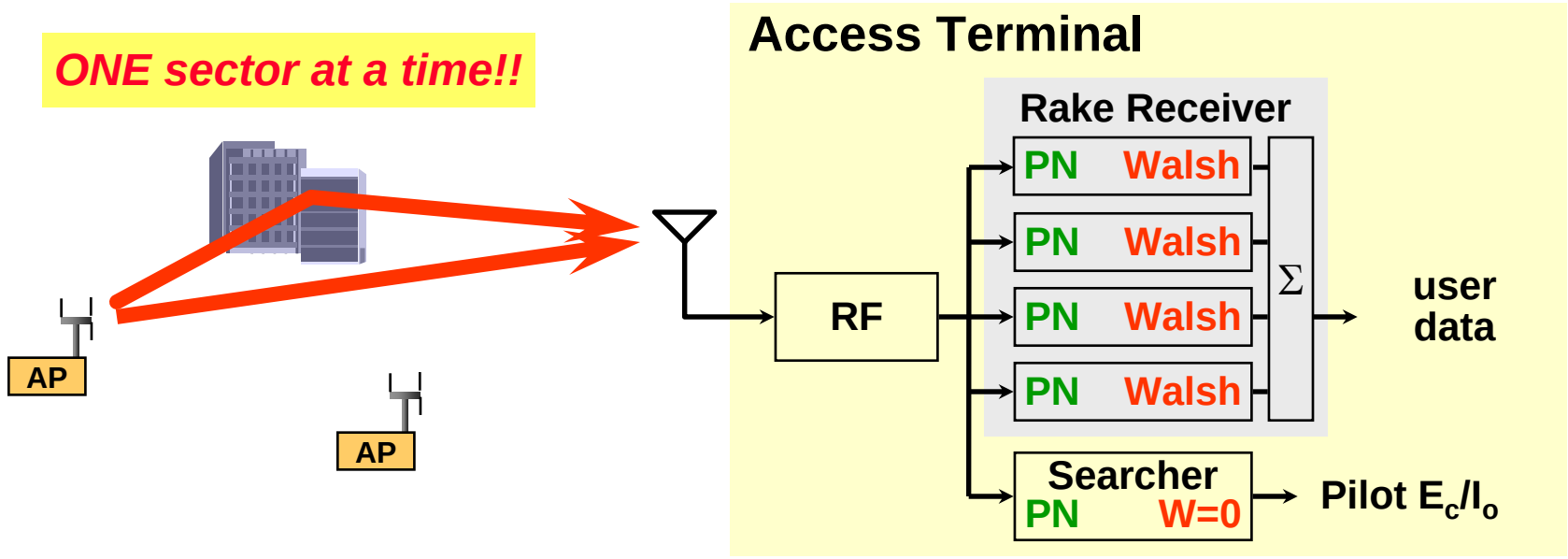
Rake Receiver
#1 PN168+0 W23
#2 PN168+2 W23
#3 PN168+9 W23
#4 PN168+5 W23
Pilot Searcher

Access Terminal Architecture And ~~Handoffs~~ Route Updates

Block Diagram of an Access Terminal

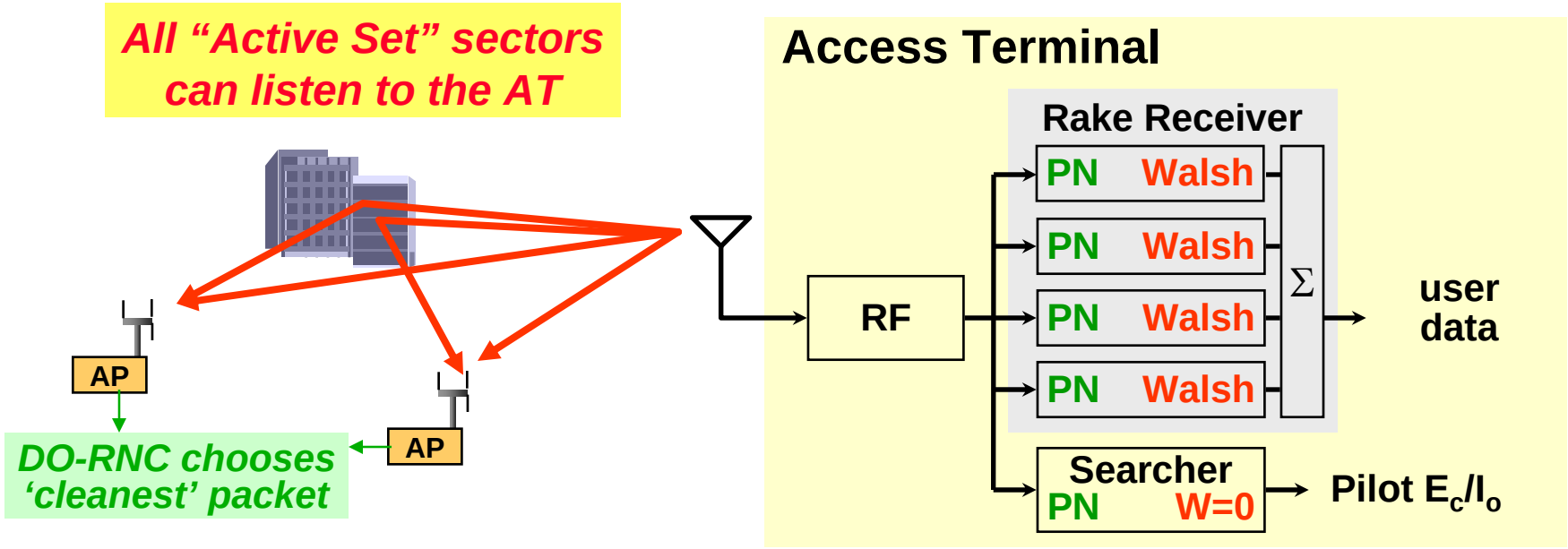


1xEV-DO Forward Link: AT Rake Receivers



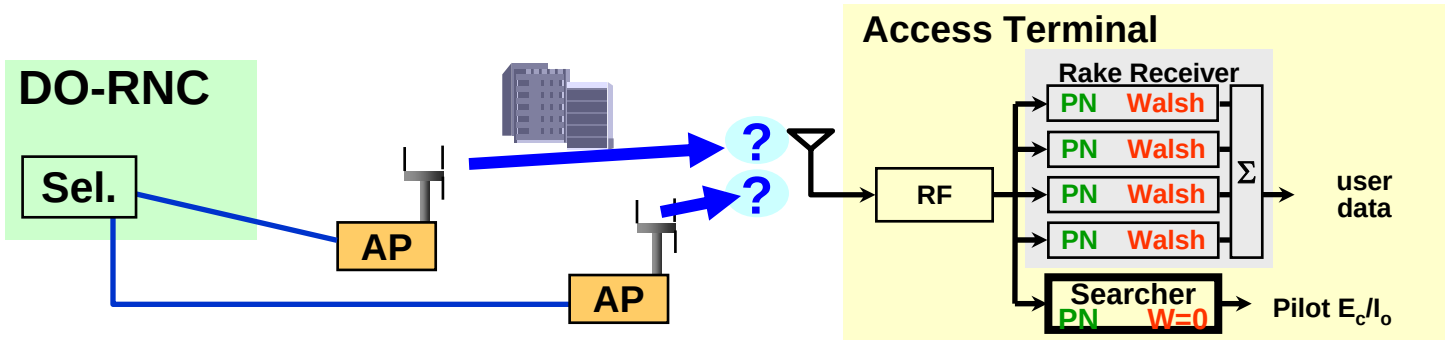
- Burst by burst, the Access Terminal asks for transmission from whichever Active sector it hears best, at the max speed it can successfully use
- Using latest multipath data from its pilot searcher, the Access Terminal uses the combined outputs of the four traffic correlators ("rake fingers")
- Each rake finger can be set to match any multipath component of the signal
- The terminal may be a dual-mode device also capable of 1xRTT voice/data
  - fingers could even be targeted on different AP, but in 1xEV-DO mode only a single AP transmits to us, never more than one at a time, so this capability isn't needed or helpful in 1xEV-DO mode

1xEV-DO Reverse Link: Soft Handoff



- The AT uses the Route Update protocol to frequently update its preferences of which sectors it wants in its active set
- Frame-by-frame, all the sectors in the Active Set listen for the AT's signal
- Each sector collects what it heard from the AT, and sends it back to the DO-RNC.
- The DO-RNC uses the cleanest (lowest number of errors) packet

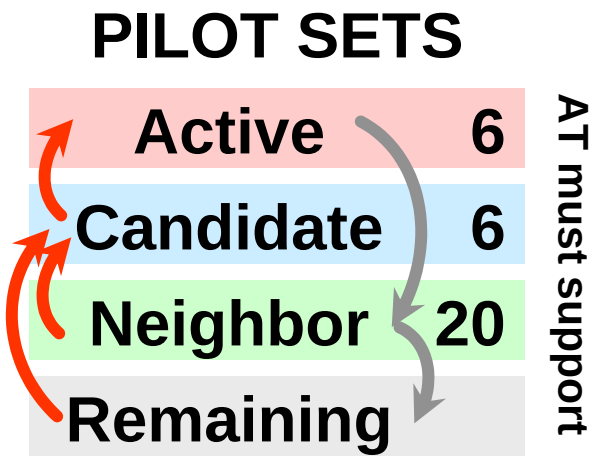
1xEV-DO Route Update Mechanics



- 1xEV-DO Route Update is 'driven' by the Access Terminal
  - Access Terminal continuously checks available pilots
  - Access Terminal tells system pilots it currently sees
  - System puts those sectors in the active set, tells Access Terminal
- Access terminal requests data bursts from the sector it likes best
  - tells which sector and what burst speed using the DRC channel
  - so there is no "Soft Handoff" on the forward link, just fast choices
- All sectors in Active Set try to hear AT, forward packets to the DO-RNC
  - so the reverse link does benefit from CDMA soft handoff

Route Update Pilot Management Rules

- The Access Terminal considers pilots in ***sets***
  - **Active**: sectors who listen and can transmit
  - **Candidates**: sectors AT requested, but not yet approved by system to be active
  - **Neighbors**: pilots told to AT by system, as nearby sectors to check
  - **Remaining**: any pilots used by system but not already in the other sets (div. by PILOT_INC)
- Access Terminal sends a **Route Update Message** to the system whenever:
  - It transmits on the Access Channel
  - In idle state, it notices the serving sector is far from the sector where last updated
  - In connected state, whenever it notices the Handoff Parameters suggest a change



HANDOFF PARAMETERS

PilotAdd **PilotDrop**

PilotDrop Timer **Pilot Compare**

Dynamic Thresholds?

Softslope
AddIntercept
DropIntercept
NeighborMaxAge

Format of Traffic Channel Assignment Message

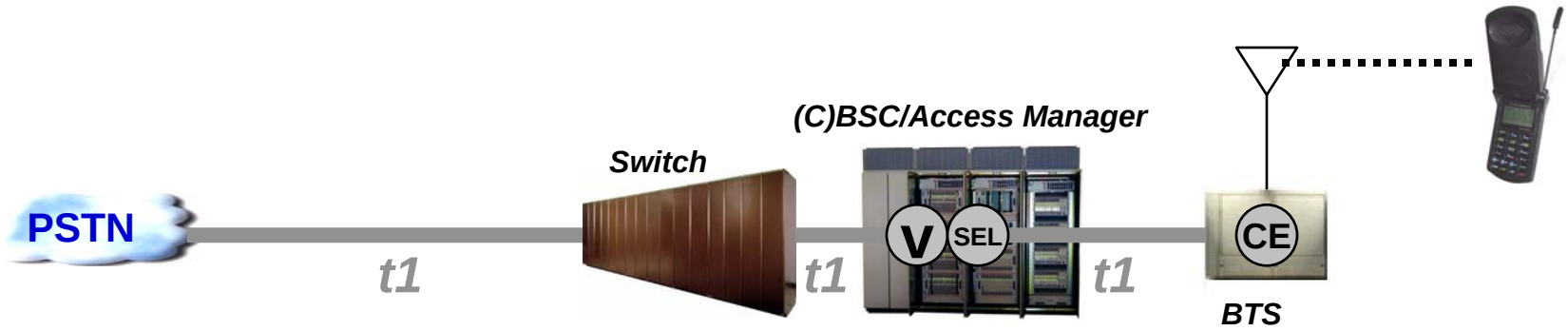
- The Traffic Channel Assignment Message assigns all or some of the sectors the access terminal requested in its most recent Route Update request
- The message lists every Active pilot; if it doesn't list it, it's not approved as active
- Notice the MAC index and DRC Cover so the access terminal knows how to request forward link bursts on the data rate control channel

Field	Length (bits)
MessageID	8
MessageSequence	8
ChannelIncluded	1
Channel	0 or 24
FrameOffset	4
DRCLength	2
DRCChannelGain	6
AckChannelGain	6
NumPilots	4
NumPilots occurrences of the following fields	
PilotPN	9
SofterHandoff	1
MACIndex	6
DRCCover	3
RABLength	2
RABOffset	3

Neighbor Structure Maintained by the AT			
Pilot PN	**Channel**	**SrchWinSize**	SrchWin**Offset**

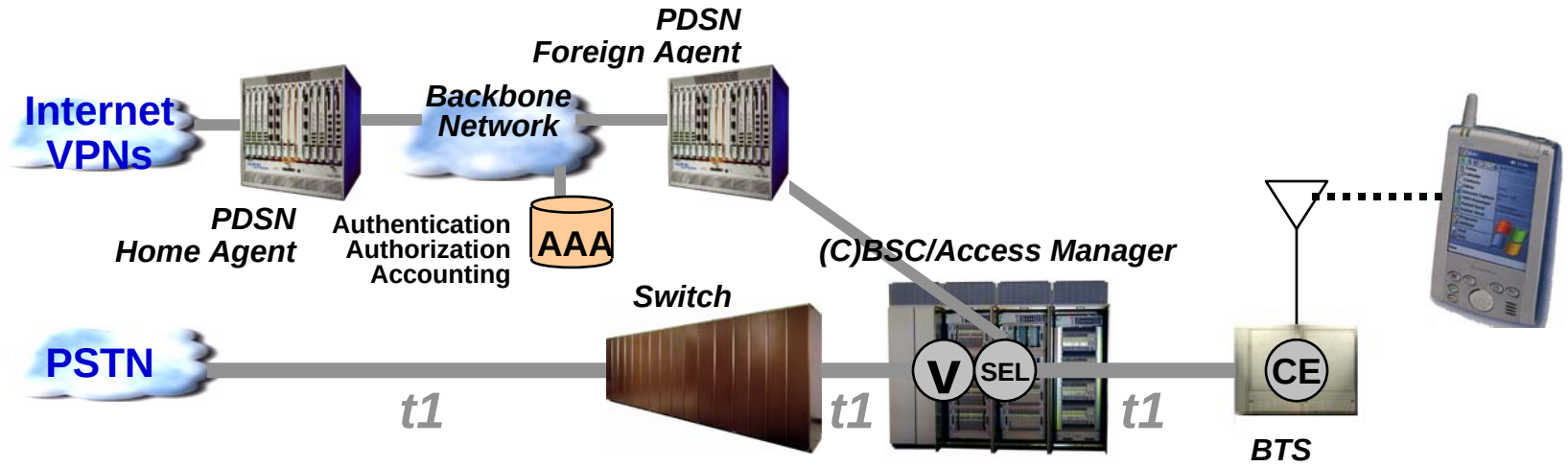
1xEV-DO Network Architecture
Simple IP and Mobile IP

CDMA Network for Circuit-Switched Voice Calls



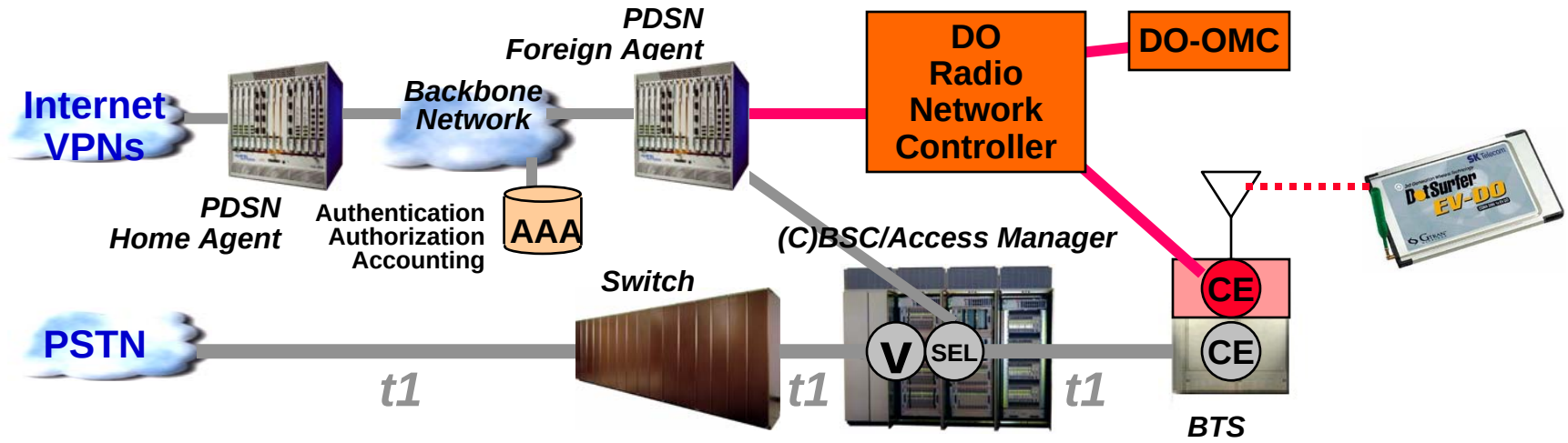
- The first commercial IS-95 CDMA systems provided only circuit-switched voice calls

CDMA 1xRTT Voice and Data Network



- CDMA2000 1xRTT networks added two new capabilities:
  - channel elements able to generate and carry independent streams of symbols on the I and Q channels of the QPSK RF signal
    - this roughly doubles capacity compared to IS-95
  - a separate IP network implementing packet connections from the mobile through to the outside internet
    - including Packet Data Serving Nodes (PDSNs) and a dedicated direct data connection (the Packet-Radio Interface) to the heart of the BSC
- The overall connection speed was still limited by the 1xRTT air interface

1xEV-DO Overlaid On Existing 1xRTT Network

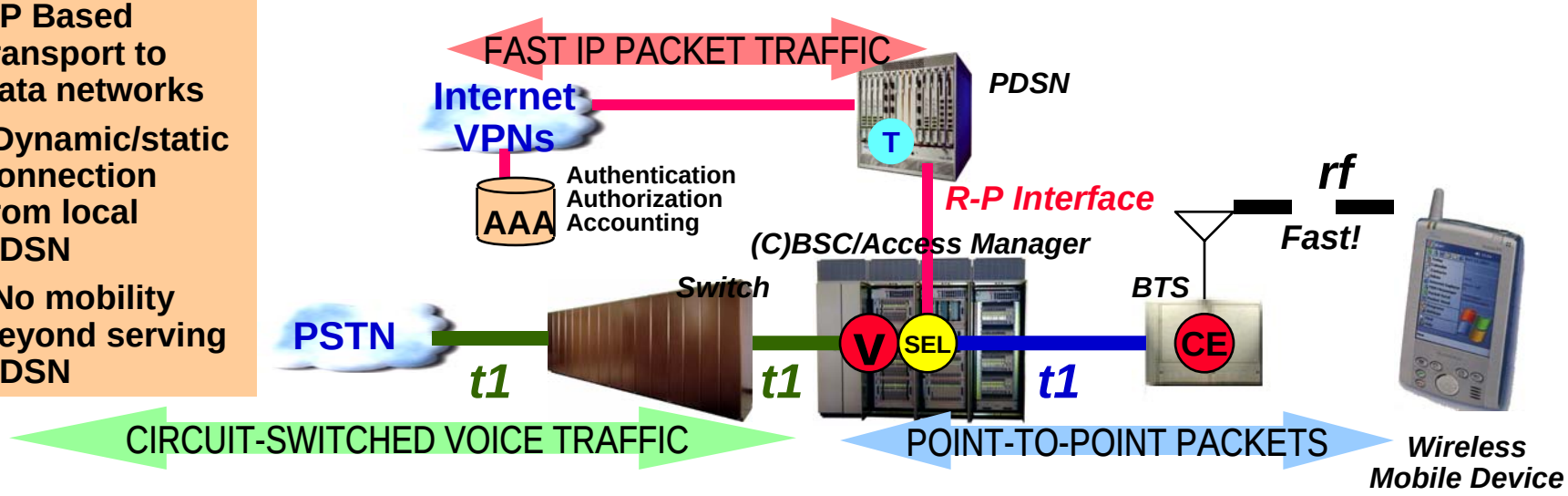


- 1xEV-DO requires faster resource management than 1x BSCs can give
  - this is provided by the new Data Only Radio Network Controller (DO-RNC)
- A new controller and packet controller software are needed in the BTS to manage the radio resources for EV sessions
  - in some cases dedicated channel elements and even dedicated backhaul is used for the EV-DO traffic
- The new DO-OMC administers the DO-RNC and BTS PCF addition
- Existing PDSNs and backbone network are used with minor upgrading
- The following sections show Lucent, Motorola, and Nortel's specific solutions

Simple IP Network Architecture

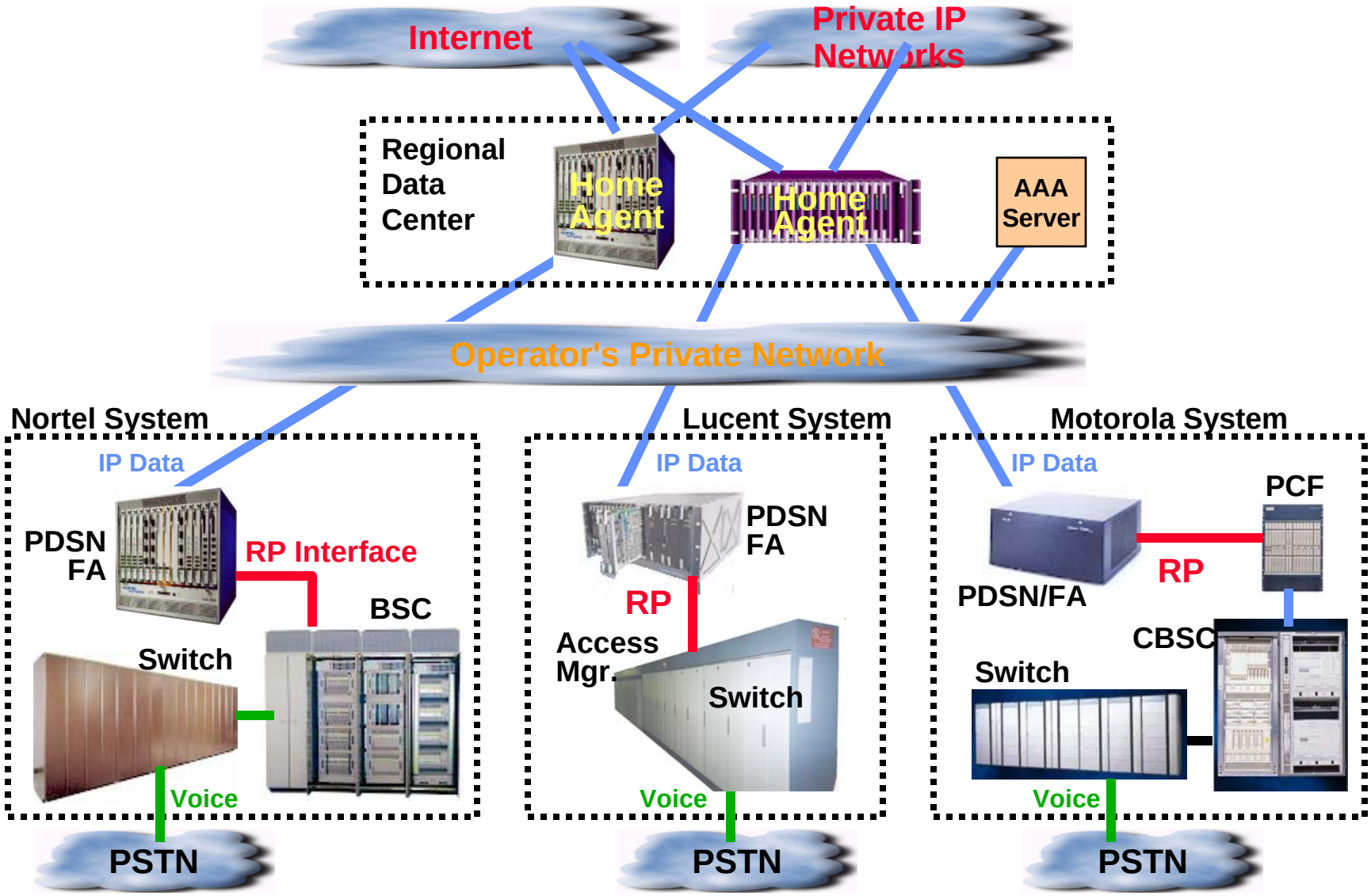
Simple IP

- **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

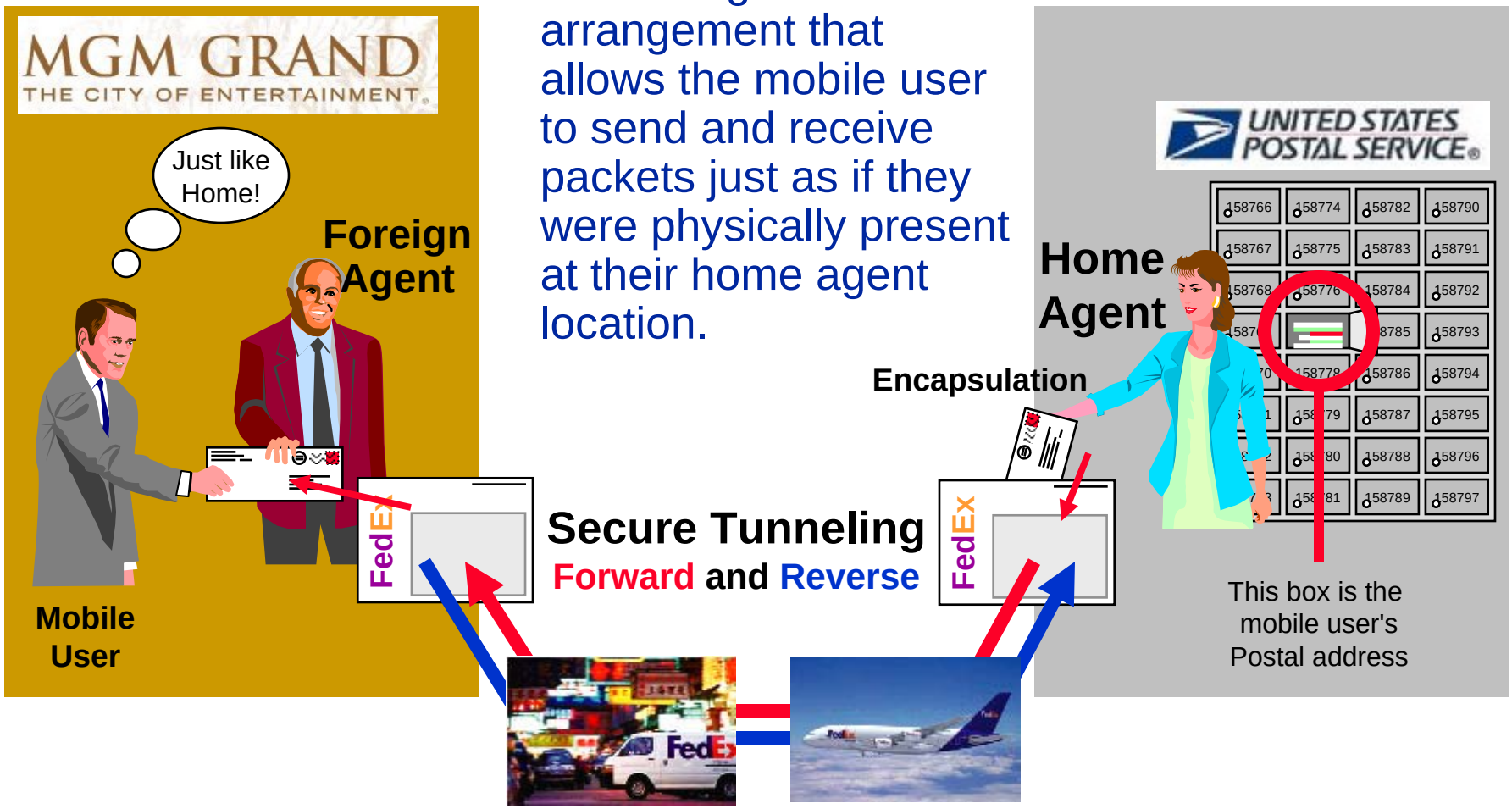
- Subscriber's IP routing service is provided by a public IP network
- Mobile station is assigned a static IP address belonging to its Home Agent
- Mobile can maintain the static IP address even for handoff between radio networks connected to separate PDSNs!
- Mobile IP capabilities will be especially 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

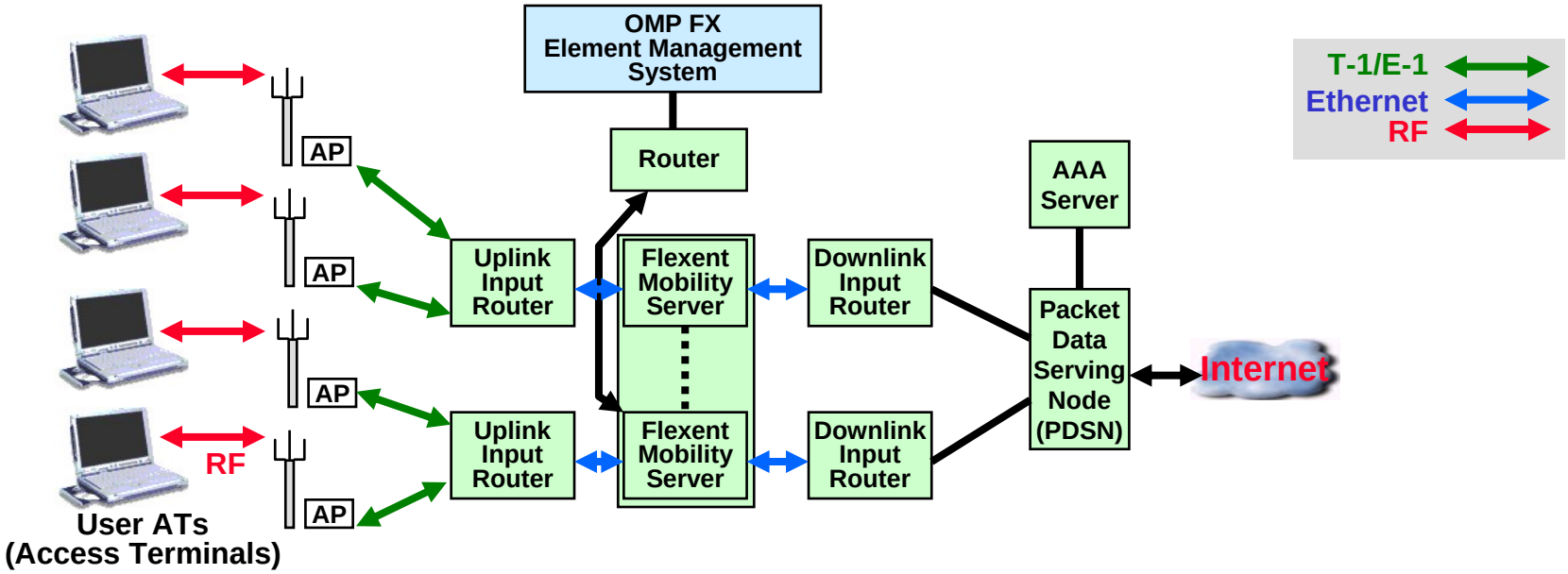
How the PDSN HA and FA Forward Your Packets

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.



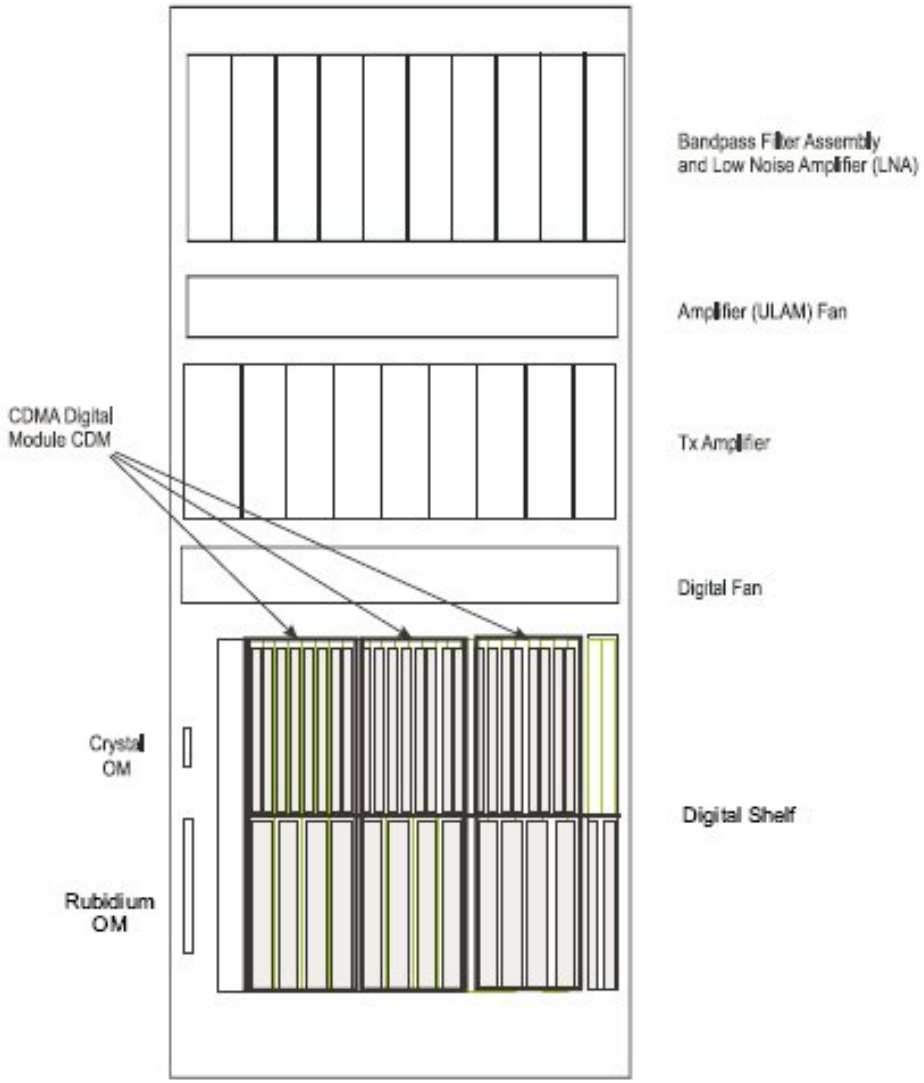
Lucent 1xEV-DO Architecture

Lucent 1xEV-DO Radio Access Network (RAN)



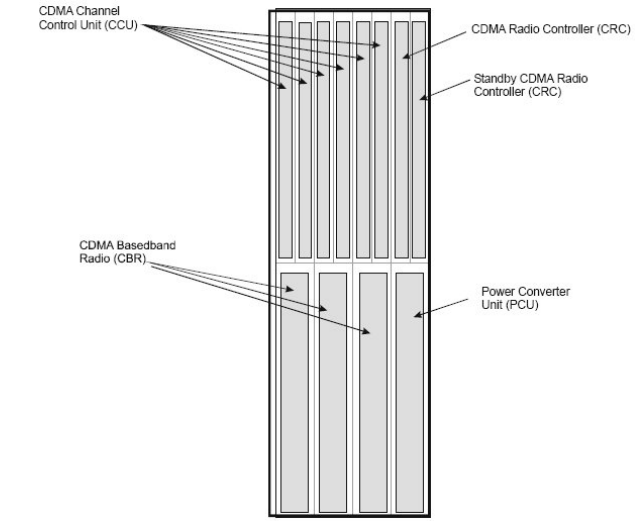
- A Lucent 1xEV-DO Radio Access Network (RAN) includes
  - 1xEV-DO base stations and the
  - 1xEV-DO Flexent® Mobility Server (FMS).
- The 1xEV-DO equipment may be collocated with IS-95 and/or 1xRTT equipment, creating 1xEV-DO/IS-95 and 1xEVDO/3G-1X combination base stations.

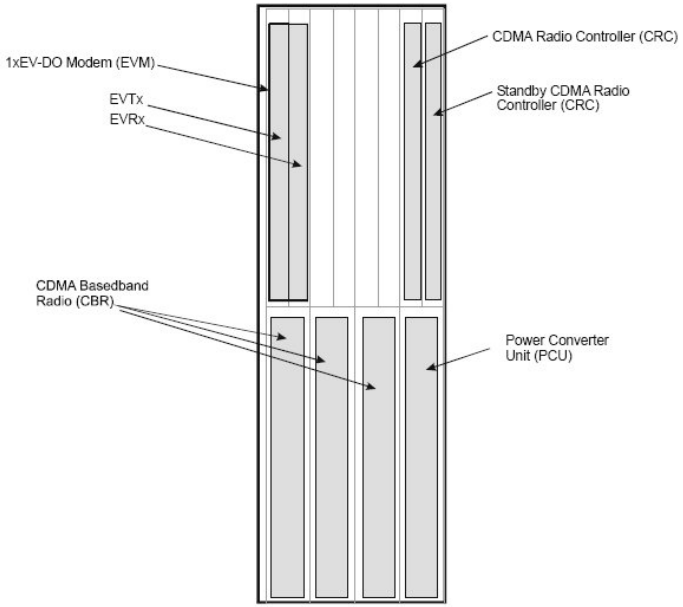
1xEV-DO in Lucent Flexent Mod Cell Cabinets



- Lucent Mod Cell cabinets can support up to three IS-95 or 1xRTT carriers on three sectors
- 1xEV-DO CDMA Digital Modules (CDM) can be mixed with conventional CDMs in the same cabinet
- the same RF hardware (filters, amplifiers, other RF components) can be used for IS-95, 1xRTT, and 1xEV-DO

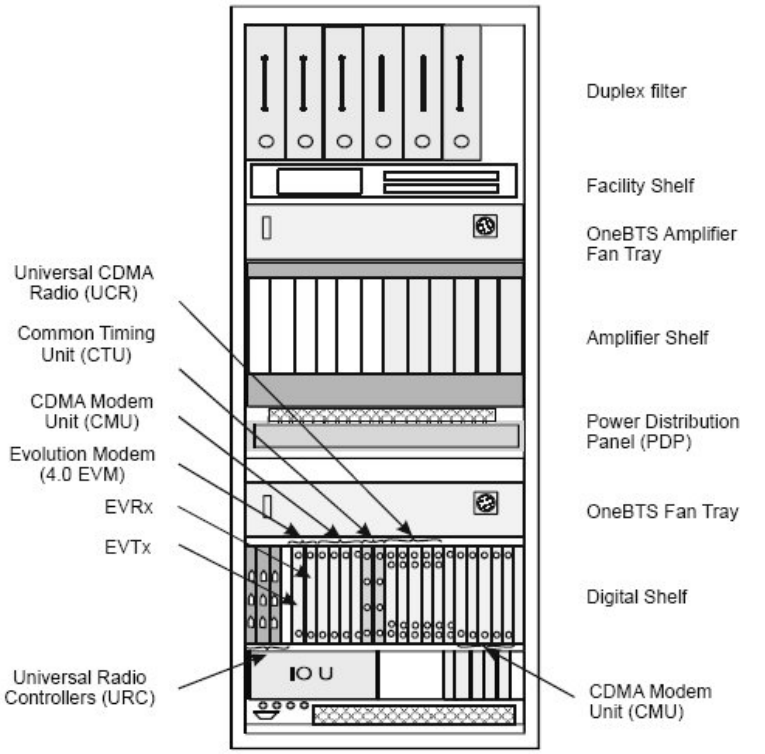
Lucent CDMA Digital Module (CDM) Configurations

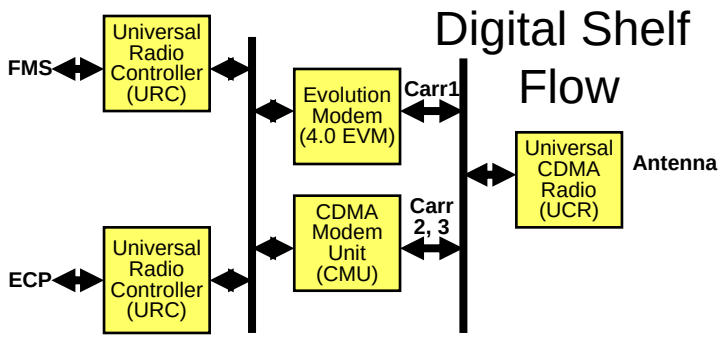




- At upper left is a CDM for conventional IS-95 / 1xRTT service. It includes
  - CRC CDMA Radio controller
  - up to 6 CCU CDMA Channel Units
  - PCU power converter module
  - CBR CDMA Baseband Radio
- At lower left is a CDM for 1xEV-DO
  - it must be occupy the leftmost slot
  - all CCU packs are removed and replaced by a single 1xEV-DO modem (EVM) occupying 2 slots
  - the CRC must be 44WW13D or later

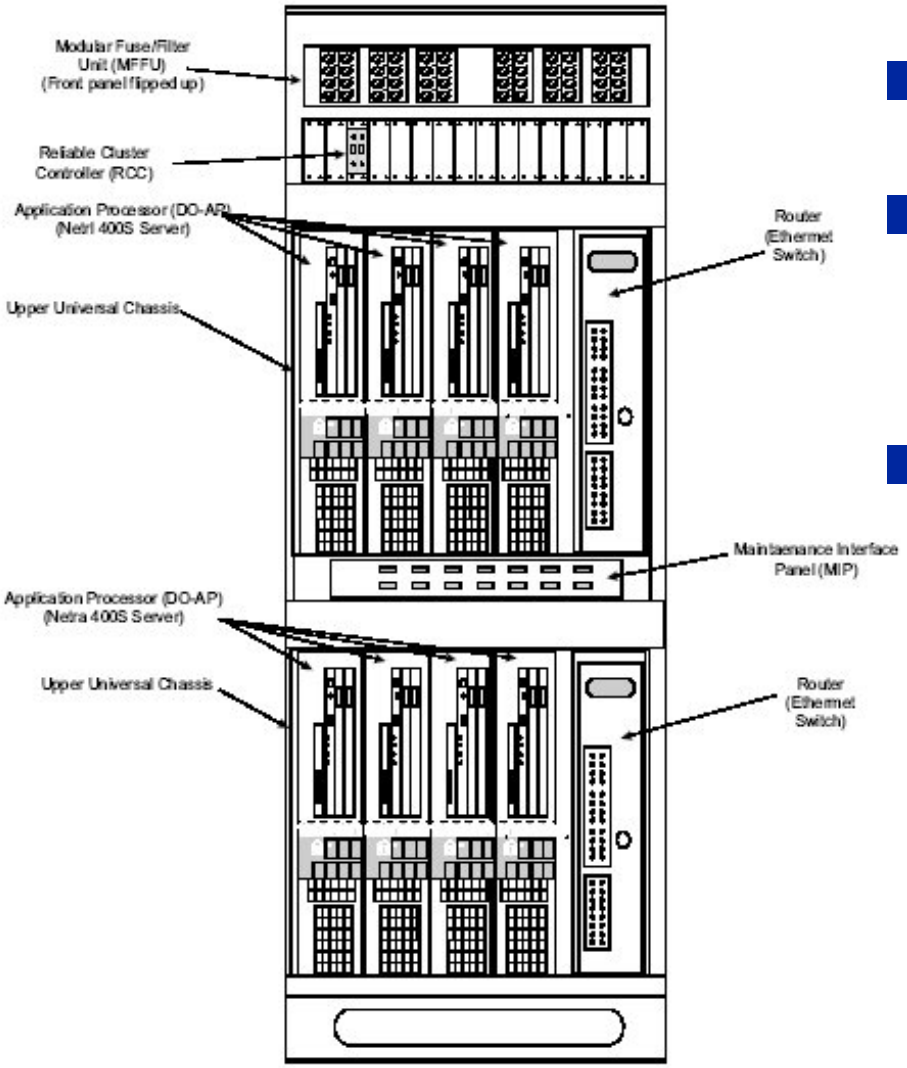
1xEV-DO in Lucent Mod Cell 4.0 Cabinets





- The Mod Cell 4 cabinet comes in many variations
- Instead of per-carrier dedicated CDMs, resources are pooled
- URCs (Universal Radio Controllers) are used to steer data for each carrier to EVMs for EVDO or CMUs for IS-95/1xRTT.
  - in a mixed-mode system, a URC is required for EVDO and a URC for IS-95/1xRTT
- The modulated signal from a 4.0 EVM or CMU is upconverted to the RF carrier frequency by the UCR
  - each UCR (Universal CDMA Radio) can handle up to three carriers

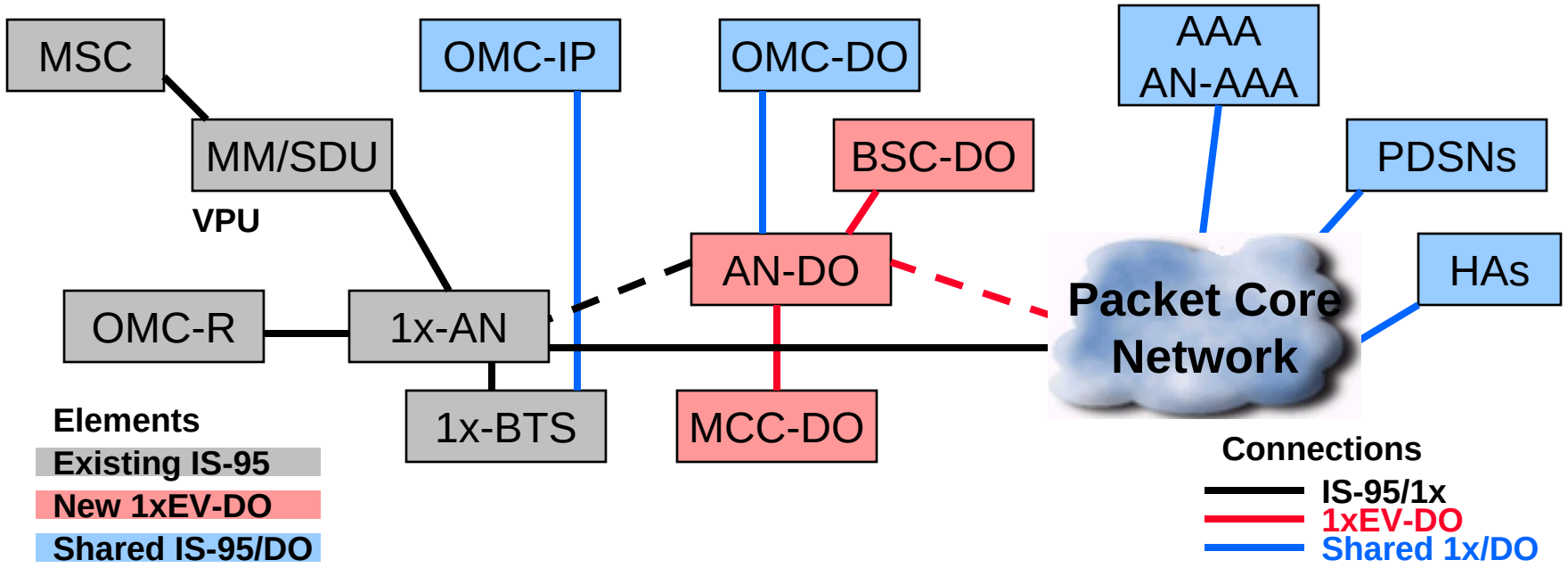
Lucent 1xEV-DO Flexent Mobility Server (FMS)



- The Flexent Mobility Server is the heart of the Radio Access Network
- It provides four processors running the 1xEV-DO Application Processor (DO-AP), which provides the Packet Controller Function (PCF)
- The PCF provides air link and radio resource management to implement 1xEV-DO user sessions, including the dormant state and other DO-specific features

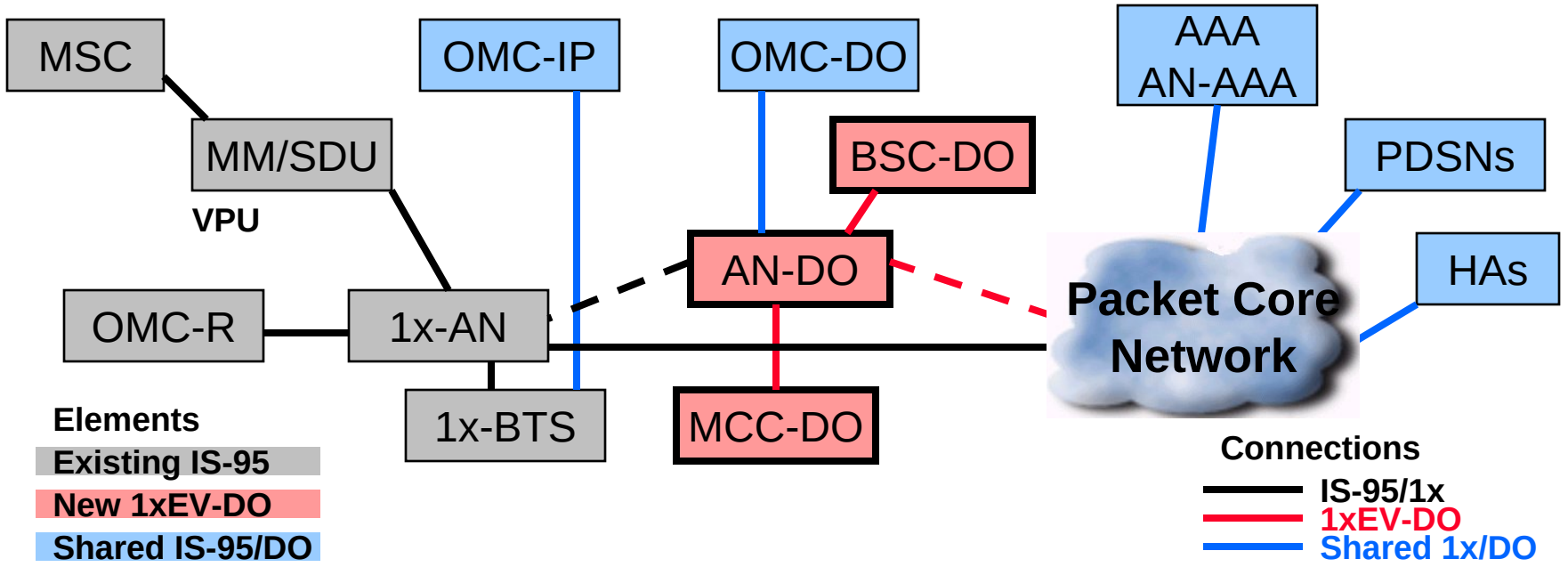
Motorola 1xEV-DO Architecture

Motorola 1xEV-DO System Architecture



- New 1xEV-DO carrier appears as a standard carrier addition to existing network elements
  - new MCC-DO cards and OMC-R database revisions needed
  - AAA and PDSN need software upgrades

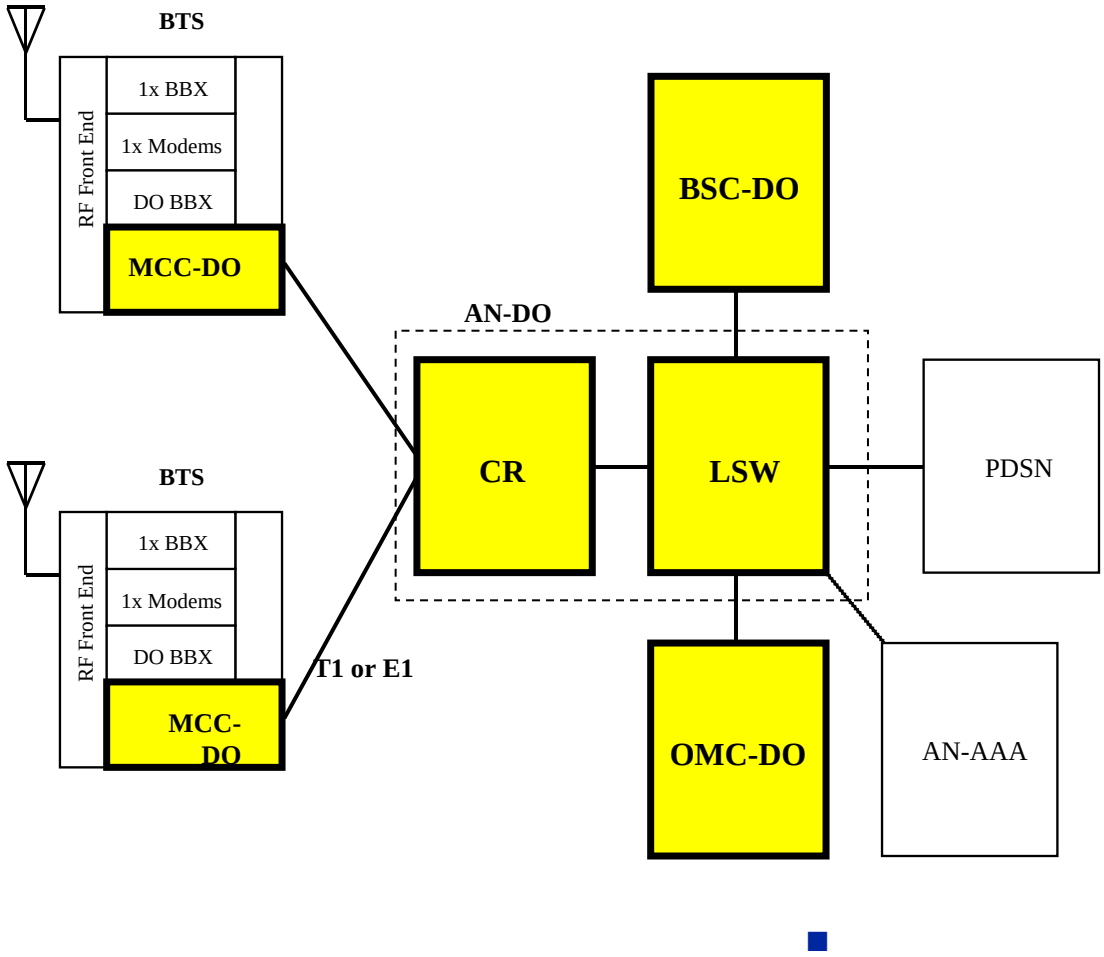
New Motorola 1xEV-DO Network Elements



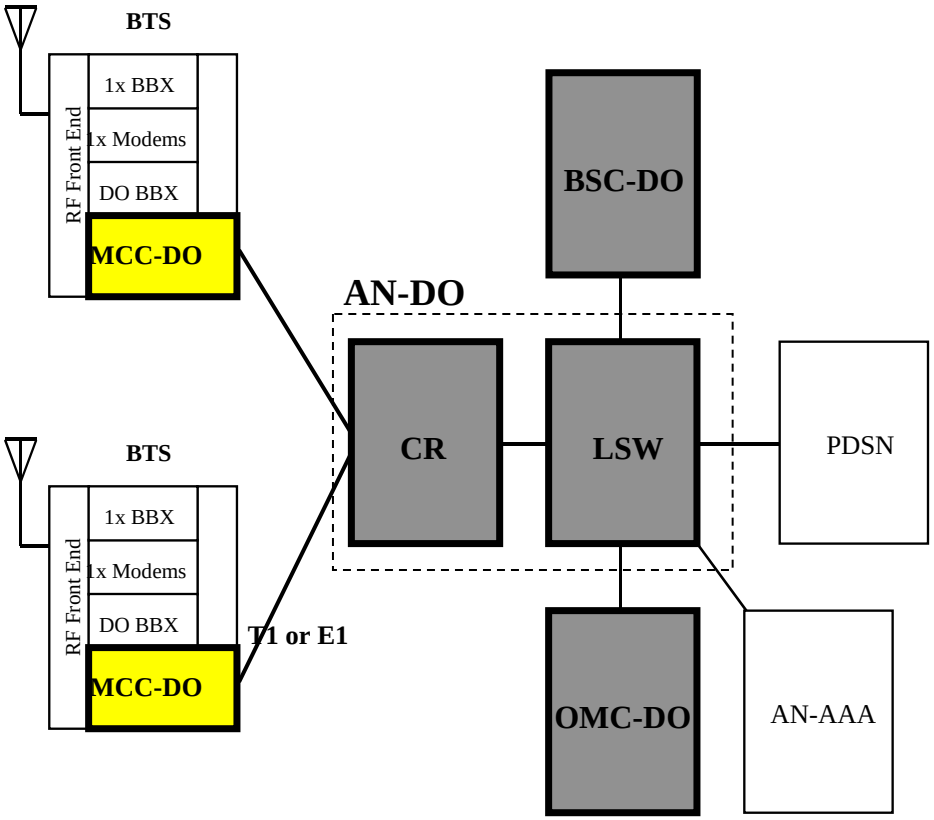
- MCC-DO (Multi-Channel Controller - Data Only)
- AN-DO (Access Node - Data only)
  - CR (Consolidation Router) Similar in function to the 1x-AN MGX
  - LSW (Layer 3 Switch) Similar in function to the 1x-AN CATs
- BSC-DO (Base Station Controller-Data Only)
  - Mobility functions like 1x MM - Packet Control & Selection – like SDU
- OMC-DO (Operations & Maintenance Center - Data Only)
- LMT (Local Maintenance Terminal)

Motorola 1xEV-DO Block Diagram and Network Upgrade Summary

	IS-2000	1xEV-DO
Tool	LMF	LMT
BTS	BTS frame & CCP shelf	
	LPA	
	BBX-1X	
	MCC-1X	MCC-DO
	GLI (Traffic)	
	GLI (Control)	
AN	AN (MGX8800)	CR
	AN (Catalyst 6509)	LSW
BSC	CBSC	BSC-DO
O&M	OMC-R	OMC-DO
	UNO	
IP Network	PDSN (Note 1)	
Telephone Network	MSC/HLR	Not Required
Data Network	Not Required	AAA



Motorola MCC-DO Functions

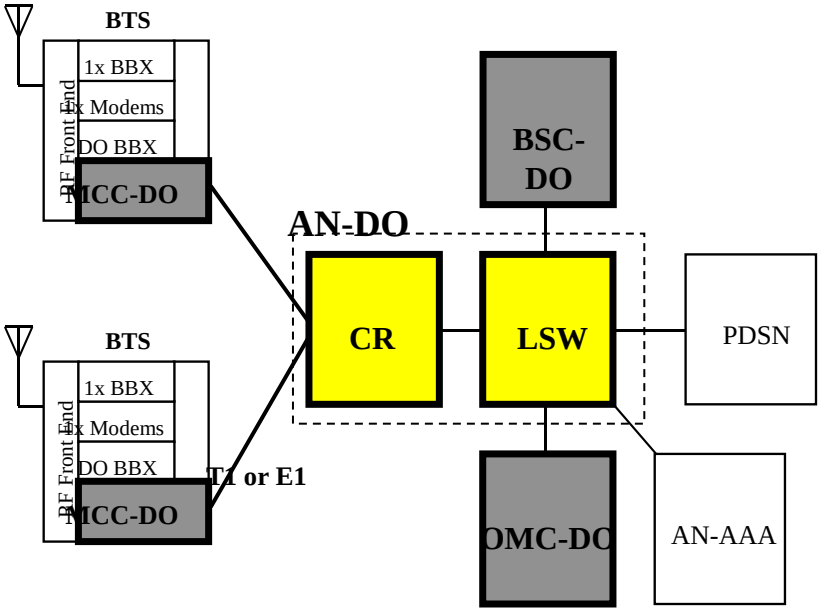




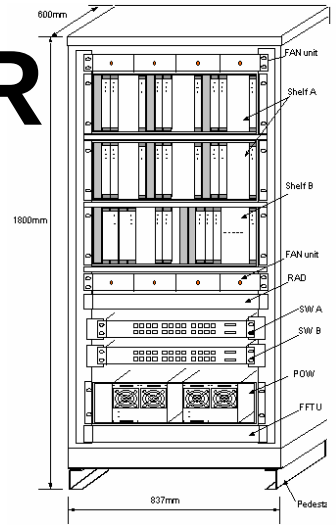
MCC- DO

- 1xEV-DO Modem
  - 1 carrier, 3 sectors per MCC-DO card
  - Supports 59 channels per sector
- Span Interface
  - Up to 3 Active Span lines per MCC-DO
  - Most operators will generally deploy with 2 spans per BTS
- BTS provides control:
  - SCAP messaging
  - Redundant BBX Selection
  - Enhanced BBX interface

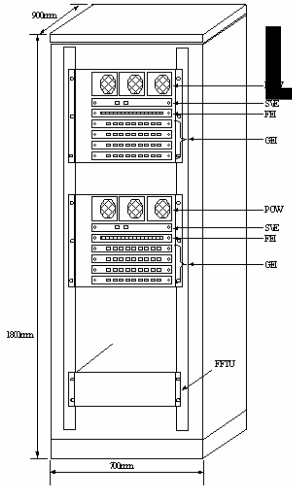
Motorola 1xEV-DO AN-DO Elements



CR

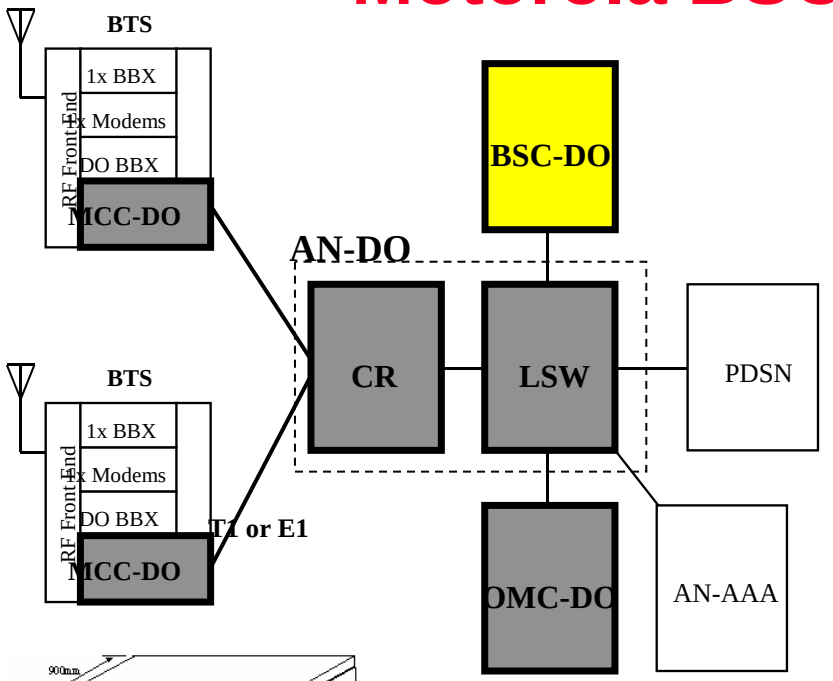


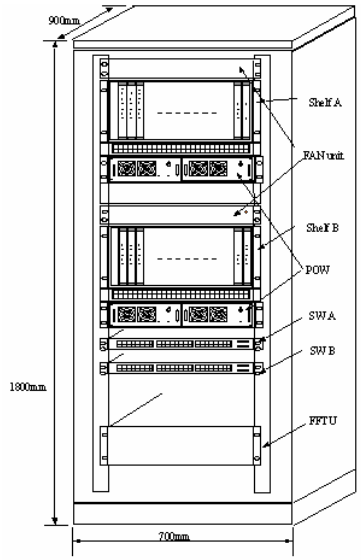
LSW



- Consolidation Router (CR)
  - Performs span aggregation for DO access points – Similar to 1x MGX
  - 1 – 2 CR frames per BSC-DO
- Layer 3 Switch (LSW)
  - Performs IP transport across DO Core Network – Similar to 1x CAT
  - Two CAT4006 Cages per frame
  - 1 LSW frame will serve all 1xEV-DO frames in a typical MTSO

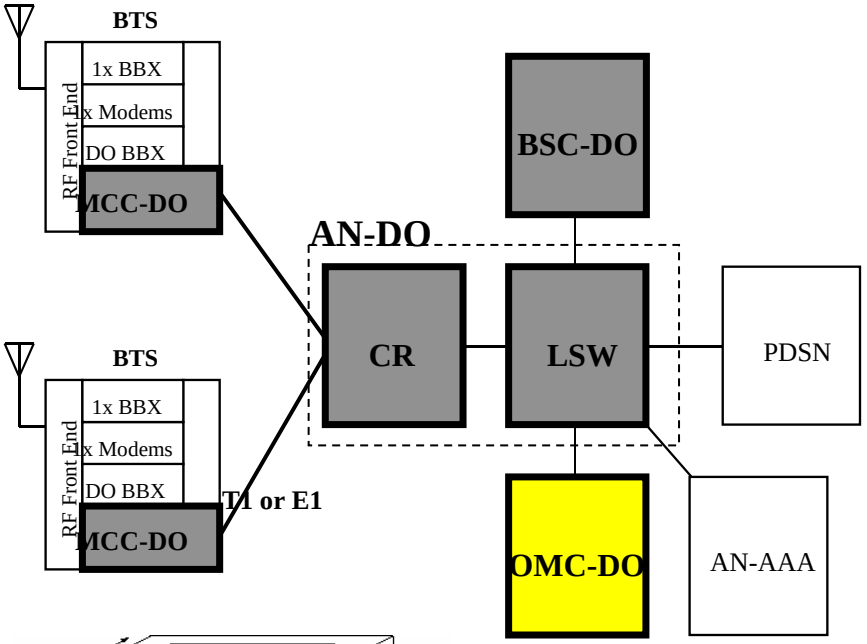
Motorola BSC-DO Functions

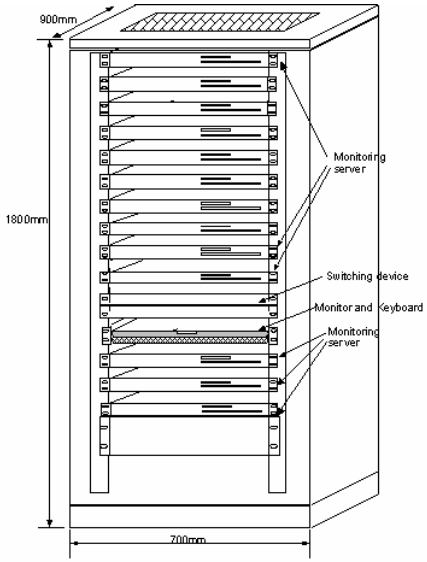




- BSC Functionality:
  - RF-scheduling, channel, connection, mobility management, security
- Access Network Control
  - Radio Resource Management
  - Connection Control
  - Access control / Collision control
  - Handoff control
- Packet Control and Session Control
  - Transmission of packet data between MCC-DO and PDSN
  - Packet Data Control
  - PDSN selection
  - Provides Authentication information to AAA
  - Management of Data Session
  - Support up to 80 MCC-DO cards per a BSC-DO
- 1 OMC-DO per each BSC-DO

Motorola 1xEV-DO Network Elements: OMC-DO





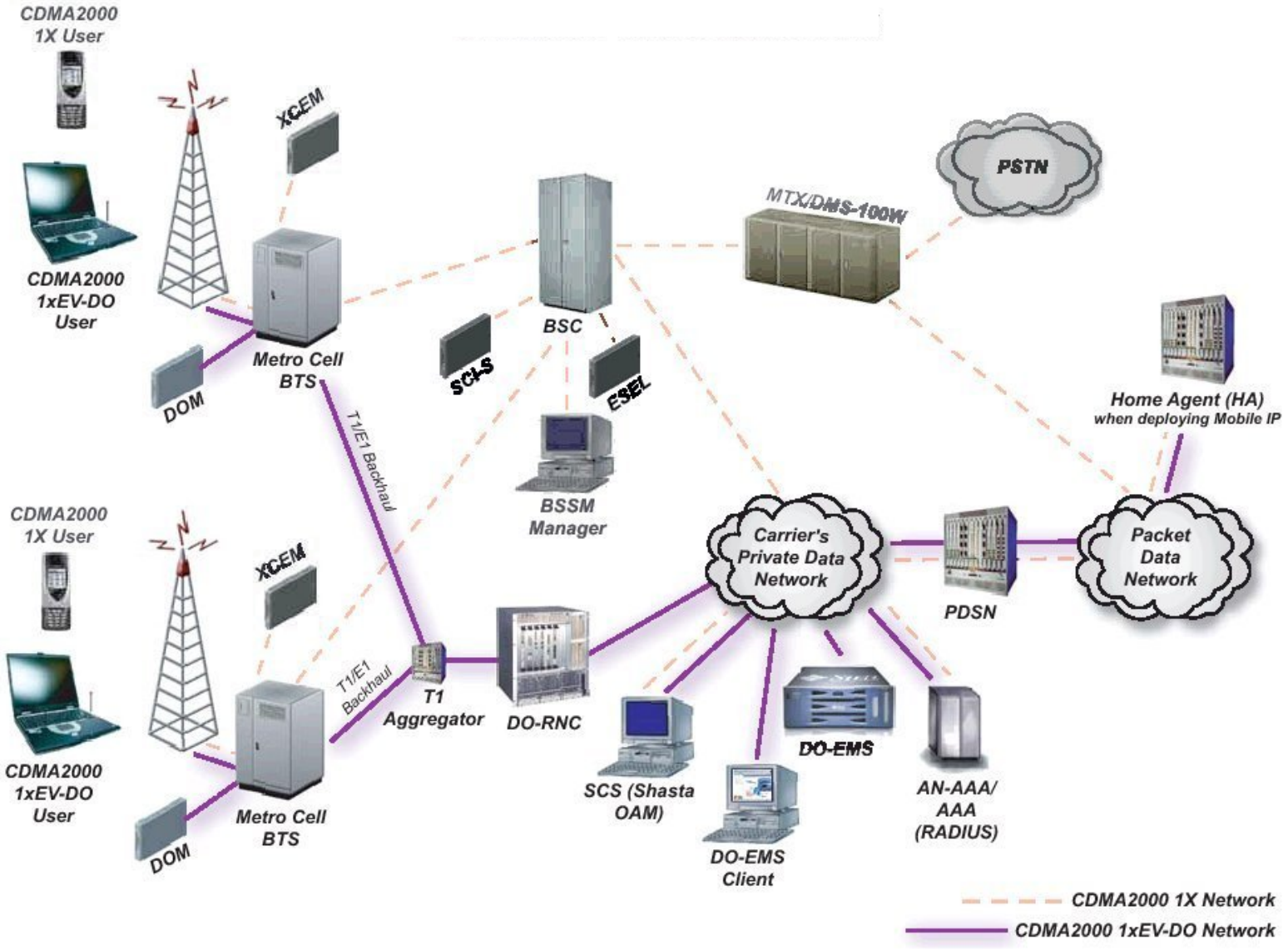
DO network element manager

- **Manages BSC-DO and MCC-DO**
- **Ethernet interface to BSC-DO**
- **Supports network management applications (fault, alarm, performance, configuration)**

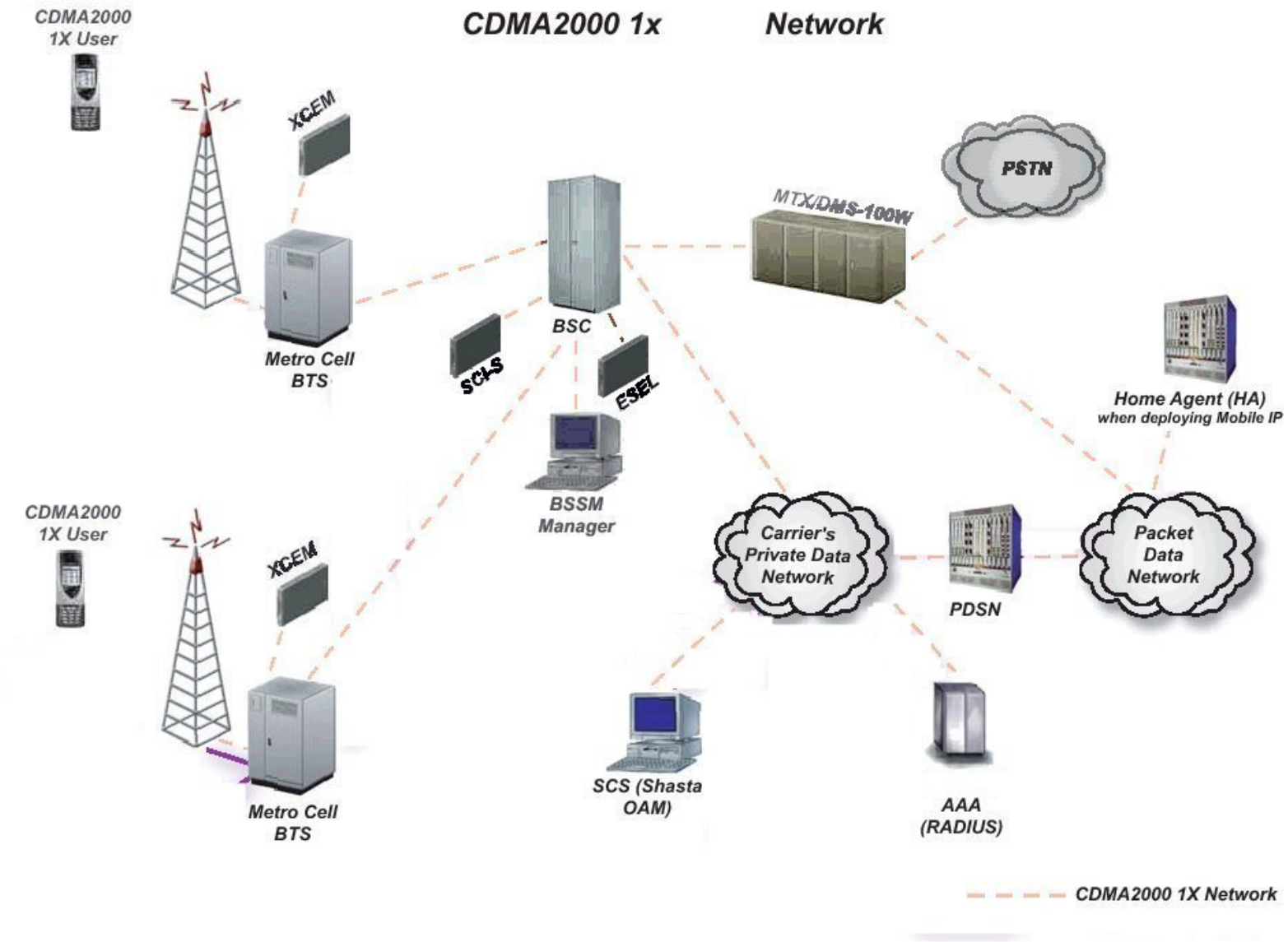
- OMC-DO provides GUI based O&M functions
  - Status Management
  - Fault Management
  - Configuration Management
  - Software Management
  - System Parameter Management
  - Performance Monitoring
  - CDL collection
  - Diagnostic & System Test
  - Logging
  - Health Check

Nortel 1xEV-DO Architecture

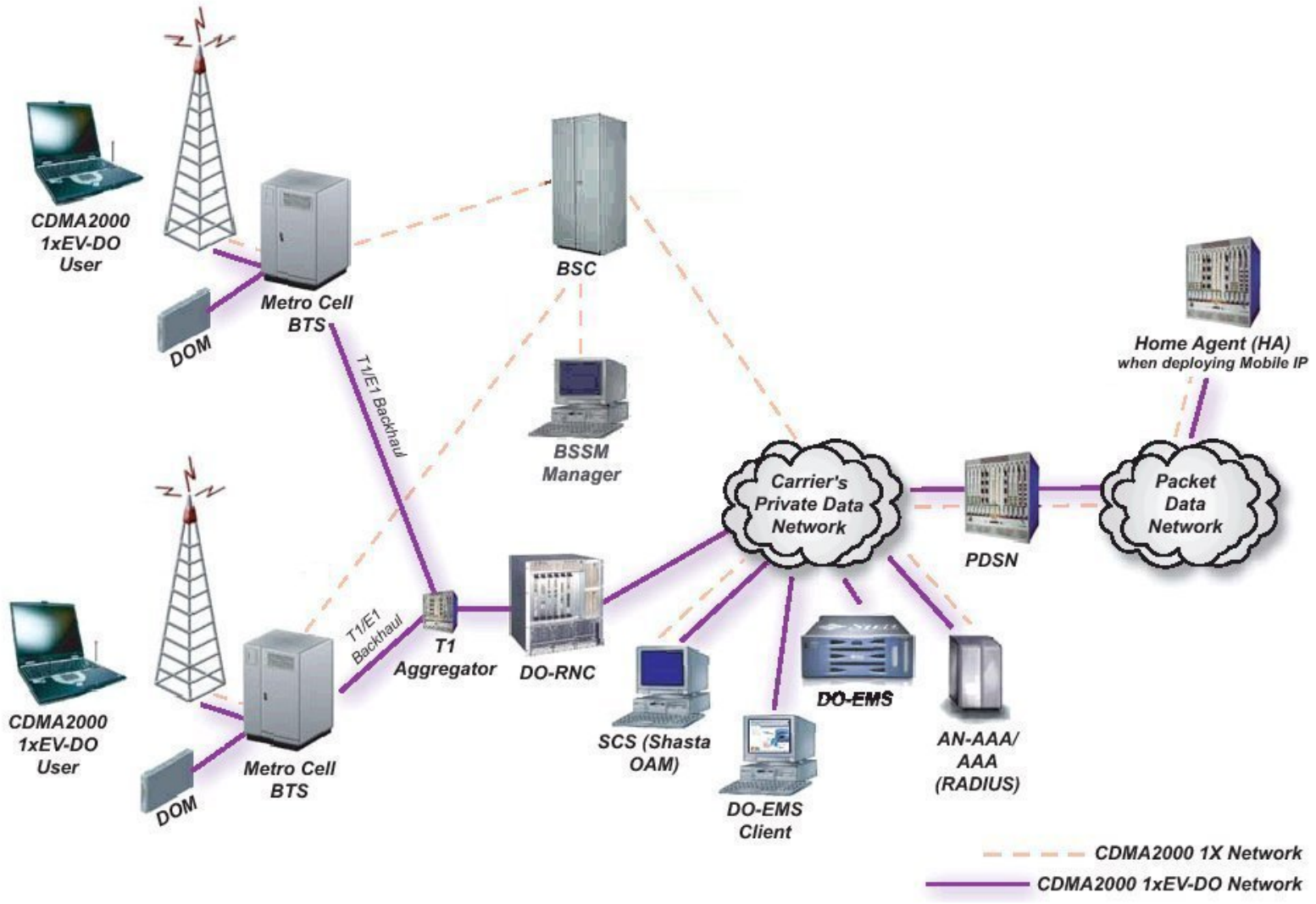
A Typical Nortel CDMA2000 System
Providing 1xRTT Voice, Data, and 1xEV-DO



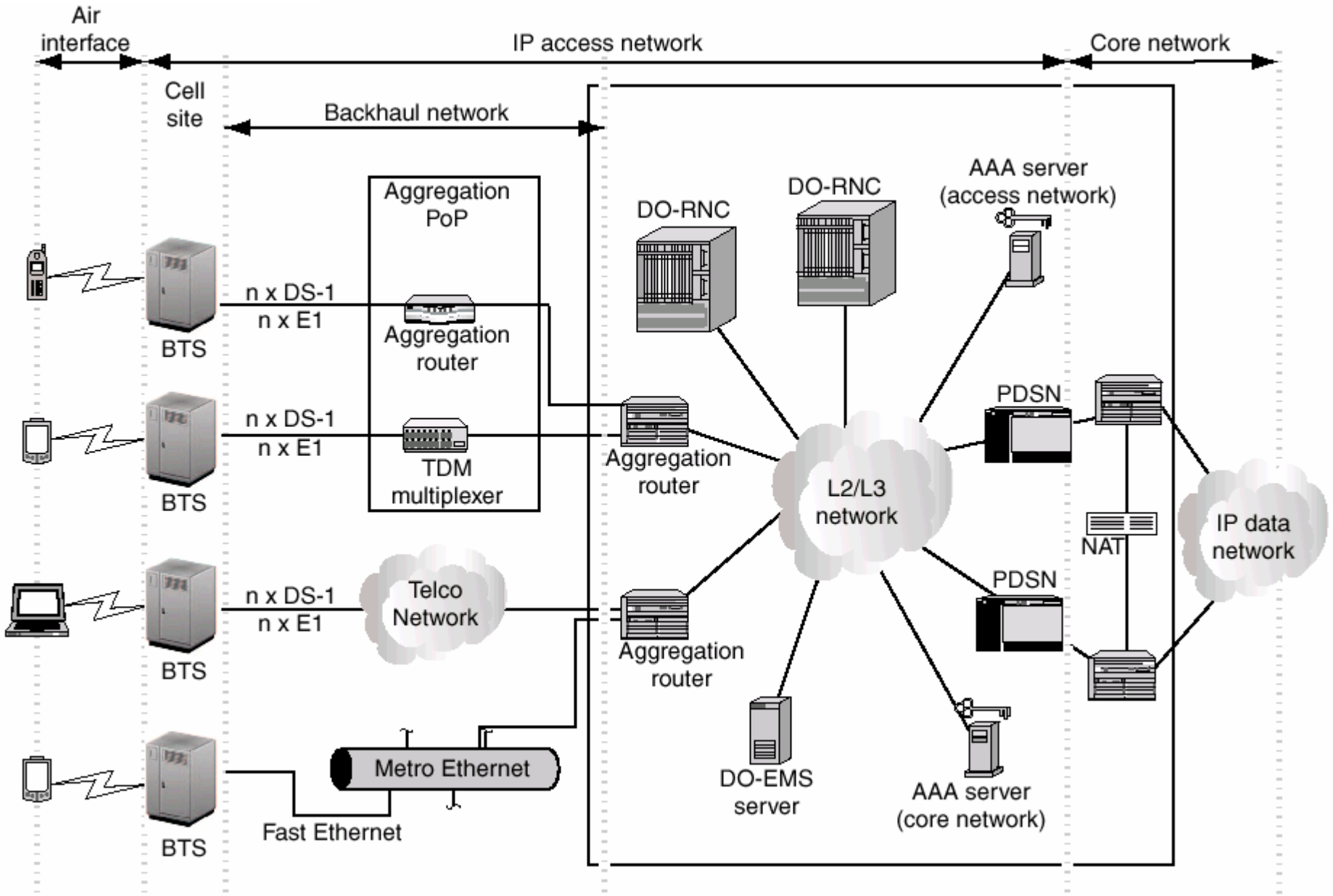
A Typical Nortel CDMA2000 System
Providing Only 1xRTT Voice, Data



A Typical Nortel CDMA2000 System
Providing 1xEV-DO Only

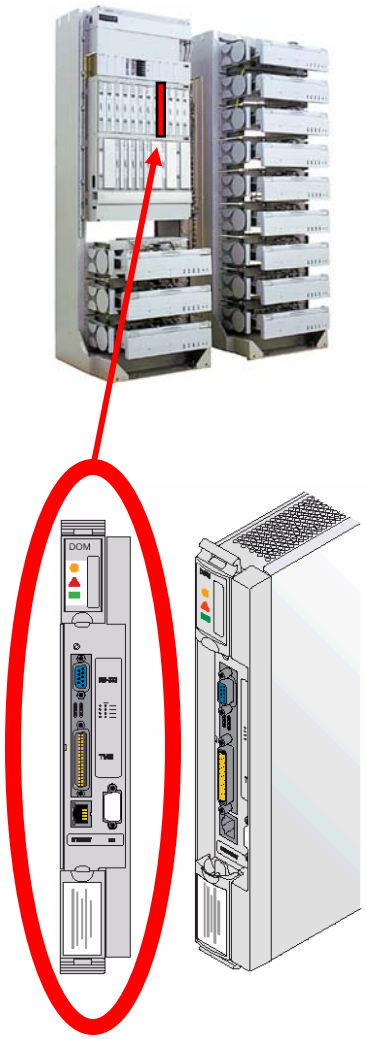


Nortel Multiple Backhaul and Configuration Possibilities



Nortel DOM: Data-Only Module

- The Data Only Module (DOM) adds 1xEV-DO capability to a MetroCell AP CEM shelf
  - transmits/receives baseband data to/from the digital control group (DCG) in the CORE module
  - CORE switches baseband to proper carrier on the MFRM for transmission
  - the DOM performs all encoding/decoding of IP packets for transport on data-only network to the Data-Only Radio Network Controller (DO-RNC)
  - One DOM supports up to a three-sector, one-carrier MetroCell AP
  - Additional DOMs support additional carriers



Nortel's DO-RNC
The Data-Only Radio Network Controller

- DO-RNC is the heart of a 1xEV-DO network, located at the central office (CO) with the BSC and/or BSS Manager (BSSM)
- DO-RNC is a stand-alone node supporting 1xEV-DO. It manages:
  - DOMs at multiple APs (even on different band classes) over IP-based backhaul network
  - access terminal state, both idle and connected
  - handoffs of ATs between cells and carrier frequencies (reverse); sector selection (fwd).
  - connections from airlink to PDSN over standard A10-A11 interfaces
  - connects to MetroCell AP via dedicated IP backhaul network
- DO-RNC is the peer of the access terminal for most over-the-air signaling protocols, including session and connection layers



Nortel DO-RNC
Data-Only
Radio Network Controller

1xEV-DO / 1xRTT Interoperability

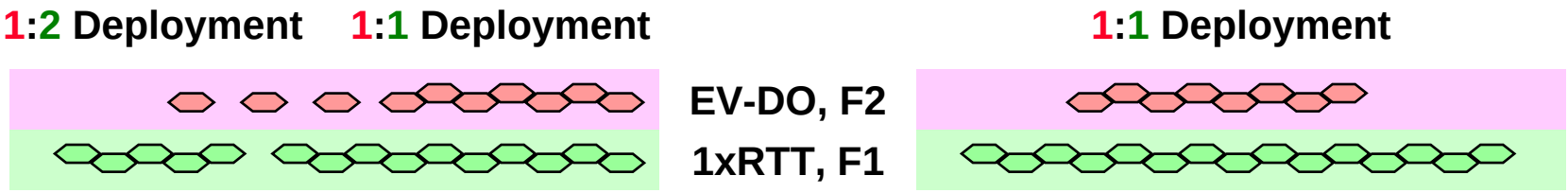
1xEV-DO/1xRTT Interoperability

- The CDMA2000 1xEV-DO Rev. 0 Standard IS-856 makes no provision for any kind of handoff to or from any other technology
- Driven by Operator interest, a “Hybrid” mode has been developed to provide some types of handoff functions to the best extent possible
- Hybrid Mode
  - is a mobile only function – neither the EV nor 1xRTT network knows anything about it
  - is a proprietary feature with vendor-specific implementation
  - has no standard-defined RF “triggers”; no “hooks”
- In the 1xEV rev. A standard, some new features are provided
  - Using the CDMA2000 Circuit Services Negotiation Protocol, the 1xEV control channel can carry 1xRTT pages too
  - this and other changes will eventually make the “hybrid” mode unnecessary and obsolete

What Handoffs are Possible in Hybrid Mode?

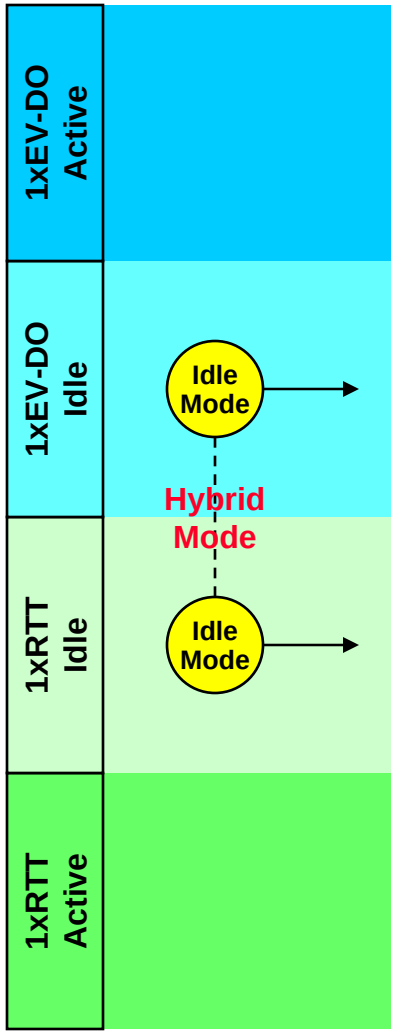
- All switching between systems occurs in Idle Mode
  - there are no “handoffs” in active traffic state in either mode
- Sessions can be transferred from one system to the other, but NOT in active traffic state
  - If there is a connection, it can be closed and then re-originated on the other system
  - In some cases this can be accomplished automatically without the end-user’s awareness – in other cases, the user must manually reconnect

Hybrid Mode Transition Scenarios



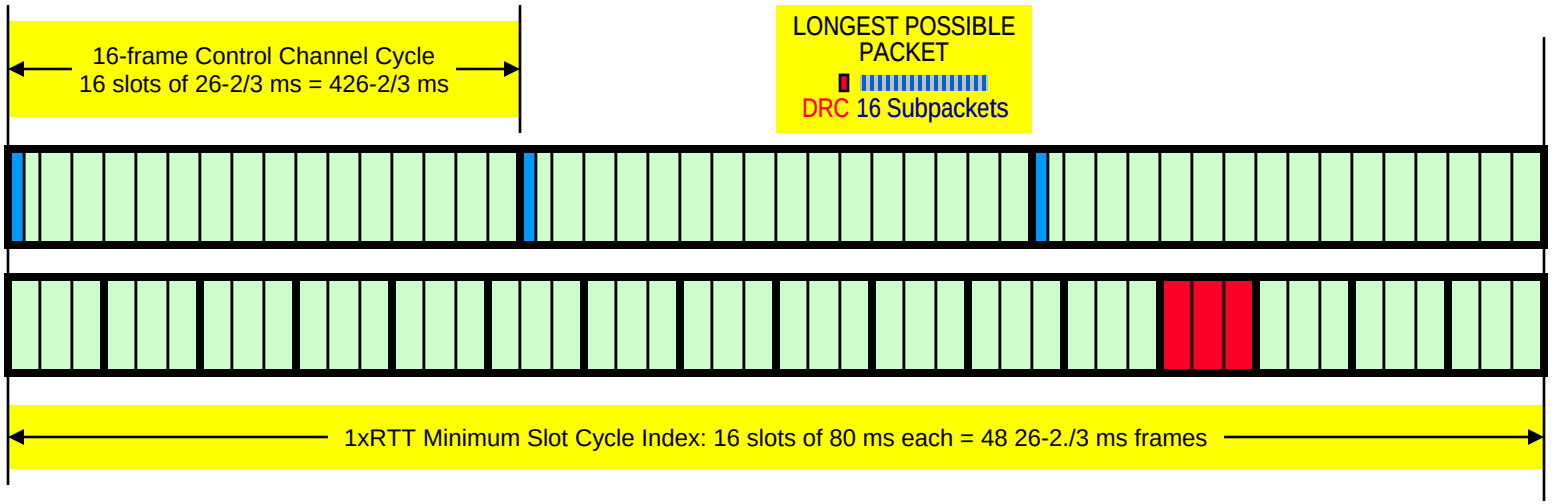
- DO systems will be Implemented in Several Configurations
  - 1:1 overlays in busy core areas
  - 1:1 or 1:N overlays in less dense areas
- Many EV>1x and 1x>EV transition events may occur as a user transitions from area to area
- Initial system acquisition is also involved as a user activates their AT in different locations
- These transitions are dependent on the Hybrid mode implementation in the AT
- The following pages show some possible transitions assuming Mobile IP and AT Hybrid Mode are implemented

1xRTT / 1xEV-DO Hybrid Idle Mode



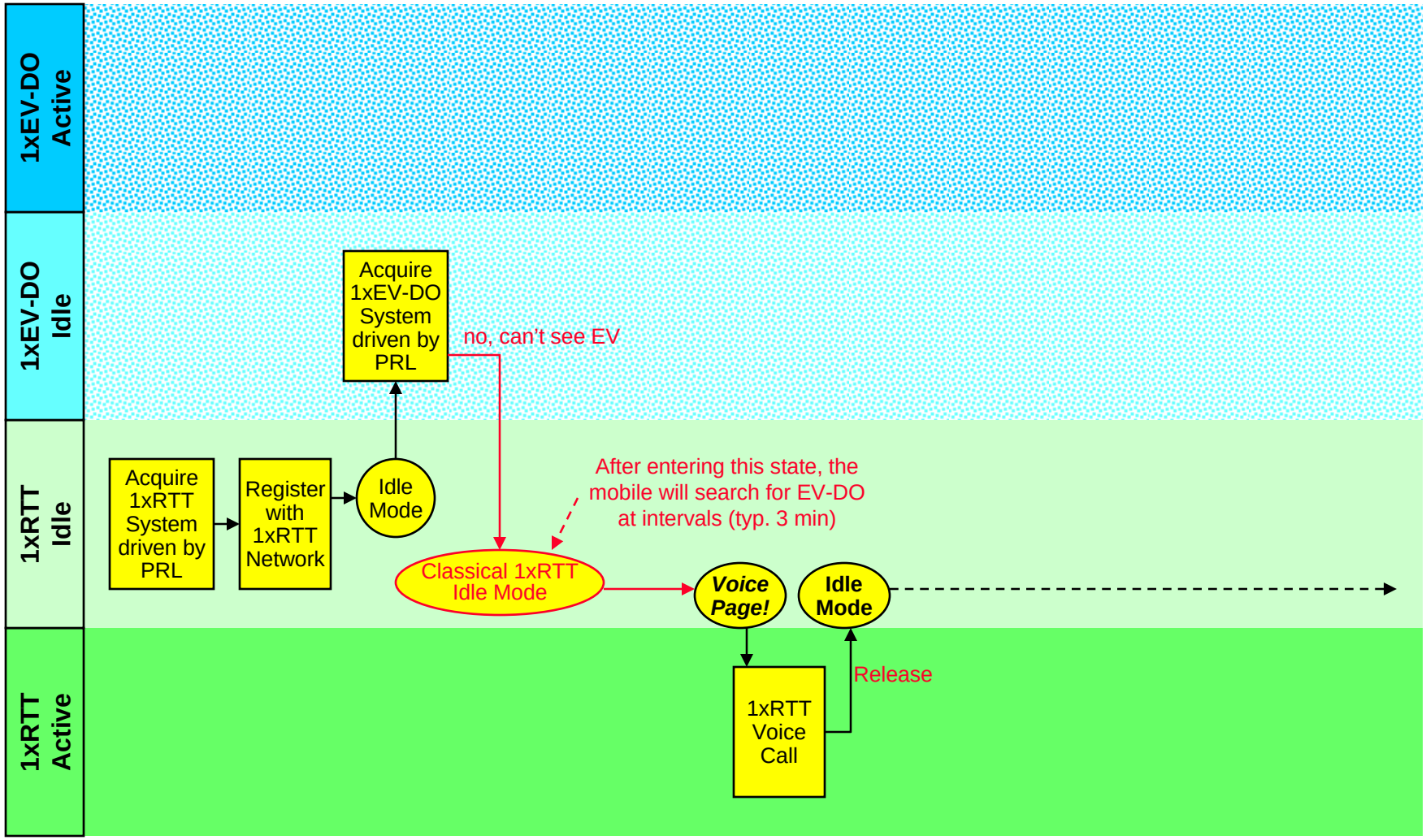
- 1xRTT/1xEV-DO Hybrid Mode
  - depends on being able to hear pages on both systems – 1xRTT and 1xEV-DO
  - is possible because of slotted mode paging
  - 1xRTT and 1xEV-DO paging slots do not occur simultaneously
  - mobile can monitor both
- During 1xEV-DO traffic operation, the hybrid-aware mobile can still keep monitoring 1xRTT paging channel
- During 1xRTT traffic operation, the hybrid-aware mobile is unable to break away; 1xRTT traffic operation is continuous
  - no opportunity to see 1xEV-DO signal
- This hybrid Idle mode capability is the foundation for all 1xRTT/1xEV mode transfers
  - the network does not trigger any transfers

Hybrid Dual-Mode Idle Operation
1xRTT / 1xEV-DO Paging Interoperability

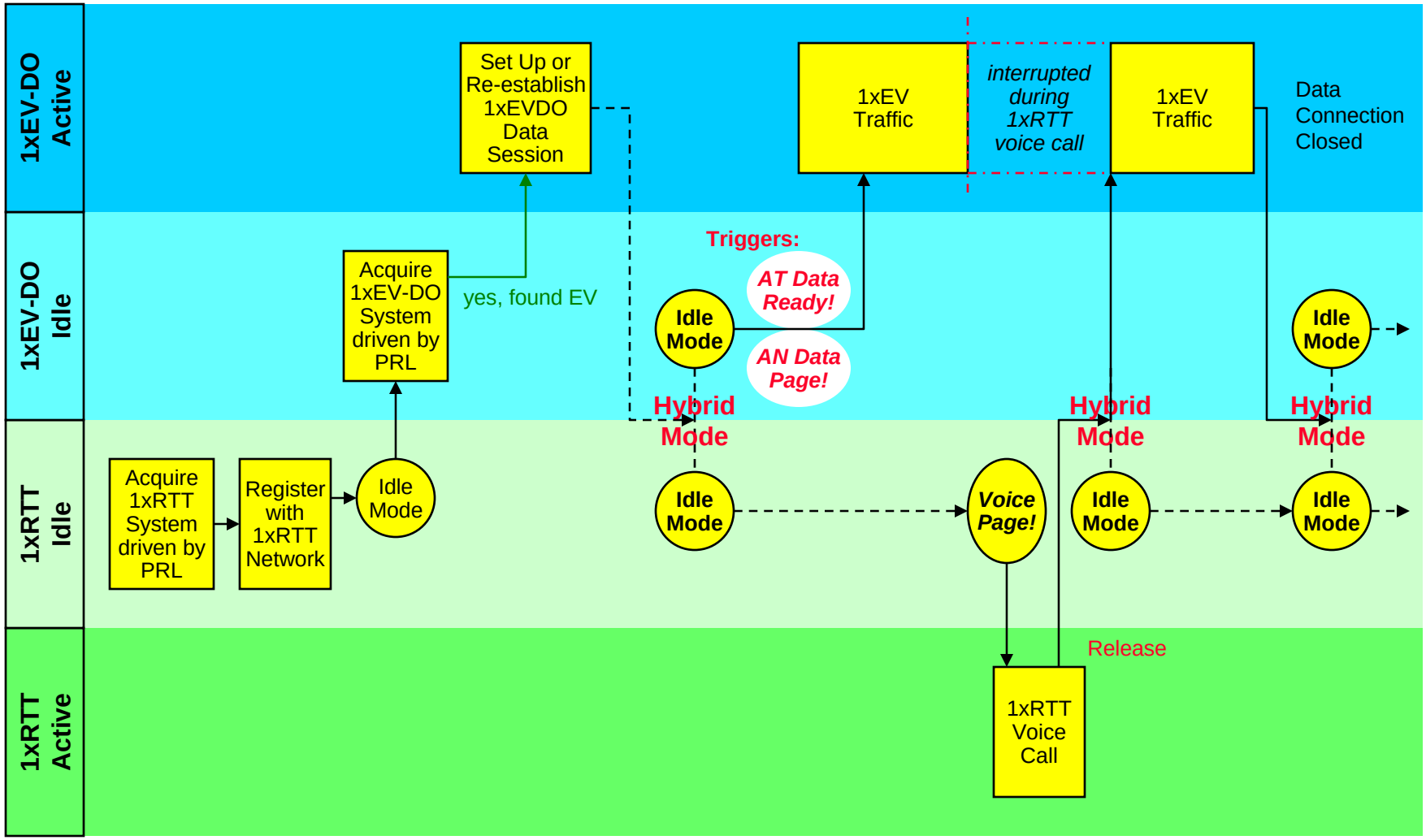


- A dual-mode 1xRTT/1xEV-DO mobile using slotted-mode paging can effectively watch the paging channels of both 1xRTT and 1xEV-DO at the same time
- How is it possible for the mobile to monitor both at the same time?
  - The paging timeslots of the two technologies are staggered
- Three of the 16 timeslots in 1xRTT conflict with the control channel slots of 1xEV-DO
  - However, conflicts can be avoided by page repetition, a standard feature in systems of both technologies

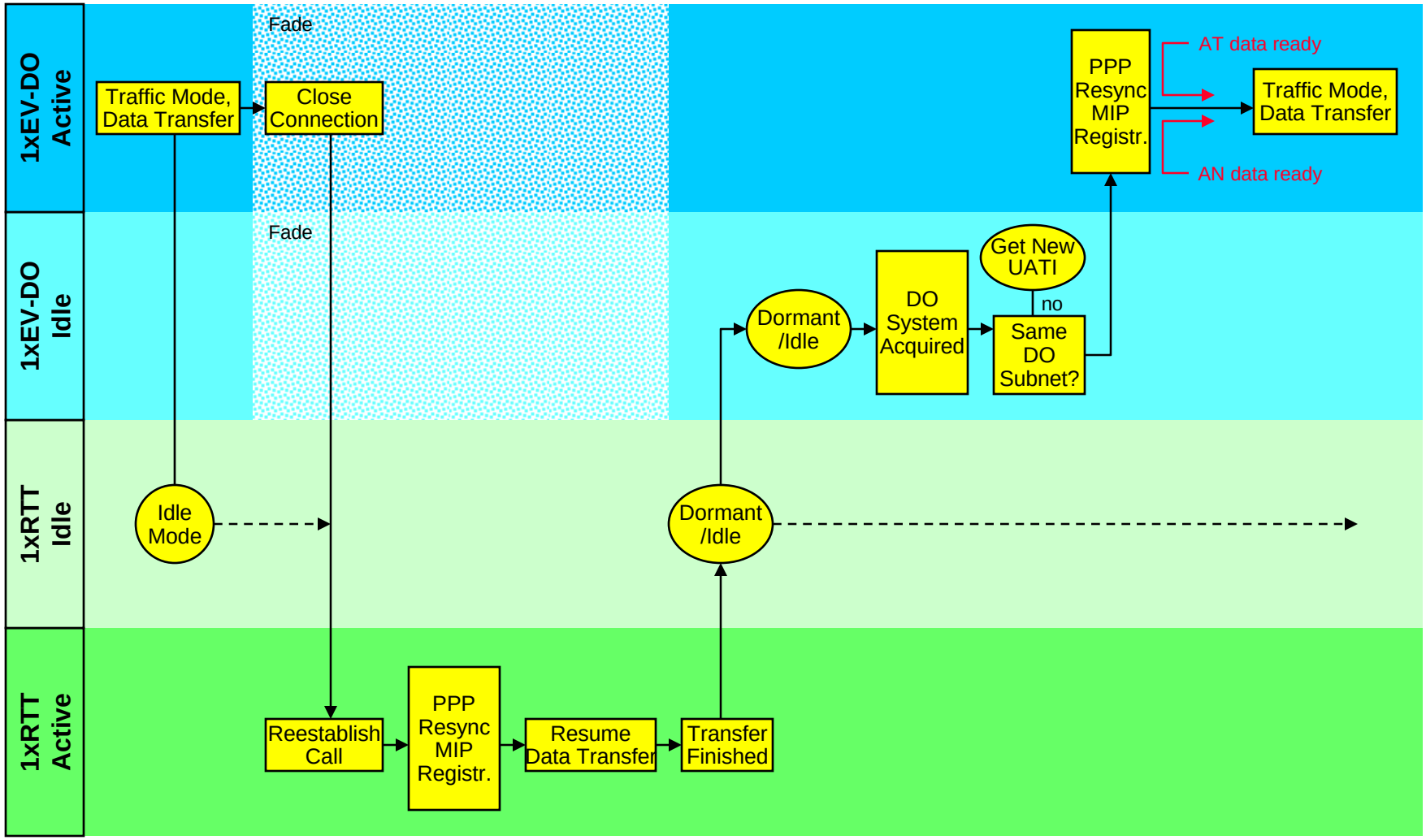
Initial System Acquisition by Hybrid Mobile when 1xEV-DO is NOT Available



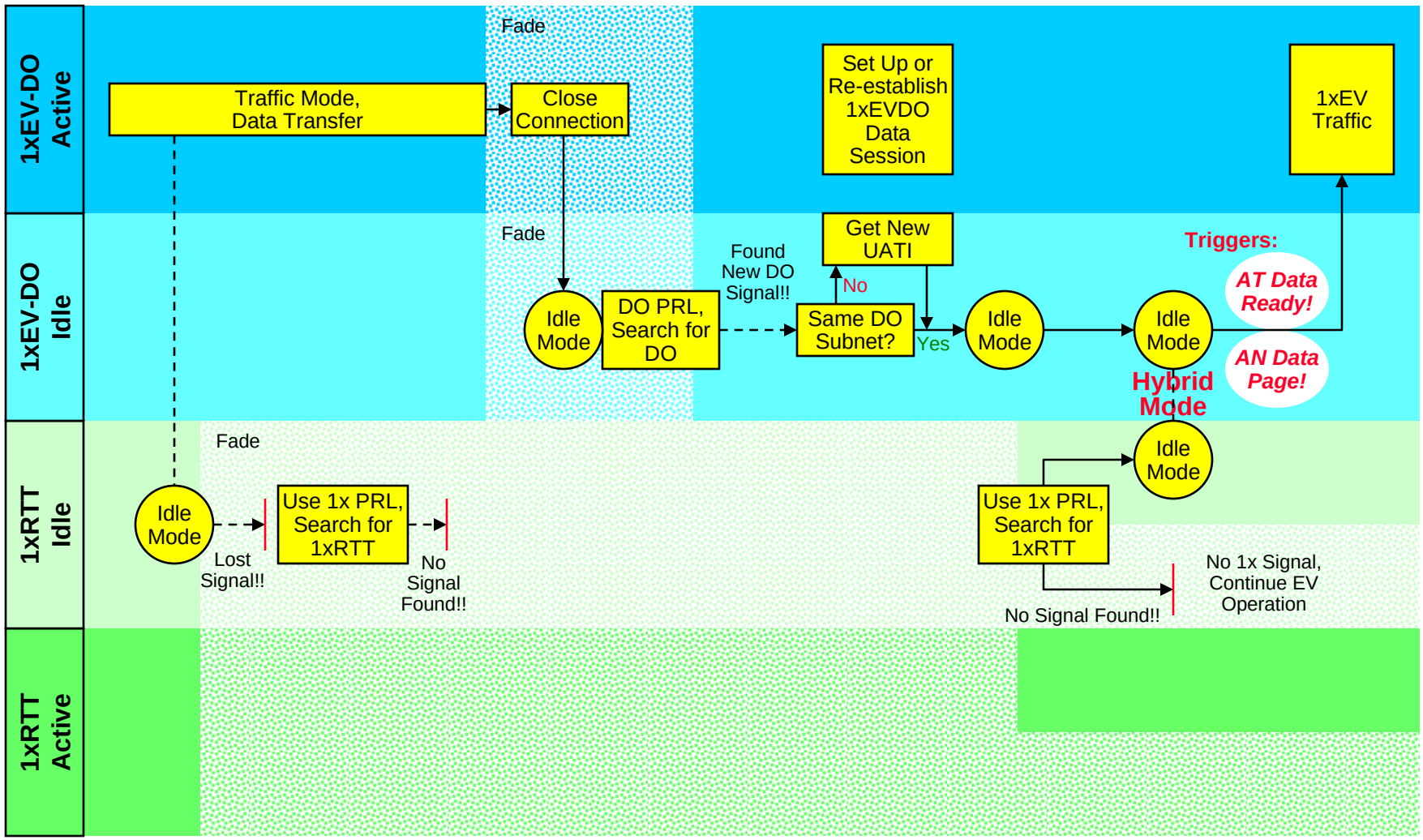
Initial System Acquisition by Hybrid Mobile when 1xEV-DO is Available



In-Traffic: EV-DO Fade with 1xRTT Available



Transition In-Traffic: Lost EV-DO and 1xRTT



Dormant Session, EV-DO Lost > 1xRTT > 1xEV-DO

