Course 131

Introduction to CDMA

Scott Baxter

www.howcdmaworks.com

800-890-0829

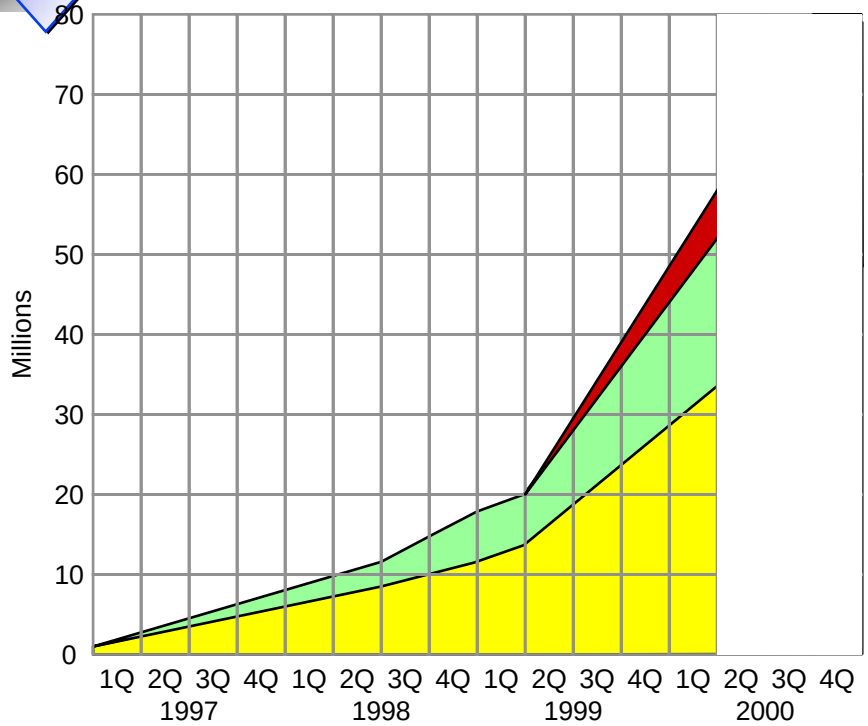
CDMA 131 Outline

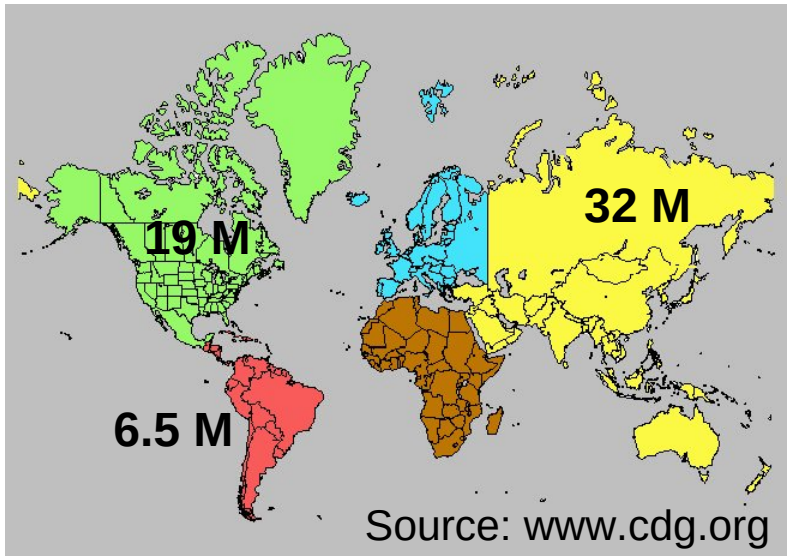
- Deployment Overview and Outlook
- CDMA Basics
  - Multiple Access Technology Survey
  - CDMA coding principles
  - Spread Spectrum principles
  - Forward and Reverse Channel Structure
- CDMA System Architecture
  - PCSC CBSC BTS OMC-R
- CDMA Details and Operation
  - Power Control
  - Handoff mechanics
  - Optimization concepts

CDMA

Deployment Status Review

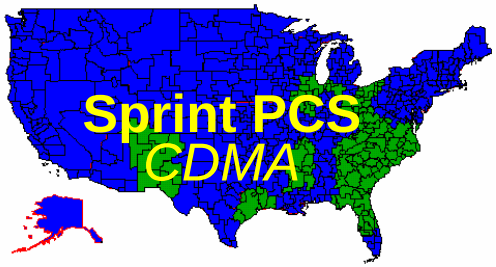
CDMA Worldwide Subscriber Growth

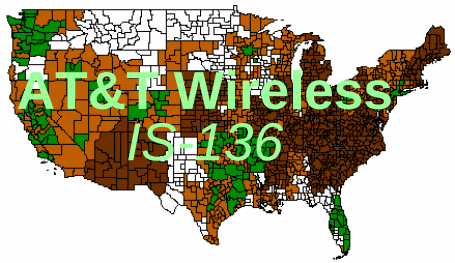


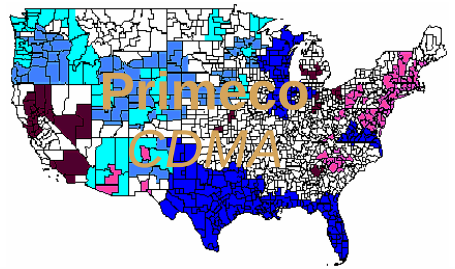


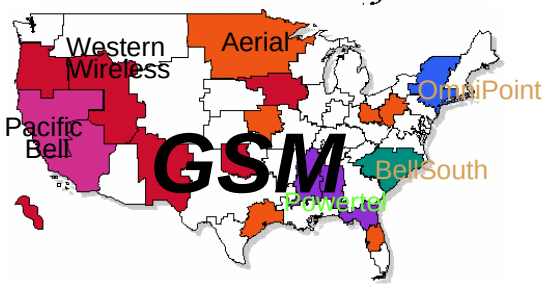
- **IS-95/J-Std008 CDMA commercial deployment began in Asia**
  - **Hong Kong, South Korea**
- **North America started later but is rapidly growing, both at 800 MHz and 1900 MHz.**
- **South/Central America is just beginning widespread commercial deployment**

United States PCS Auction Winners









The Largest Players, Areas, and Technologies

- Sprint PCS
  - **Partnership of Sprint, TCI, Cox Cable**
  - **Bid & won in 2/3 of US markets A or B blocks**
  - **Sprint itself has D and/or E blocks in remaining markets**
  - Technology: CDMA
- AT&T Wireless Systems
  - **Bid & won a majority of markets in A&B Blocks**
  - **will combine and integrate service between its new PCS 1900 systems and its former McCaw cellular 800 MHz. properties**
  - Technology: TDMA IS-54, IS-136B
- Primeco
  - **Partnership of Airtouch, US West, Bell Atlantic,**
  - Technology: CDMA
- GSM Operators
  - **Western Wireless, OmniPoint, BellSouth, GTE, Powertel, Pacific Bell**
  - Technology: TDMA (ETSI GSM)

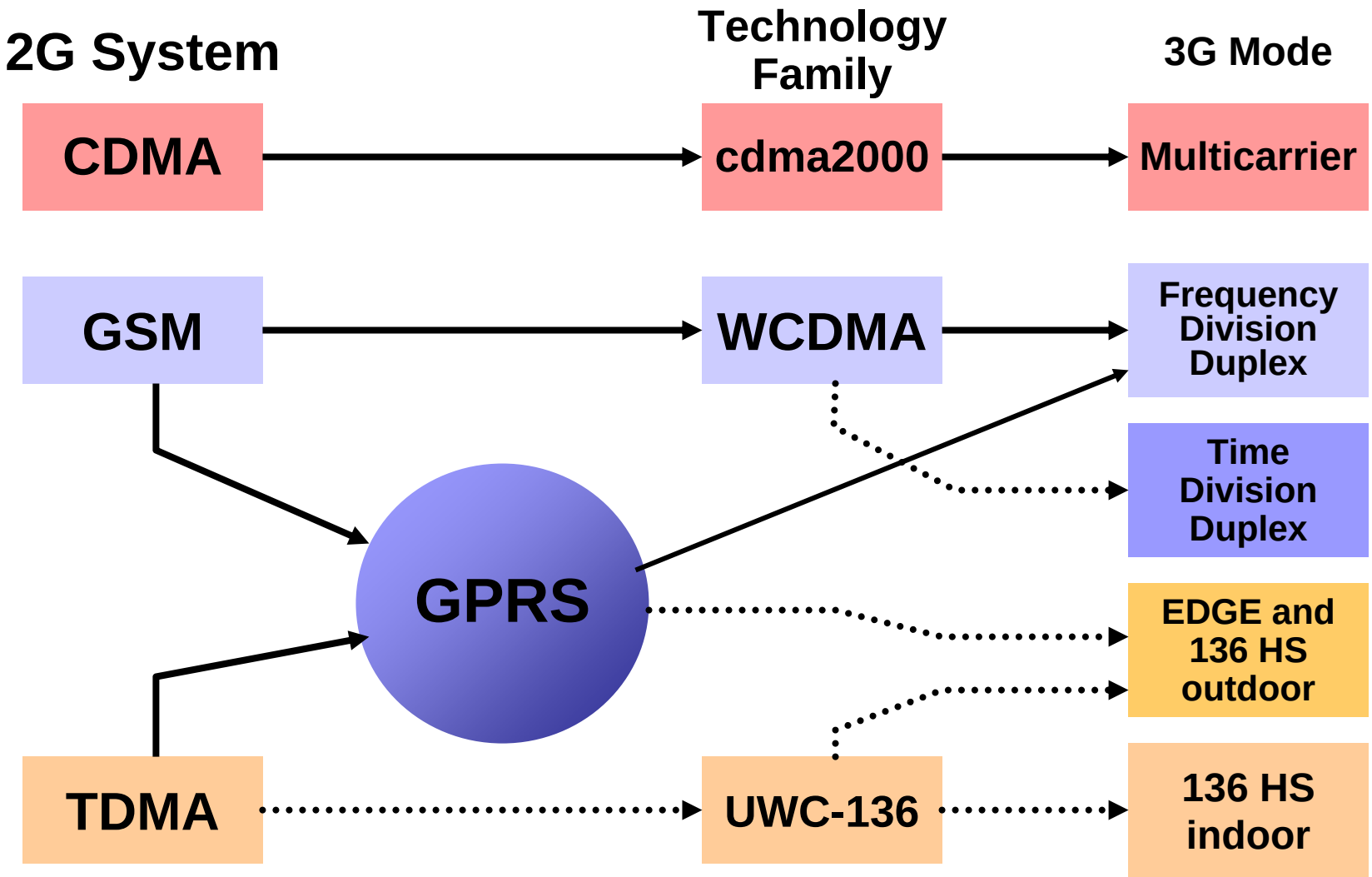
Canadian Wireless Technologies, Manufacturers, and Operators

Frequency Band, MHz	Tech-nology	Network Manu-facturer	Geographic Area								
			British Columbia	Alberta	Saskatch-ewan	Manitoba	Ontario	Quebec	New Brunswick	Nova Scotia	Newfound-land
900	IDEN	Motorola	Clearnet "MIKE"								
1900	CDMA	Lucent	Clearnet PCS								
1900	GSM	Ericsson	Microcell "FIDO"								
1900	CDMA	Nortel	BCTEL / TELUS		SaskTel	MTS	Bell		NBTel	M&T	NEWTEL / Island Tel
800 "B"	AMPS TDMA	Nortel	Mobilink Canada								
1900	IS-136	?	?								
800 "A"	AMPS TDMA	Ericsson	Rogers Cantel								

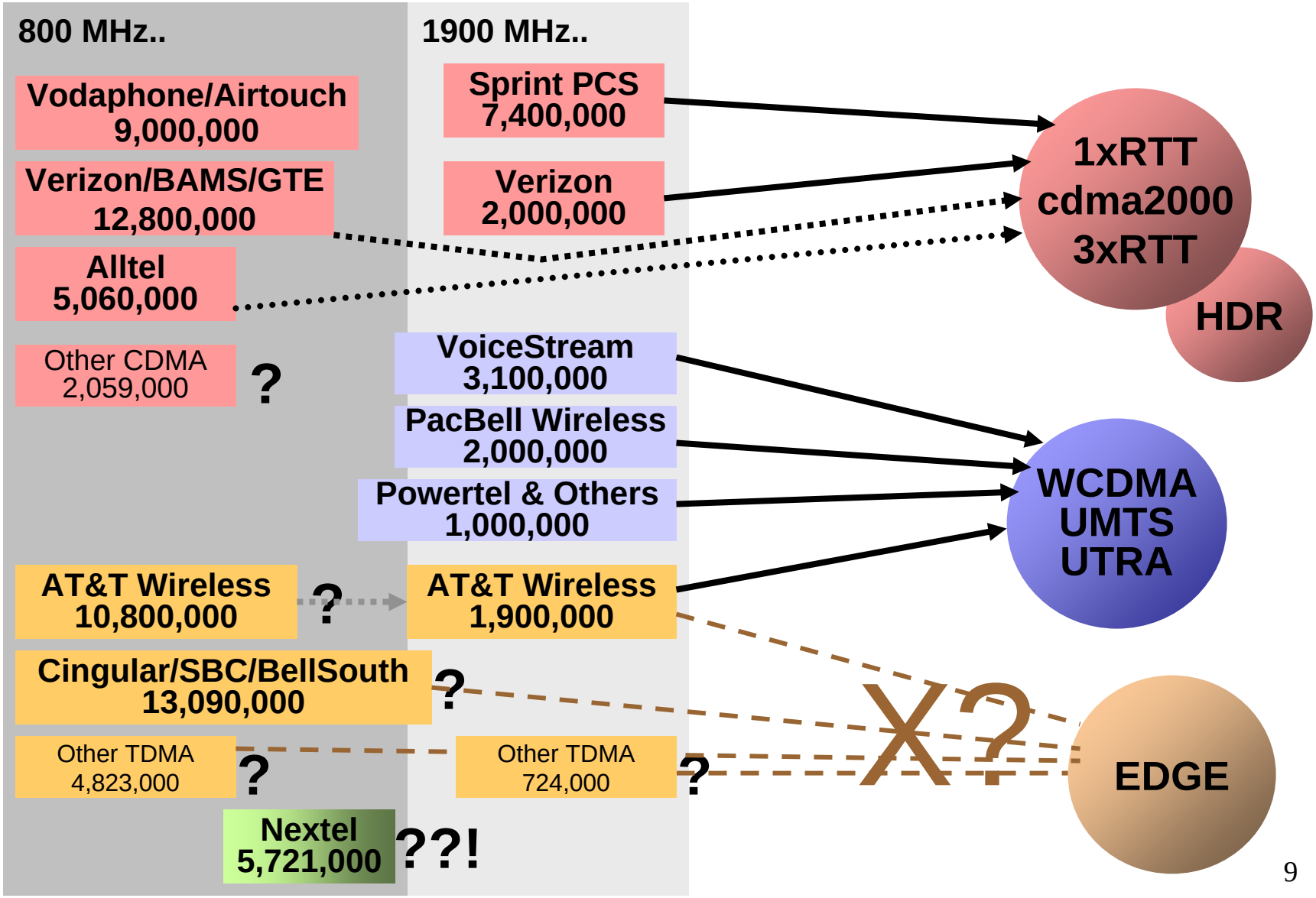
3G Wideband CDMA

- Regardless of the degree of acceptance of IS-95 “narrowband CDMA” systems, Third Generation proposals for wideband CDMA are attracting great attention both from manufacturers and carriers
- 3G systems will offer higher bandwidth services, including medium speed data service at rates up to 384 Kbs for mobile users, and up to 2 MBs for stationary users
- Operators and manufacturers are presently waiting and studying the limited number of trials of 3G systems presently underway

2G to 3G Migration Paths



North American 3G Migration Plans



Next Generation CDMA Enhancements

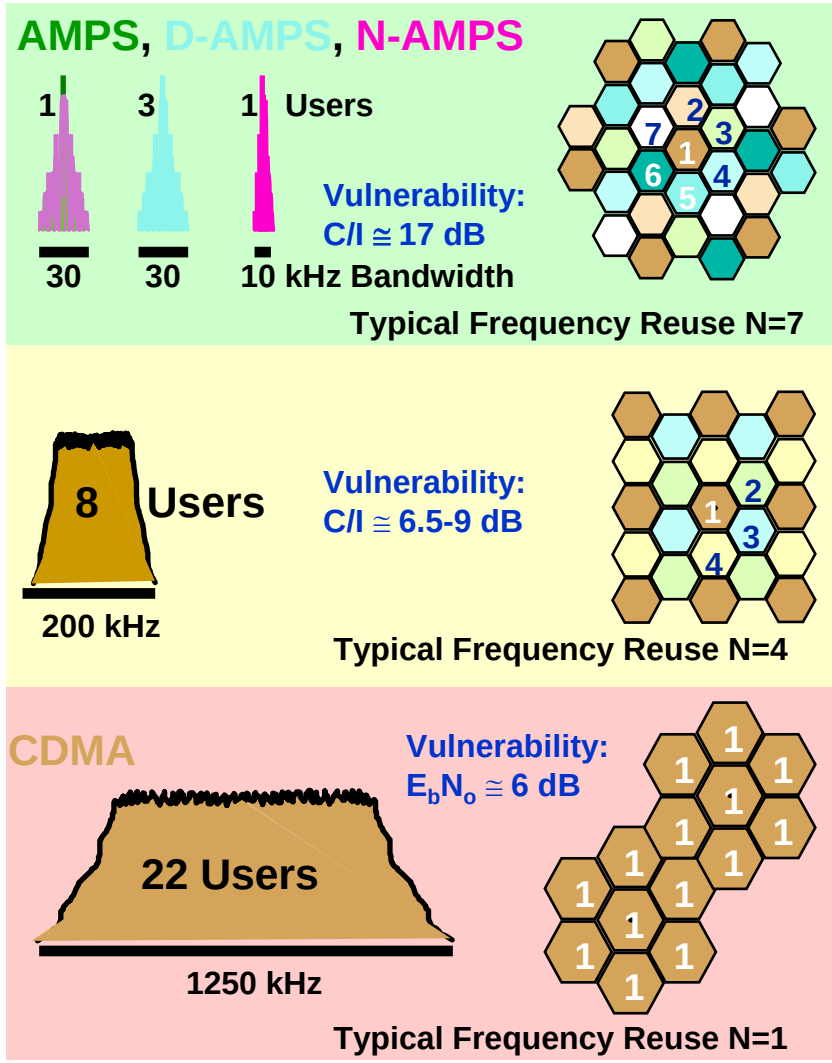
- **IS-95B**
  - **Improved handoff, faster data, improved access**
- **1xRTT (“2.5G”)**
  - **2x capacity in same chip rate & bandwidth**
  - **All IS-95B refinements**
- **Qualcomm’s HDR (High Data Rates)**
  - **Up to 2.4 Mb/s on a single CDMA signal**
- **3xRTT**
  - **US (CDMA2000) version: 3x chip rate and more**
    - **Even faster data: 2 MB bursting**
  - **European (W-CDMA) version: GPS not required**
- **UMTS Universal Mobile Terrestrial Services**
  - **The European equivalent to 3xRTT CDMA**
  - **3G migration path for today’s GSM systems**

Capacity of CDMA Networks

Wireless System Capacity

Each wireless technology (AMPS, NAMPS, D-AMPS, GSM, CDMA) uses a specific modulation type with its own unique signal characteristics

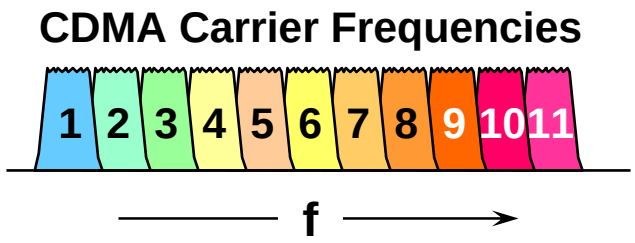
- **Signal Bandwidth determines how many RF signals will "fit" in the operator's licensed spectrum**
- Robustness of RF signal determines tolerable level of interference and necessary physical separation of cochannel cells
- **Number of users per RF signal directly affects capacity**
- **In the following page, we will develop the number of users and traffic in erlangs per site for each of the popular wireless technologies**



Wireless System Capacity Comparisons

	800 Cellular (A,B)			1900 PCS (A, B, C)			1900 PCS (D, E, F)		
Fwd/Rev Spectrum kHz.	12,500	12,500	12,500	15,000	15,000	15,000	5,000	5,000	5,000
Technology	AMPS	TDMA	CDMA	TDMA	GSM	CDMA	TDMA	GSM	CDMA
Req'd C/I or Eb/No, db	17	17	6	17	12	6	17	12	6
Freq Reuse Factor, N	7	7	1	7	4	1	7	4	1
RF Signal BW, kHz	30	30	1250	30	200	1250	30	200	1250
Total # RF Carriers	416	416	9	500	75	11	166	25	3
RF Sigs. per cell @N	59	59	9	71	18	11	23	6	3
# Sectors per cell	3	3	3	3	3	3	3	3	3
#CCH per sector	1	1	0	1	0	0	1	0	0
RF Signals per sector	18	18	9	22	6	11	6	2	3
Voicepaths/RF signal	1	3	22	3	8	22	3	8	22
SH average links used			1.66			1.66			1.66
Unique Voicepaths/carrier			13.253			13.253			13.253
Voicepaths/Sector	18	54	198	66	48	242	18	16	66
Unique Voicepaths/Sector	18	54	119	66	48	145	18	16	39
P.02 Erlangs per sector	11.5	44	105.5	55.3	38.4	130.9	11.5	9.83	30.1
P.02 Erlangs per site	34.5	132	316.5	165.9	115.2	392.7	34.5	29.49	90.3
Capacity vs. AMPS800	**1**	**3.8**	**9.2**	**4.8**	**3.3**	**11.4**	**1.0**	**0.9**	**2.6**

Multicarrier CDMA Capacity



Fwd/Rev Spectrum kHz.	12,500	1,800	3,050	4,300	5,550	6,800	8,050	9,300	10,550	11,800	13,050	14,300
Technology	**AMPS**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**	**CDMA**
Req'd C/I or Eb/No, db	17	6	6	6	6	6	6	6	6	6	6	6
Freq Reuse Factor, N	7	1	1	1	1	1	1	1	1	1	1	1
RF Signal BW, kHz	30	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
Total # RF Carriers	416	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RF Sigs. per cell @N	59	1	2	3	4	5	6	7	8	9	10	11
# Sectors per cell	3	3	3	3	3	3	3	3	3	3	3	3
#CCH per sector	1	0	0	0	0	0	0	0	0	0	0	0
RF Signals per sector	18	1	2	3	4	5	6	7	8	9	10	11
Voicepaths/RF signal	1	22	22	22	22	22	22	22	22	22	22	22
SH average links used	1	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
Unique Voicepaths/carrier	1	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
Voicepaths/Sector	18	22	44	66	88	110	132	154	176	198	220	242
Unique Voicepaths/Sector	18	13	26	39	53	66	79	92	106	119	132	145
P.02 Erlangs per sector	11.5	7.4	18.4	30.1	43.1	55.3	67.7	80.2	93.8	105.5	119.1	130.9
P.02 Erlangs per site	34.5	22.2	55.2	90.3	129.3	165.9	203.1	240.6	281.4	316.5	357.3	392.7
Capacity vs. AMPS800	**1**	**0.64**	**1.60**	**2.6**	**3.7**	**4.8**	**5.9**	**7.0**	**8.2**	**9.2**	**10.4**	**11.4**

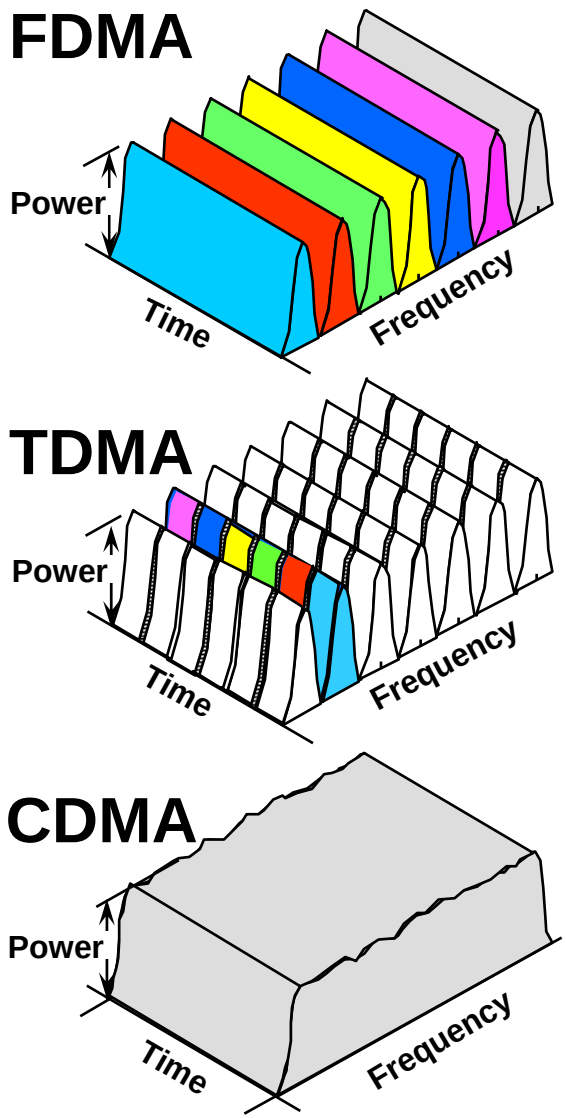
Current CDMA Network Capacity Issues

- Today, CDMA networks for the most part are still single-carrier
  - this severely limits the capacity of one BTS to approximately 20 erlangs
  - implementing additional carriers brings logistical problems involving handoffs and system acquisition by mobiles
- Multiple-carrier operation is essential to achieve reasonable capacities
- Within networks, there are strategies for squeezing the most out of overloaded single-carrier BTSs. Some of the main points are:
  - reduce Pilot, Sync, and Paging levels as low as possible, thereby gaining precious additional energy for traffic channels
  - reduce BTS traffic channel DGU settings as low as possible without provoking forward link FER.

CDMA Basics

Multiple Access Technologies

- **FDMA** (example: AMPS)
  - **Frequency Division Multiple Access**
    - each user has a private frequency
- **TDMA** (examples: IS-54/136, GSM)
  - **Time Division Multiple Access**
    - each user has a private time on a private frequency
- **CDMA** (IS-95, J-Std. 008)
  - **Code Division Multiple Access**
    - users co-mingle in time and frequency but each user has a private code



Other Technologies: Avoiding Interference

- **AMPS, TDMA and GSM depend on physical distance separation to keep interference at low levels**
- **Co-channel users are kept at a safe distance by careful frequency planning**
- **Nearby users and cells must use different frequencies to avoid interference**

AMPS-TDMA-GSM

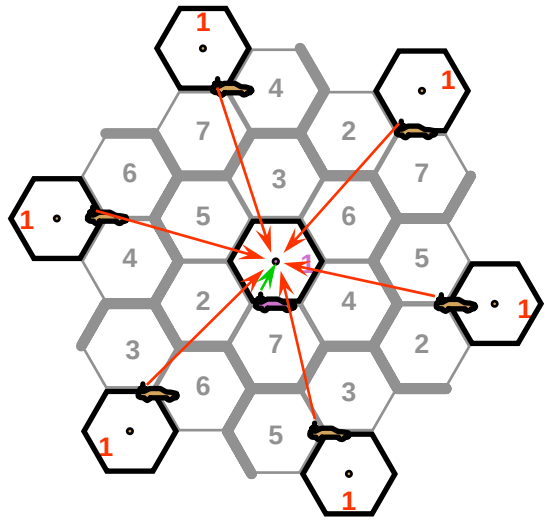


Figure of Merit: C/I
(carrier/interference ratio)
AMPS: +17 dB
TDMA: +14 to 17 dB
GSM: +7 to 9 dB.

CDMA: Using A New Dimension

- All CDMA users occupy the same frequency at the same time! Time and frequency are not used as discriminators
- CDMA interference comes mainly from nearby users
- CDMA operates by using CODING to discriminate between users
- Each user is a small voice in a roaring crowd -- but with a uniquely recoverable code

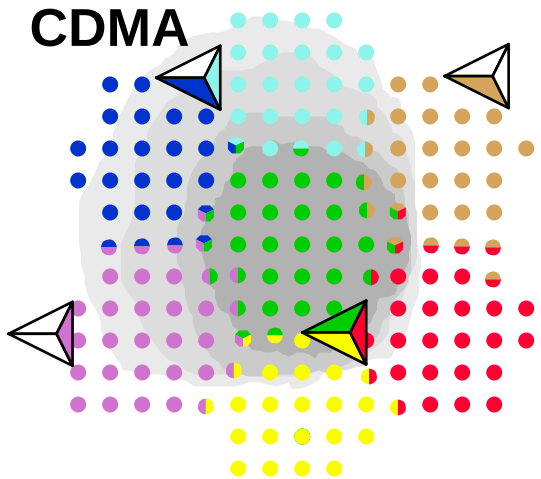
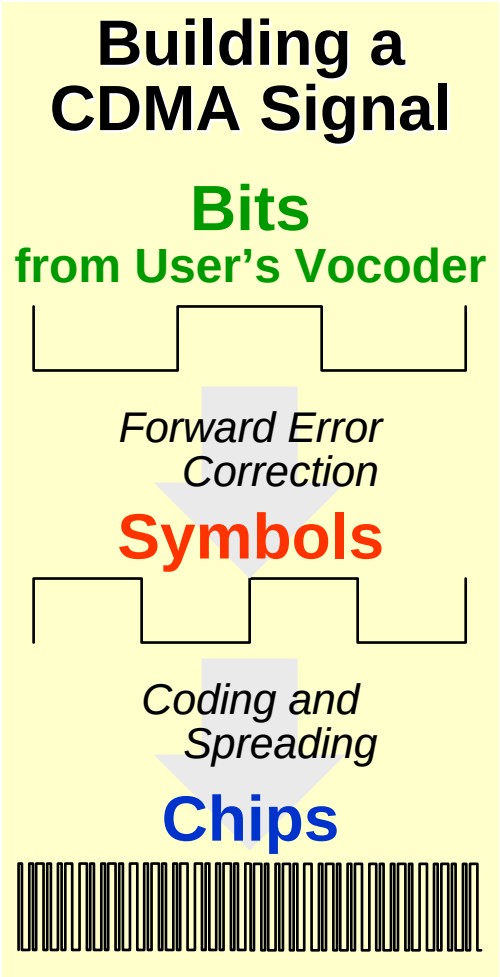


Figure of Merit: C/I
(carrier/interference ratio)
AMPS: +17 dB
TDMA: +14 to +17 dB
GSM: +7 to 9 dB.
CDMA: -10 to -17 dB.
CDMA: E_b/N_o ~+6 dB.

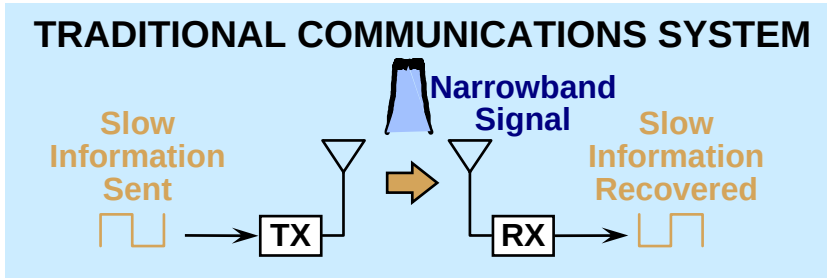
CDMA Uses Code Channels

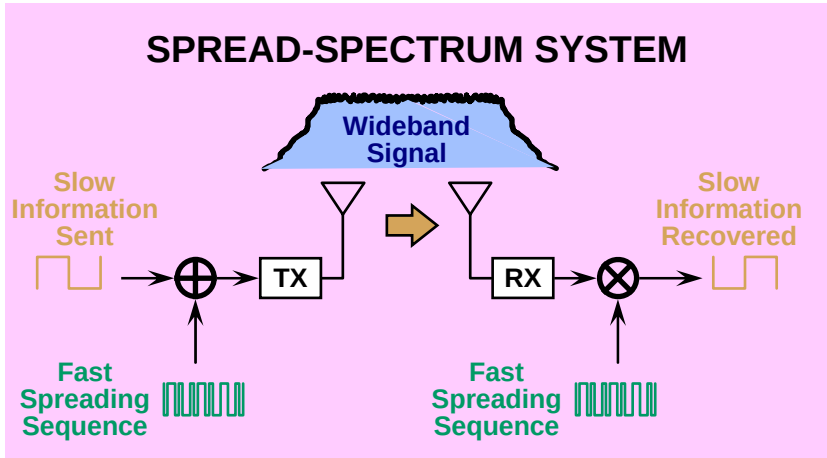
- A CDMA signal uses many chips to convey just one bit of information
- Each user has a unique chip pattern, in effect a code channel
- To recover a bit, integrate a large number of chips interpreted by the user's known code pattern
- Other users' code patterns appear random and integrate toward low values, hence don't disturb the bit decoding decision



CDMA is a Spread-Spectrum System

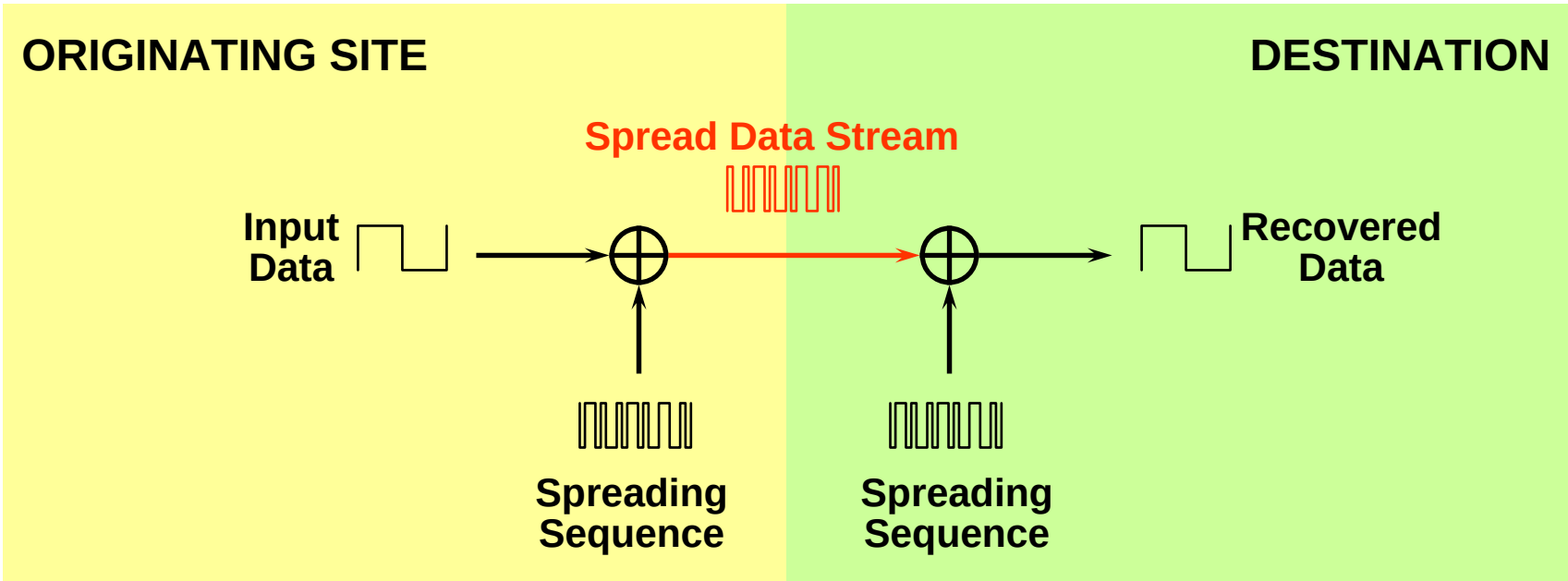
- **Traditional technologies try to squeeze signal into minimum required bandwidth**
- **CDMA uses larger bandwidth but uses resulting processing gain to increase capacity**





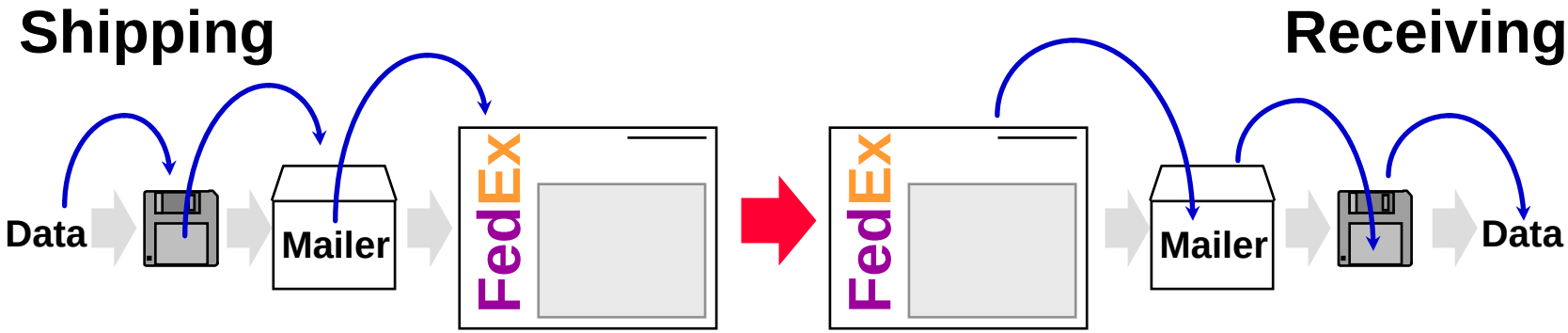
Spread Spectrum Payoff:
Processing Gain

Spreading: What we do, we can undo



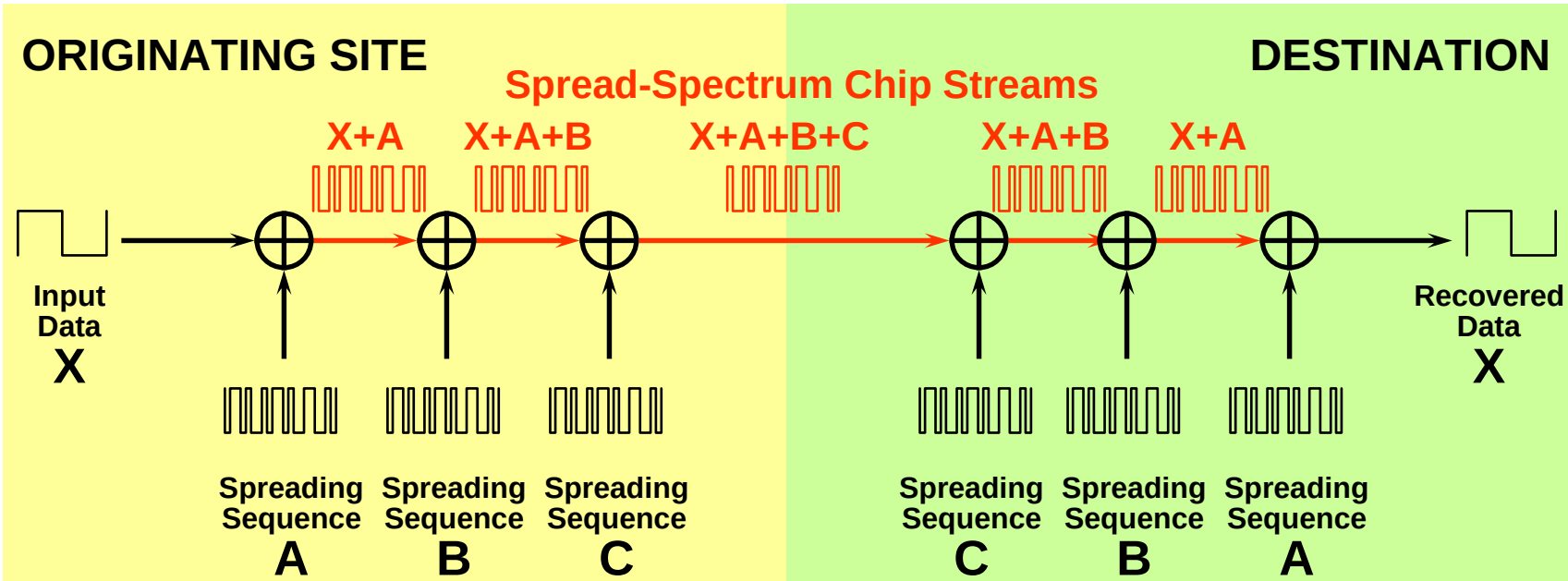
- Sender combines data with a fast spreading sequence, transmits spread data stream
- Receiver intercepts the stream, uses same spreading sequence to extract original data

"Shipping and Receiving" via CDMA



- **Whether in shipping and receiving, or in CDMA, packaging is extremely important!**
- **Cargo is placed inside "nested" containers for protection and to allow addressing**
- **The shipper packs in a certain order, and the receiver unpacks in the reverse order**
- **CDMA "containers" are spreading codes**

CDMA's Nested Spreading Sequences

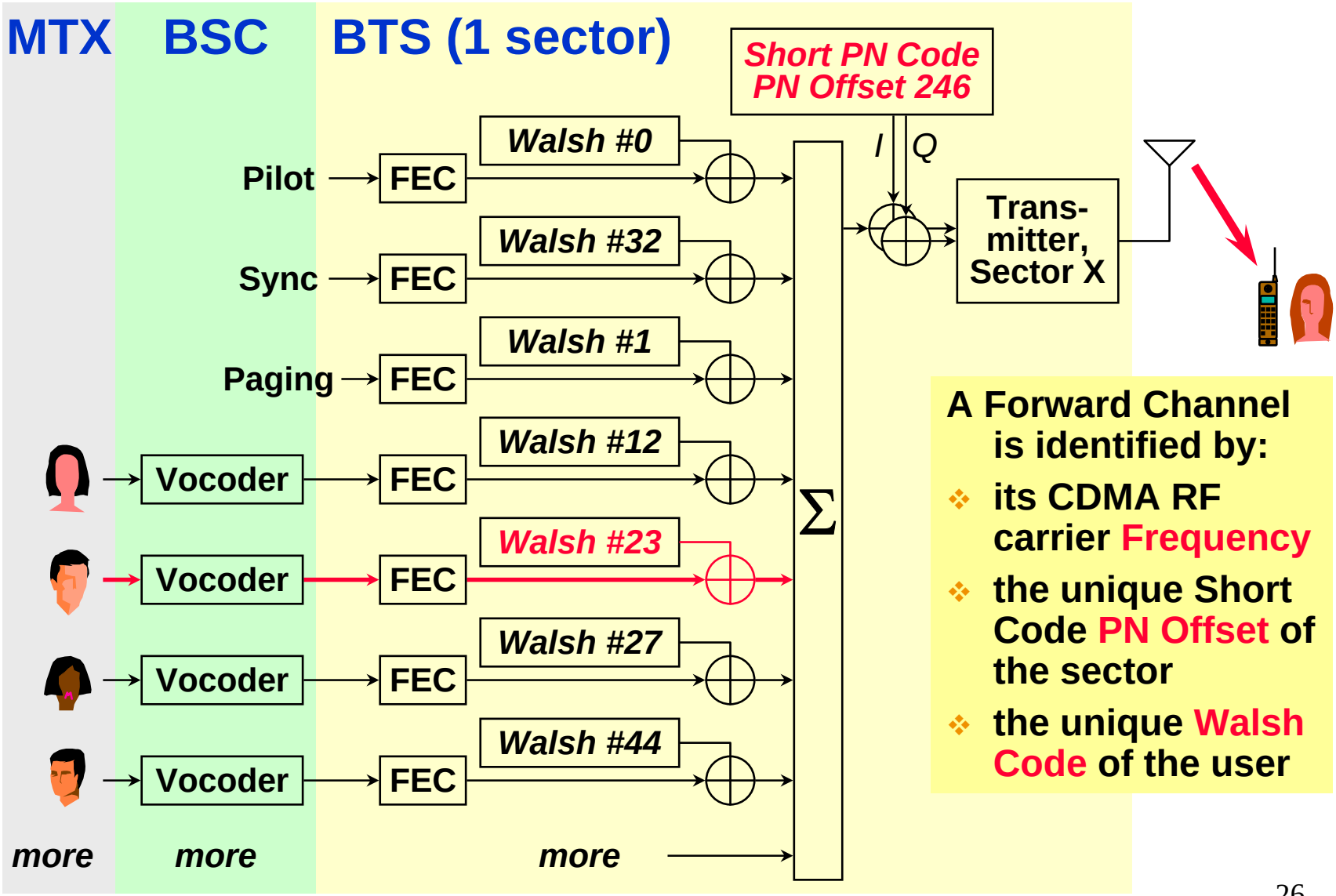


- CDMA combines three different spreading sequences to create unique, robust channels
- The sequences are easy to generate on both sending and receiving ends of each link
- "What we do, we can undo"

The Three CDMA Spreading Sequences

- **Walsh Codes:** *64 are available*
  - **64 chips long -- lasts 1/19200 sec**
  - **mutually orthogonal**
- **PN Short Code:** *one pair is used (I & Q)*
  - **32K long -- lasts 26-2/3 mS, repeats 75x in 2 sec.**
    - **generated in 15-bit tapped shift register**
  - **Nearly self-orthogonal if compared out-of-sync**
- **PN Long Code:** *only one is used*
  - **2^{42}-1 chips long -- lasts 40+ days!**
    - **generated in 42-bit tapped shift register**
  - **Any short sample is nearly orthogonal with any other short sample**

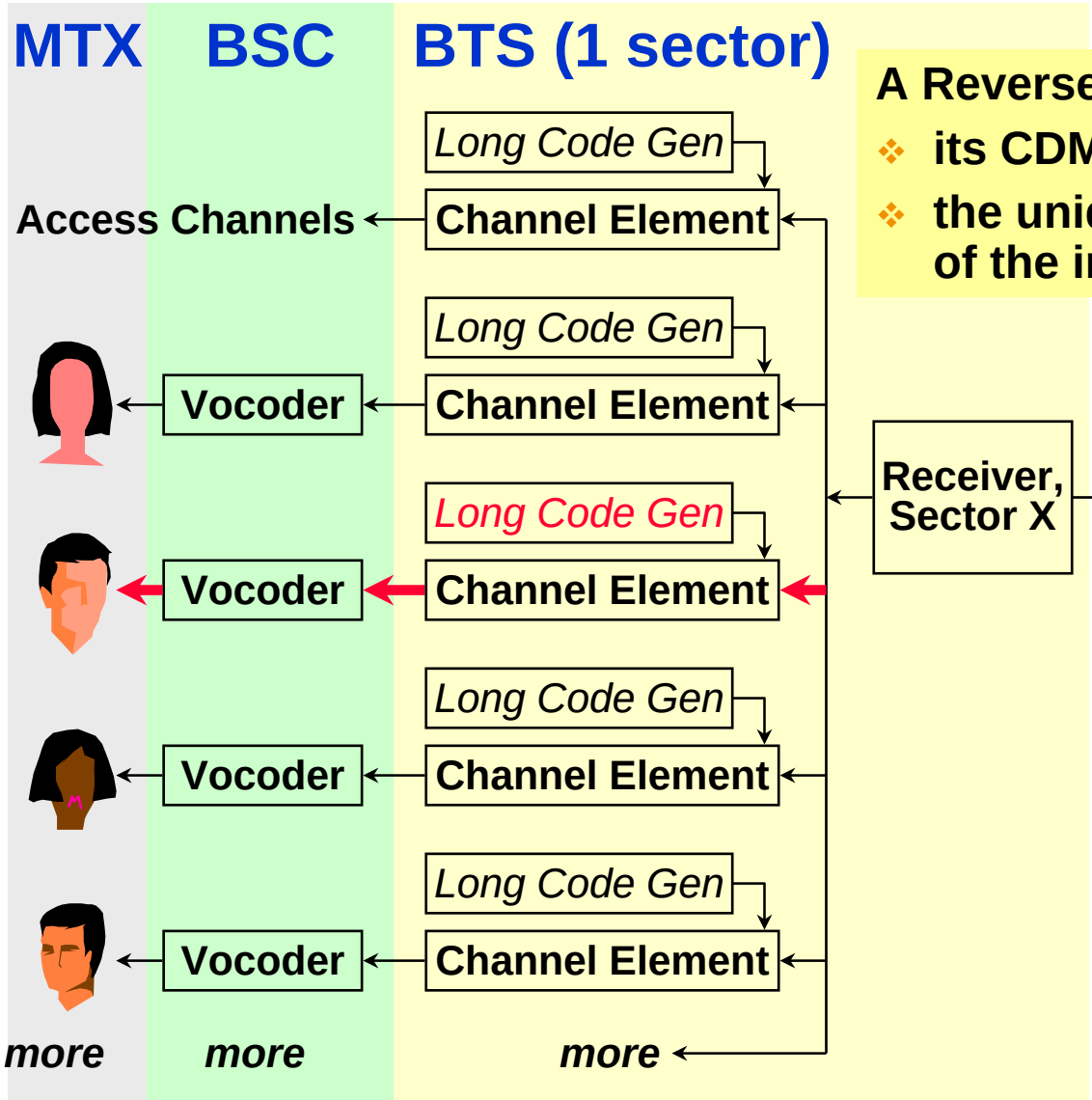
Code Channels in the Forward Direction



A Forward Channel is identified by:

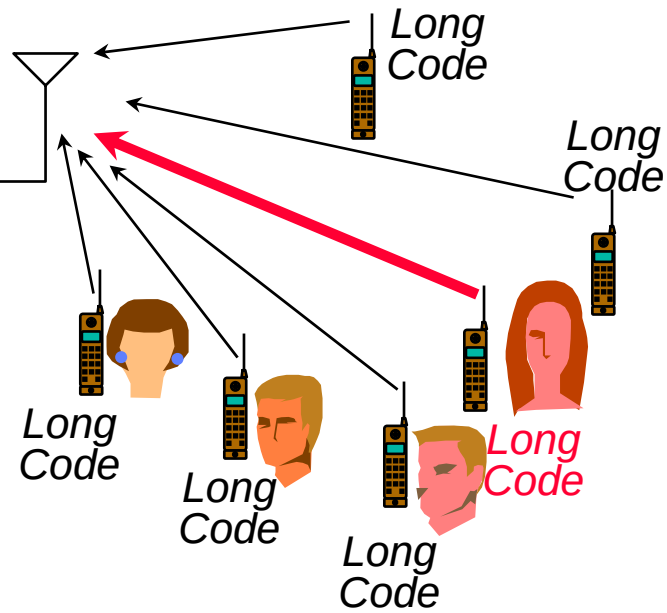
- its CDMA RF carrier Frequency
- the unique Short Code PN Offset of the sector
- the unique Walsh Code of the user

Code Channels in the Reverse Direction



A Reverse Channel is identified by:

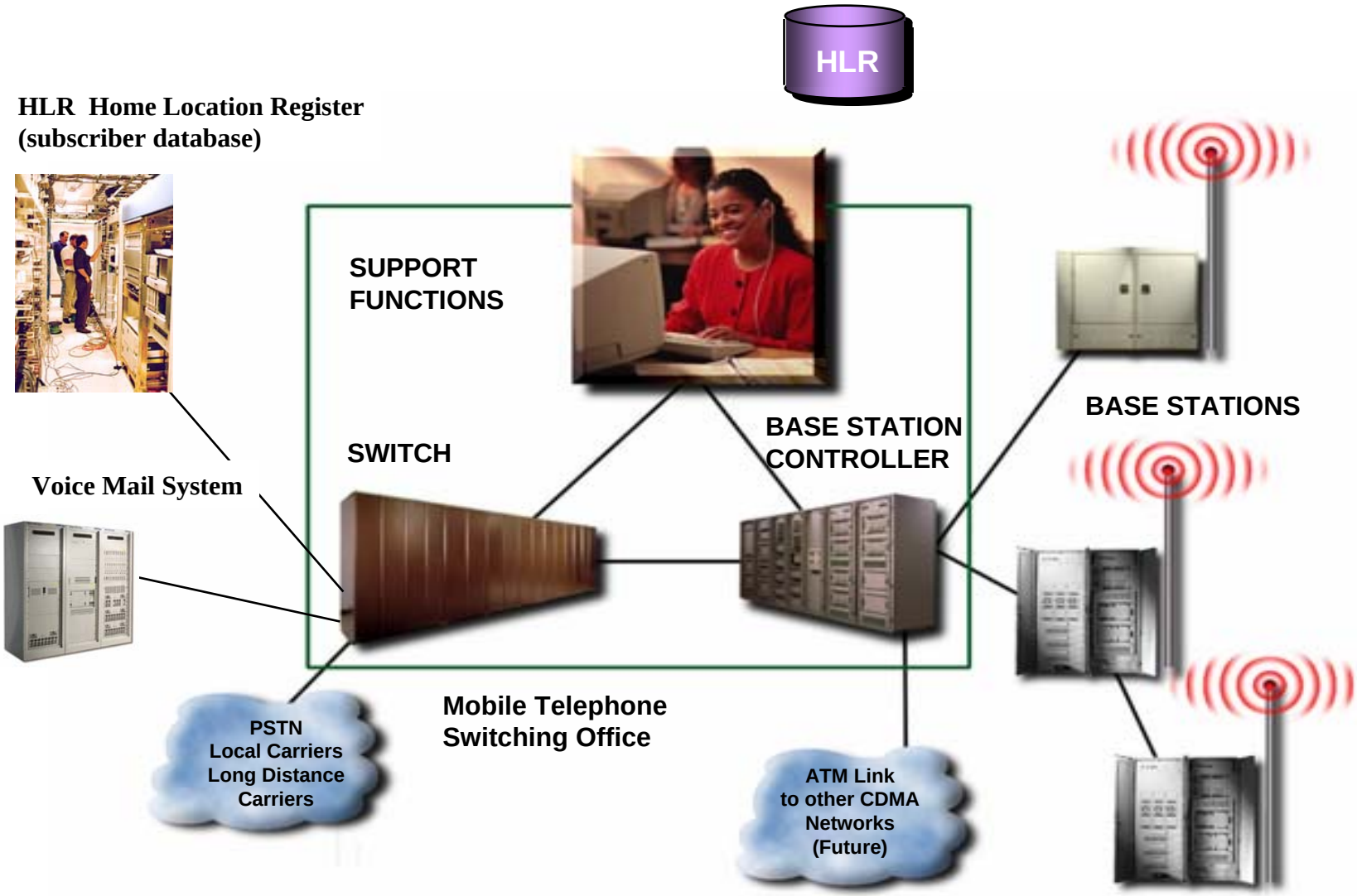
- **its CDMA RF carrier Frequency**
- **the unique Long Code PN Offset of the individual handset**



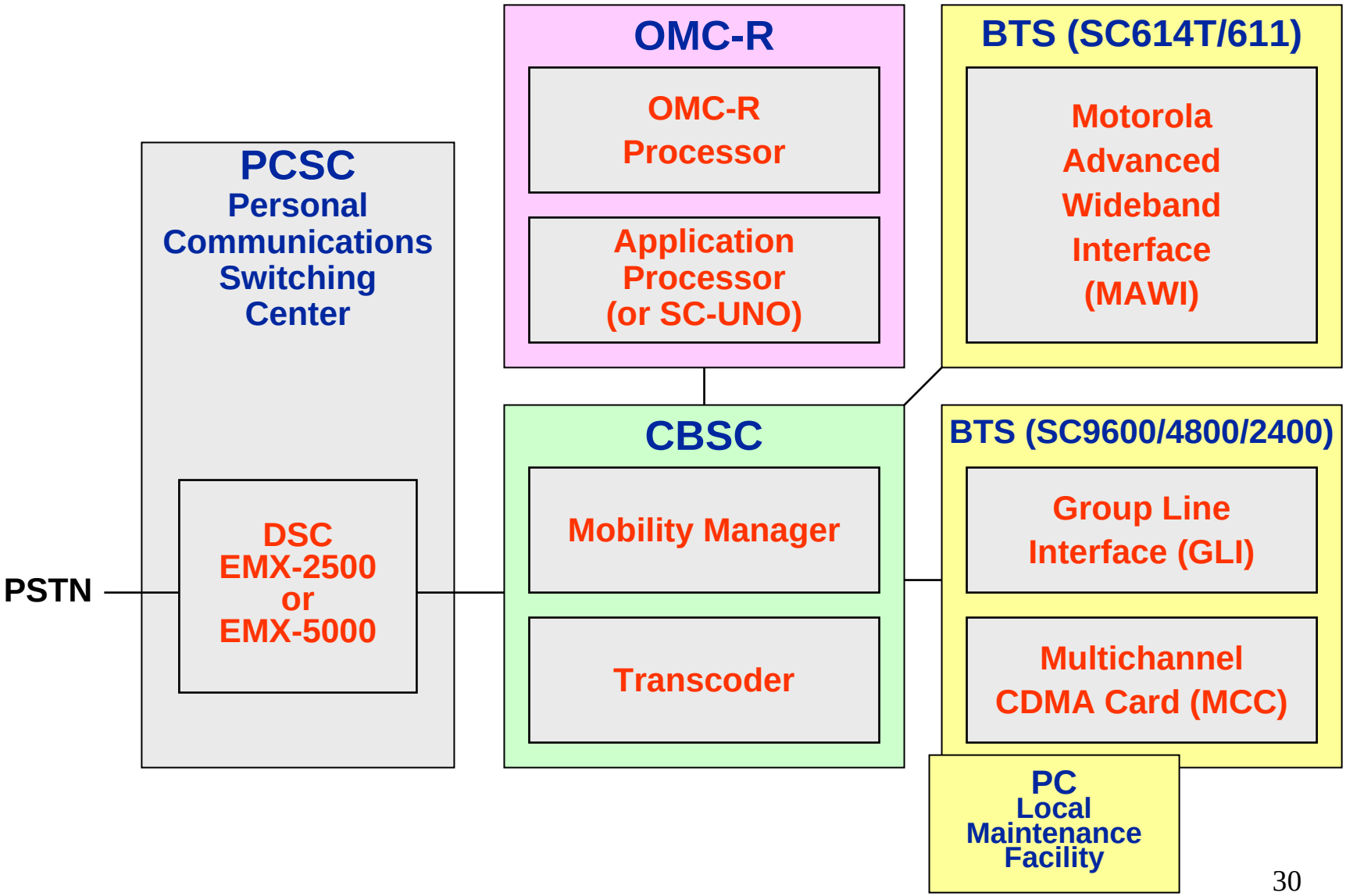
CDMA Network Architecture

www.motorola.com

Structure of a Typical Wireless System

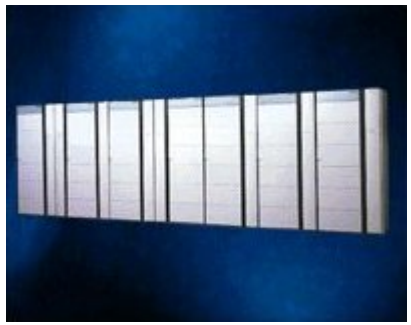


Motorola CDMA System Architecture

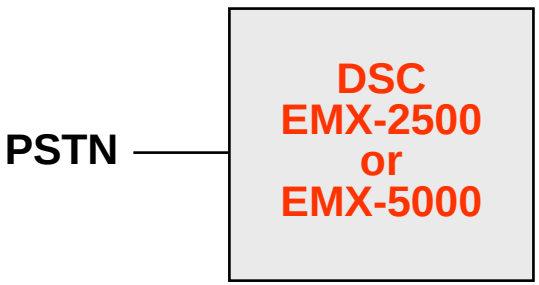


The Motorola PCSC

EMX-2500

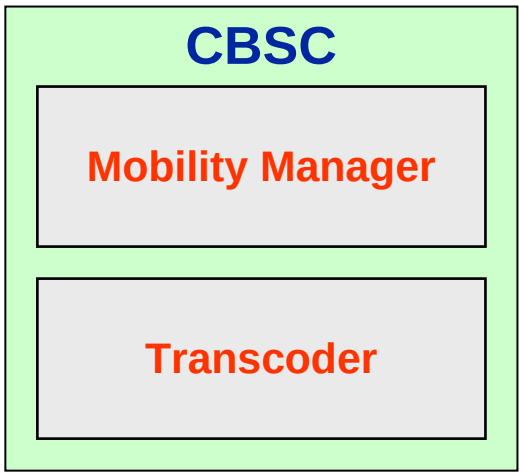


EMX-5000



- Personal Communications Switching Center
- Primary functions
  - Call Processing
  - HLR-VLR access
  - Intersystem call delivery (IS-41C)
  - Billing Data Capture
  - Calling Features & Services

The Motorola CBSC



- Centralized Base Station Controller
- Mobility Manager
  - allocation of BTS resources
  - handoff management
  - Call management & supervision
- Transcoder
  - vocoding
  - soft handoff management
  - FER-based power control
  - routing of all traffic and control packets

The Motorola BTS Family

BTS (SC614T/611)

Motorola Advanced Wideband Interface (MAWI)

BTS (SC9600/4800/2400)

Group Line Interface (GLI)

Multichannel CDMA Card (MCC)

PC Local Maintenance Facility

- **Primary function: Air link**
  - generate, radiate, receive CDMA RF signal IS-95/J.Std. 8
  - high-efficiency T1 backhaul
  - test capabilities

SC614T

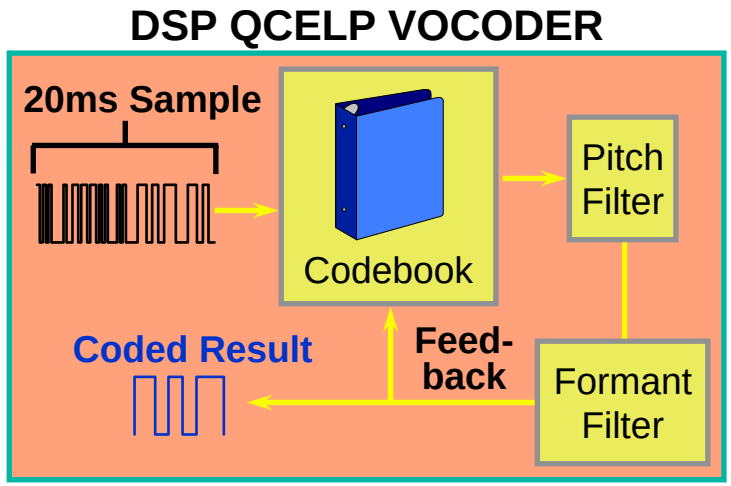
SC611 Microcell

SC4852

CDMA Details and Operation

Variable Rate Vocoding & Multiplexing

- Vocoders compress speech, reduce bit rate
- CDMA uses a superior Variable Rate Vocoder
  - full rate during speech
  - low rates in speech pauses
  - increased capacity
  - more natural sound
- Voice, signaling, and user secondary data may be mixed in CDMA frames

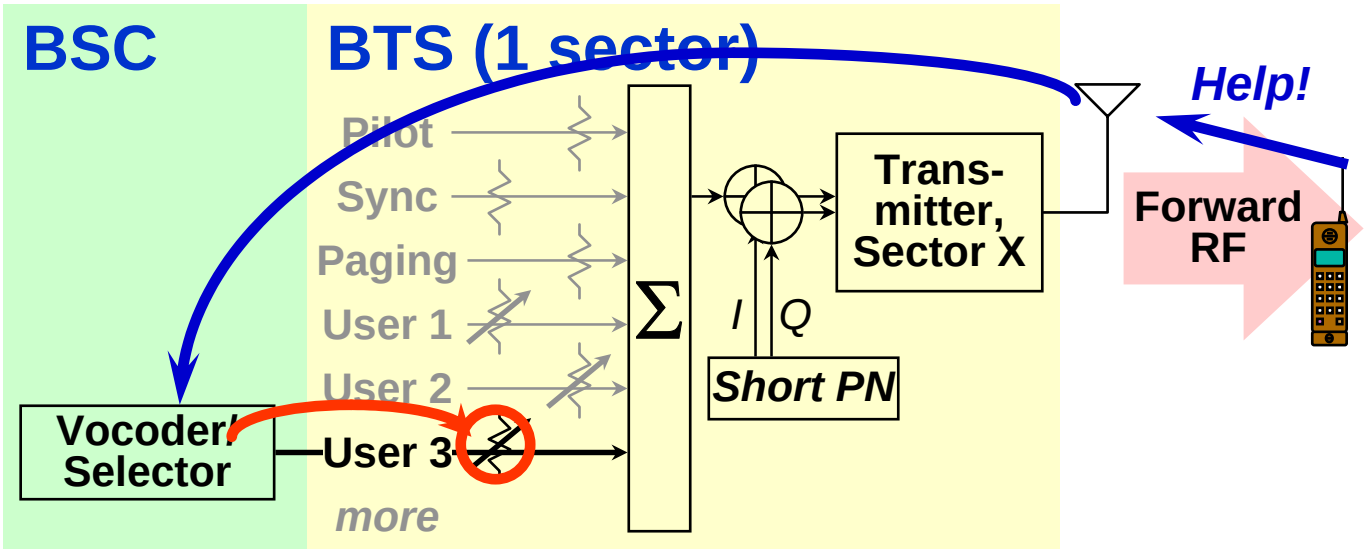


bits	Frame Sizes
288	Full Rate Frame
144	1/2 Rate Frame
72	1/4 Rt.
36	1/8

Frame Contents: can be a mixture of

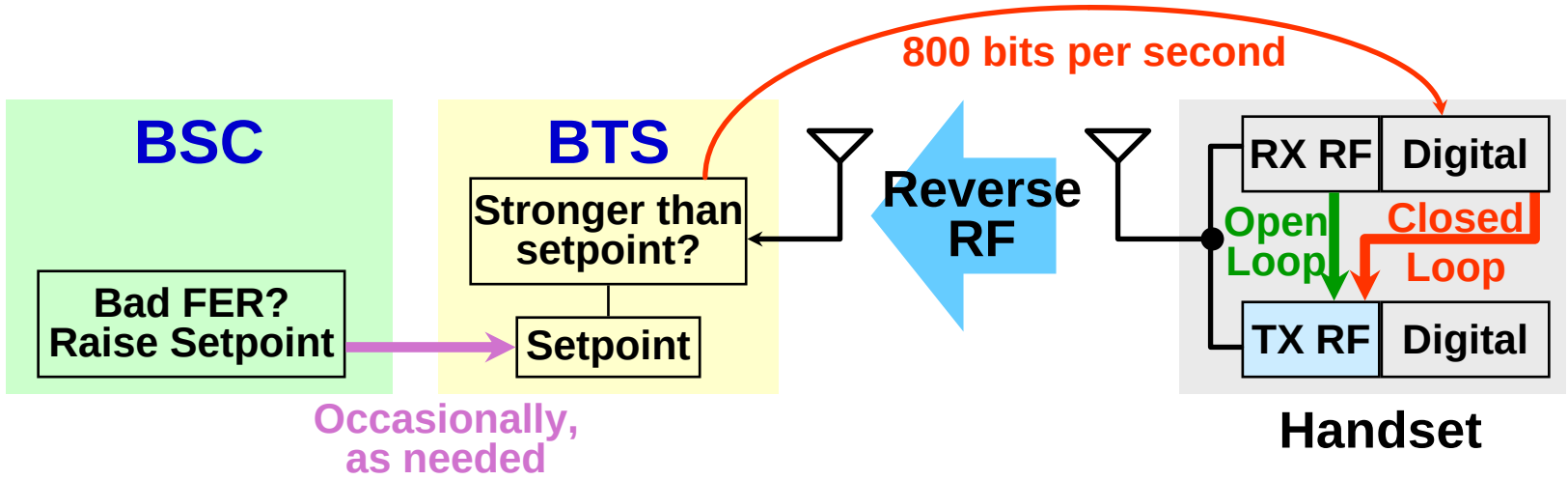
Voice | Signaling | Secondary

Forward Power Control



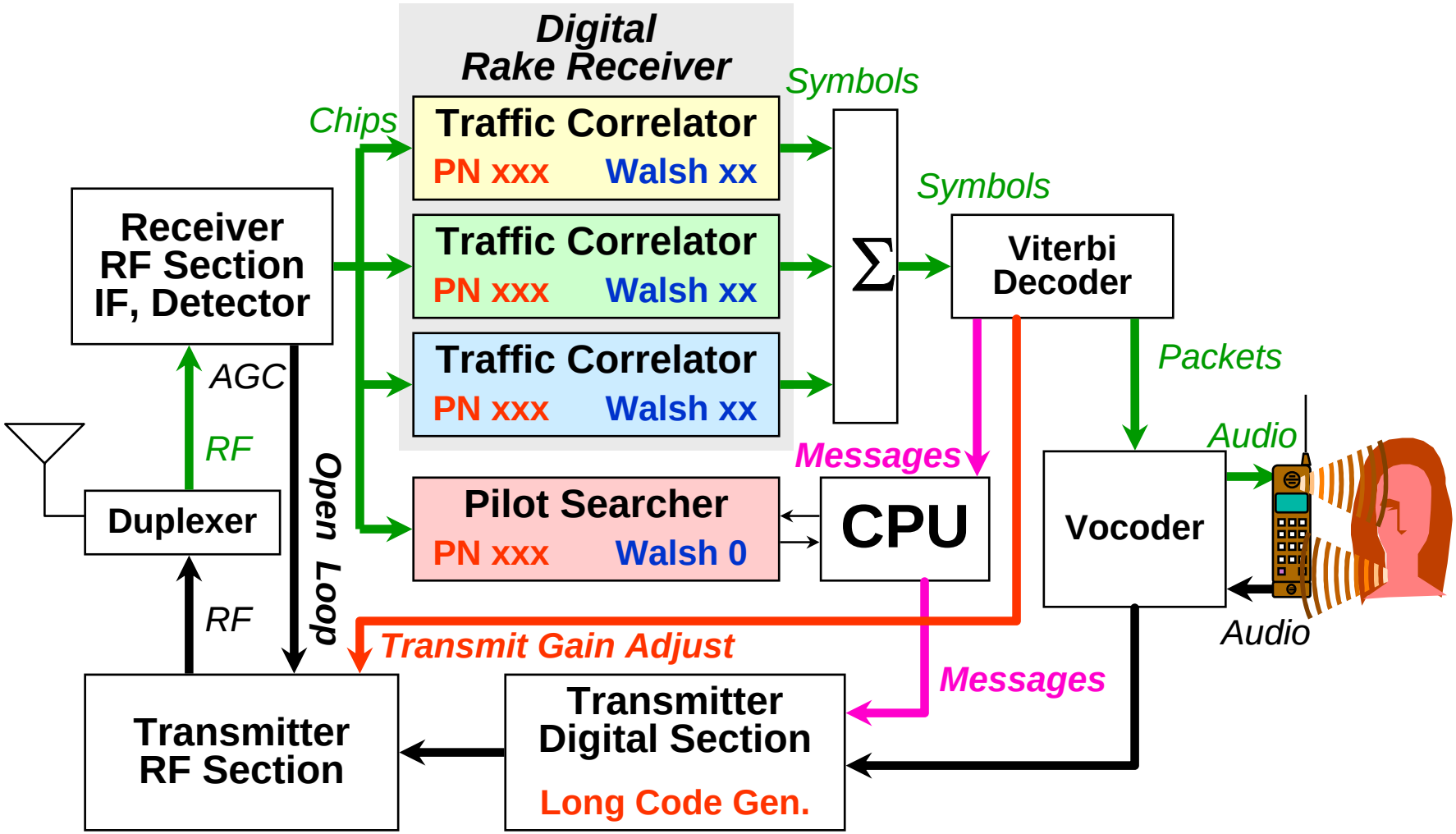
- The BTS continually reduces the strength of each user's forward baseband chip stream
- When a particular handset sees errors on the forward link, it requests more energy
- The complainer's chip stream gets a quick boost; afterward, continues to diminish

Reverse Power Control

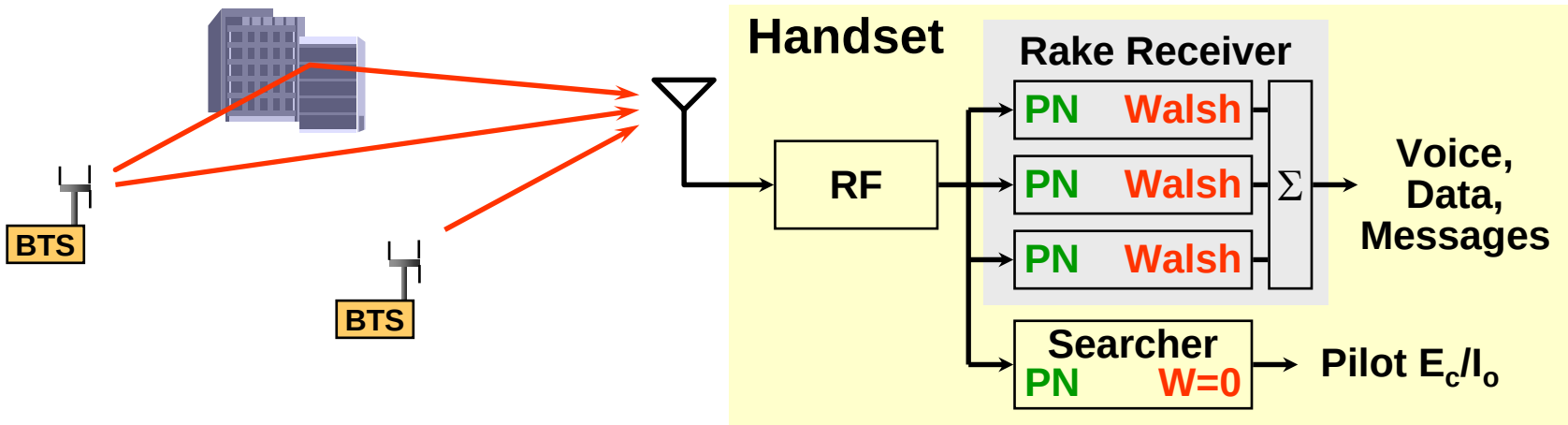


- Three methods work in tandem to equalize all handset signal levels at the BTS
  - Reverse *Open* Loop: handset adjusts power up or down based on received BTS signal (AGC)
  - Reverse *Closed* Loop: Is handset too strong? BTS tells up or down 1 db 800 times/second
  - Reverse *Outer* Loop: BSC has FER trouble hearing handset? BSC adjusts BTS setpoint

What's In a Handset?

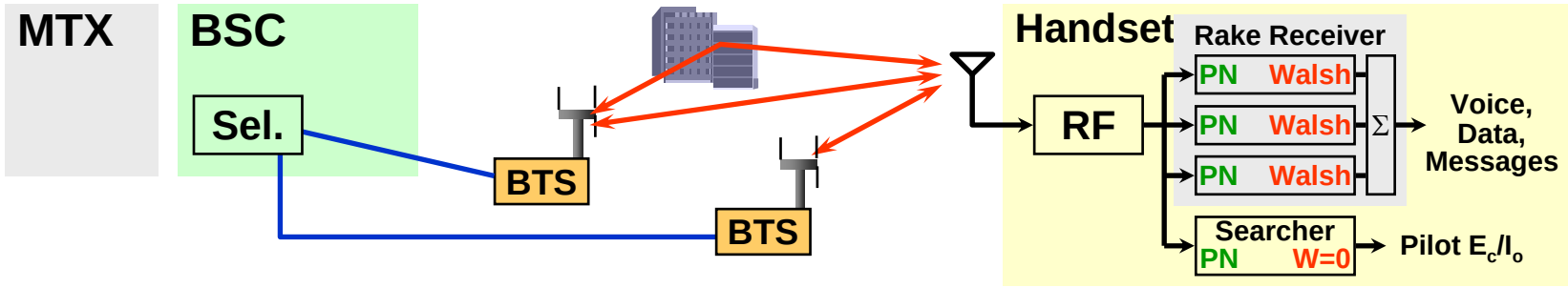


The Rake Receiver



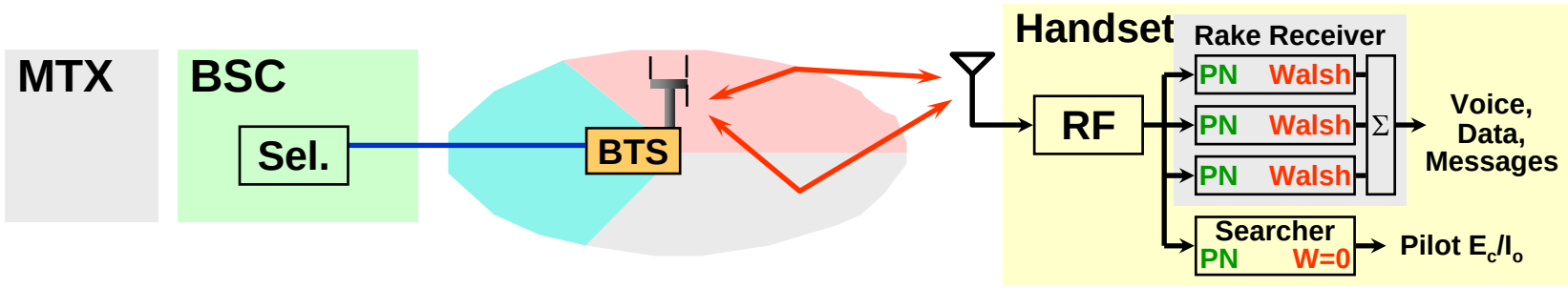
- Every frame, handset uses combined outputs of the three traffic correlators ("rake fingers")
- Each finger can independently recover a particular PN offset and Walsh code
- Fingers can be targeted on delayed multipath reflections, or even on different BTSs
- Searcher continuously checks pilots

CDMA Soft Handoff Mechanics



- CDMA soft handoff is driven by the handset
  - Handset continuously checks available pilots
  - Handset tells system pilots it currently sees
  - System assigns sectors (up to 6 max.), tells handset
  - Handset assigns its fingers accordingly
  - All messages sent by dim-and-burst, no muting!
- Each end of the link chooses what works best, on a frame-by-frame basis!
  - Users are totally unaware of handoff

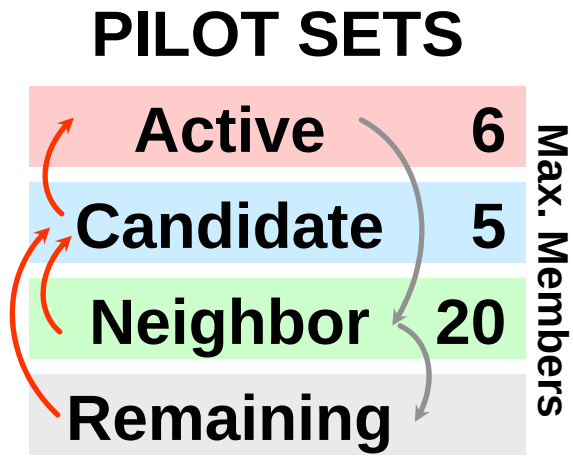
Softer Handoff



- Each BTS sector has unique PN offset & pilot
- Handset will ask for whatever pilots it wants
- If multiple sectors of one BTS simultaneously serve a handset, this is called Softer Handoff
- Handset is unaware, but softer handoff occurs in BTS in a single channel element
- Handset can even use combination soft-softer handoff on multiple BTS & sectors

Pilot Sets and Soft Handoff Parameters

- Handset views pilots in *sets*
- Handset sends message to 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
- Handoff setup processing time usually <<1 second



HANDOFF PARAMETERS

T_ADD	T_DROP
T_TDROP	T_COMP

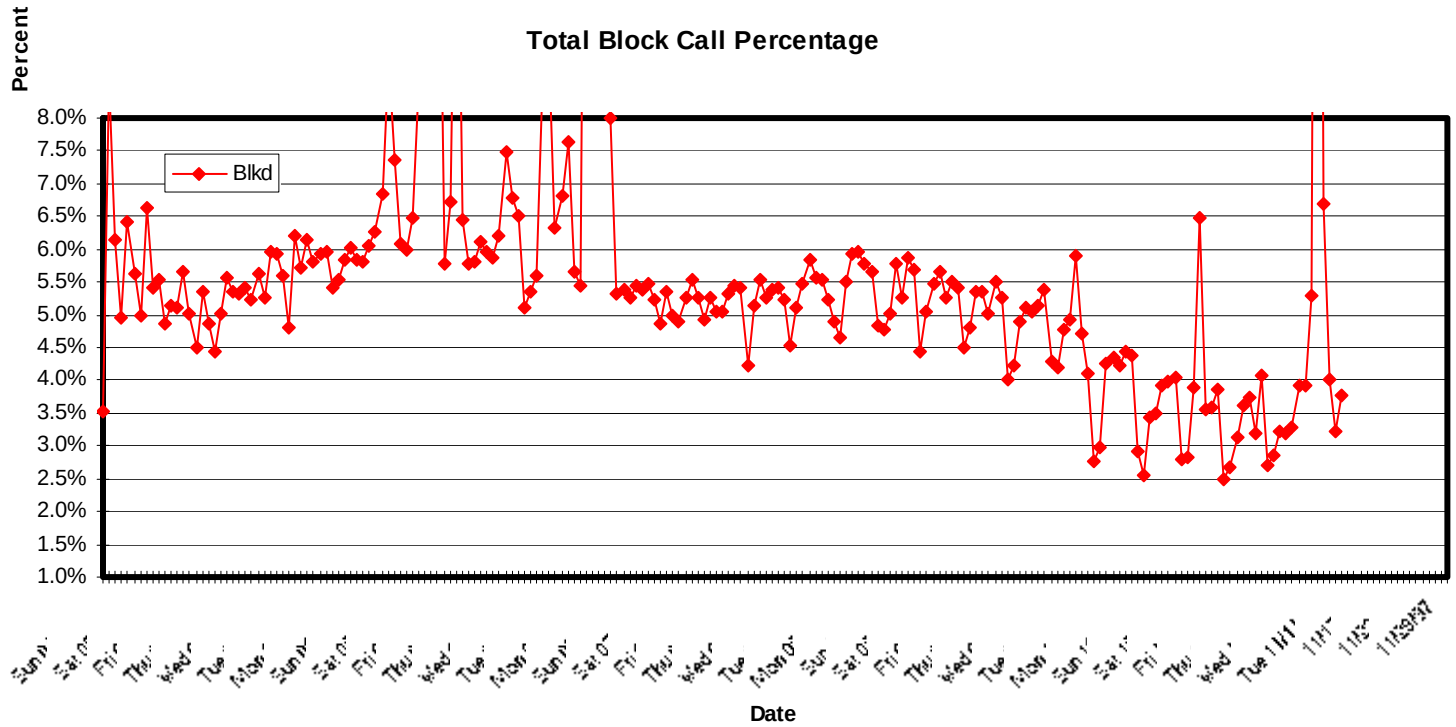
Overall Handoff Perspective

- **Soft & Softer Handoffs are the best**
  - **but a handset can receive BTS/sectors simultaneously only on *one* frequency**
  - **all involved BTS/sectors must connect to networked CBSCs (the CBSC must choose packets each frame)**
  - ***frame timing* must be same on all BTS/sectors**
- **If above not possible, handoff still can occur but will be "hard" like AMPS/TDMA/GSM**
  - **intersystem handoff: hard**
  - **change-of-frequency handoff: hard**
  - **CDMA-to-AMPS handoff: hard, no handback**
    - **auxiliary trigger mechanisms available**

CDMA Performance Optimization

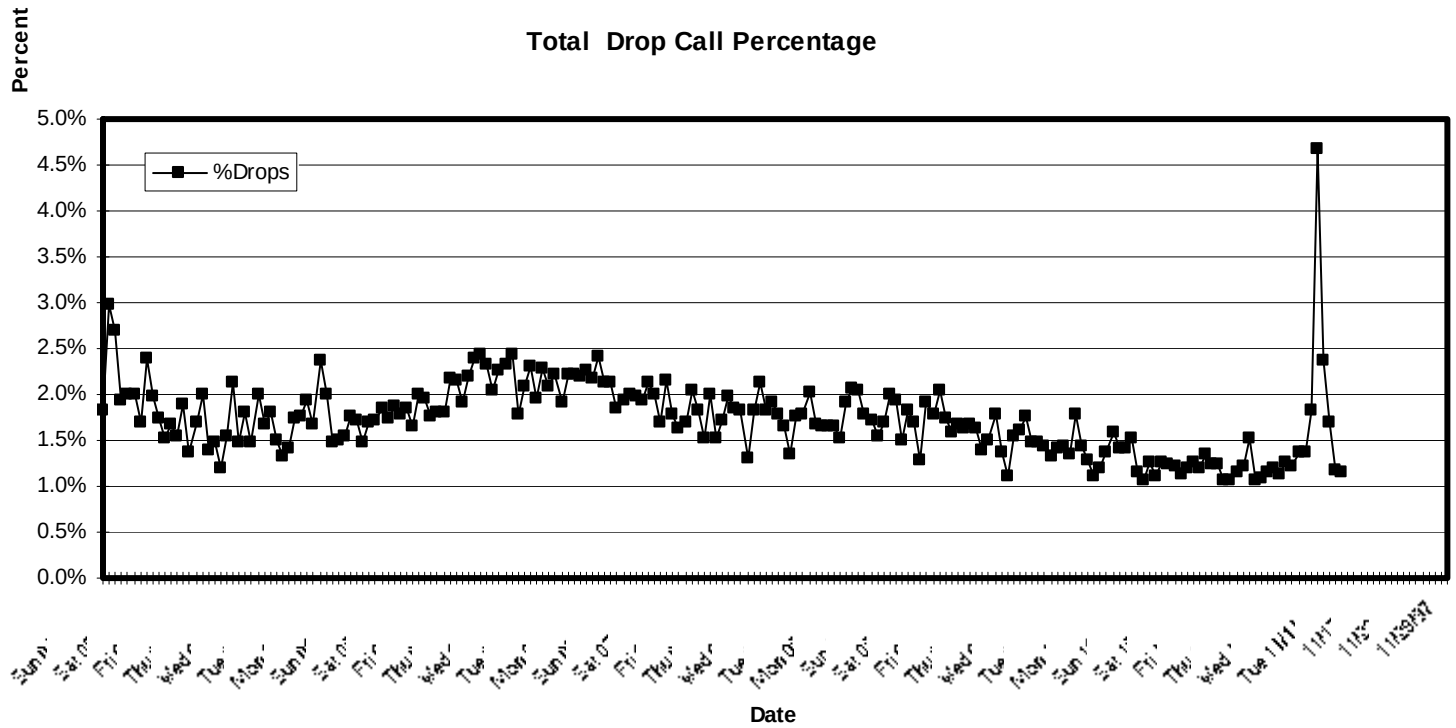
- Key Performance Indicators and Objectives
  - Dropped Calls, Access Failures, system FER
  - Soft Handoff Percentage
  - Capacity
- Success comes from managing resources
  - Handoff: keep dynamics fast, delays short
    - Neighbor lists well-optimized
  - RF Coverage: holes vs. excessive overlap
  - PN Planning, optimum Search Window sizes
  - Per-Cell anomalies: watch parameters for clues

Total Blocked Call Percentage Example



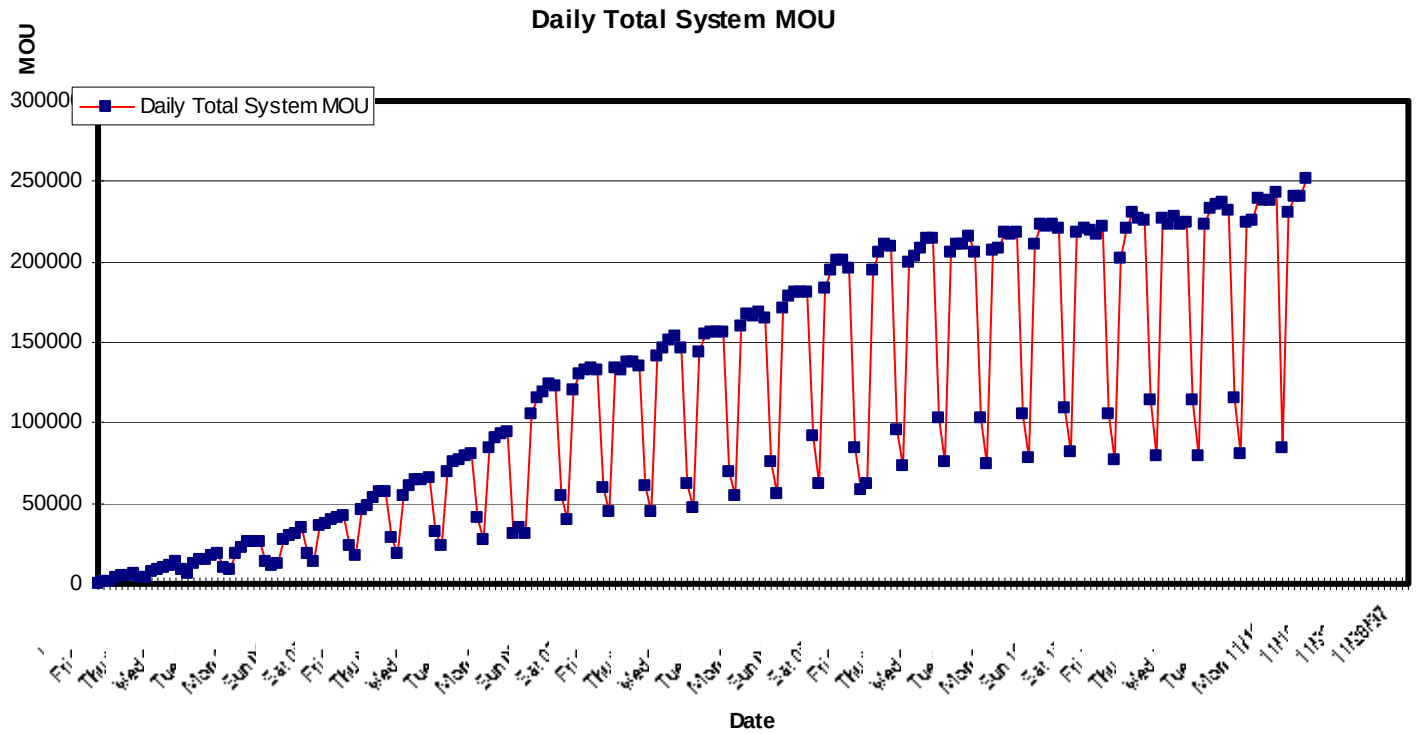
- This is an example of a cumulative system-wide total blocked call percentage chart maintained by one PCS customer

Dropped Call Percentage Tracking Example



- Dropped call percentage tracking by a PCS customer.

Total System Daily MOU Example

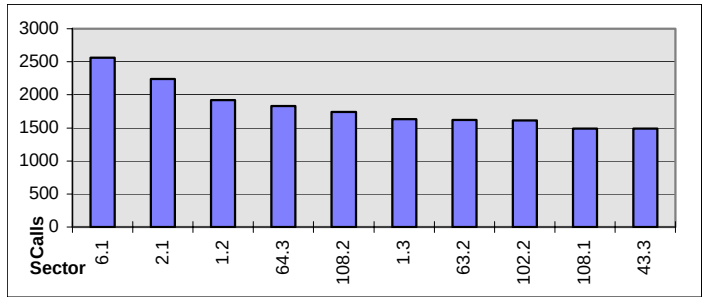


- Total system daily MOU plotted by a PCS customer

"Top Ten" Performance Tracking Example

Call Attempts

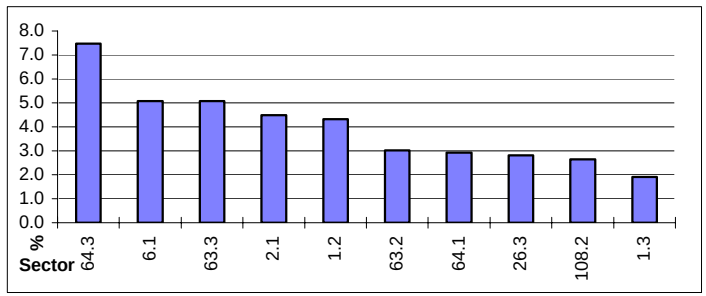
Eng Site	MSC Site	Call Att	Call Succ	%Call Succ	Block Calls	%Blck Calls	Acc Fail	%Acc Fail	Drop Calls	%Drop Calls
6.1	13X	2561	2234	87.2	130	5.1	130	5.1	145	5.7
2.1	2X	2244	2017	89.9	101	4.5	101	4.5	93	4.1
1.2	1Y	1922	1743	90.7	83	4.3	83	4.3	66	3.4
64.3	93Z	1833	1549	84.5	137	7.5	136	7.4	110	6.0
108.2	30Y	1740	1589	91.3	46	2.6	45	2.6	83	4.8
1.3	1Z	1630	1495	91.7	31	1.9	31	1.9	81	5.0
63.2	57Y	1623	1486	91.6	49	3.0	49	3.0	66	4.1
102.2	4Y	1615	1495	92.6	18	1.1	18	1.1	70	4.3
108.1	30X	1490	1387	93.1	27	1.8	27	1.8	54	3.6
43.3	42Z	1488	1410	94.8	4	0.3	4	0.3	53	3.6



September 5, 1997

% Blocked Calls

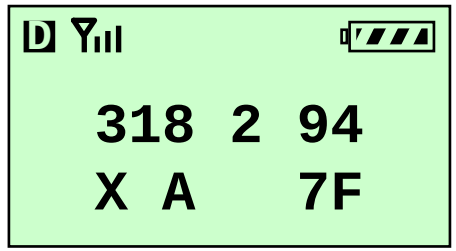
Eng Site	MSC Site	Call Att	Call Succ	%Call Succ	Block Calls	%Blck Calls	Acc Fail	%Acc Fail	Drop Calls	%Drop Calls
64.3	93Z	1833	1549	84.5	137	7.5	136	7.4	110	6.0
6.1	13X	2561	2234	87.2	130	5.1	130	5.1	145	5.7
63.3	57Z	1282	1098	85.7	65	5.1	65	5.1	90	7.0
2.1	2X	2244	2017	89.9	101	4.5	101	4.5	93	4.1
1.2	1Y	1922	1743	90.7	83	4.3	83	4.3	66	3.4
63.2	57Y	1623	1486	91.6	49	3.0	49	3.0	66	4.1
64.1	93X	1027	926	90.2	30	2.9	30	2.9	58	5.7
26.3	35Z	855	698	81.6	24	2.8	24	2.8	112	13.1
108.2	30Y	1740	1589	91.3	46	2.6	45	2.6	83	4.8
1.3	1Z	1630	1495	91.7	31	1.9	31	1.9	81	5.0



- **Many operators use scripts or spreadsheet macros to produce ranked lists of sites with heavy traffic, performance problems, etc.**

CDMA Mobile Analysis Tools

- Handset Maintenance Mode
- Real-Time Data Collection Tools
  - Qualcomm MDM
  - Grayson WMI, Surveyor
  - LCC
  - Safco
  - Comarco



- Pilot Ec/Io
- Finger Information
- RX Level, TX Power output, TX Gain Adjust, Forward FER
- Temporal Analyzer
- Markov Call Statistics
- Messaging Activity
- Pilot Set Activity

CDMA Network Analysis Tools

- Post-Processing Tools
  - Qualcomm ODA
  - Grayson IQAnalyzer
  - Safco OPAS
  - LCC Deskcat
- OM Analysis Tools
  - Metrica

- Map Plots
  - Best Ec/Io, PN, FER, handset RX & TX Powers, Transmit Gain Adjust, Number of active pilots
- Charts, Tables & Graphs
  - Handoff statistics (per-neighbor tables), parameter distributions
  - Access, Drop Call rates
- Message Search/Analysis
- Analysis of Anomalies
  - Pre-drop parameters

Bibliography

"Wireless Communications Principles & Practice" by Theodore S. Rappaport. 641 pp., 10 chapters, 7 appendices. Prentice-Hall PTR, 1996, ISBN 0-13-375536-3. If you can only buy one book, buy this one. Comprehensive summary of wireless technologies along with principles of real systems. Includes enough math for understanding and solving real problems. Good coverage of system design principles.

"The Mobile Communications Handbook" edited by Jerry D. Gibson. 577 pp., 35 chapters. CRC Press/ IEEE Press 1996, ISBN 0-8493-0573-3. $89 If you can buy only two books, buy this second. Solid foundation of modulation schemes, digital processing theory, noise, vocoding, forward error correction, excellent full-detailed expositions of every single wireless technology known today, RF propagation, cell design, traffic engineering. Each chapter is written by an expert, and well-edited for readability. Clear-language explanations for both engineers and technicians but also includes detailed mathematics for the research-inclined. Highly recommended.

"CDMA Systems Engineering Handbook" by Jhong Sam Lee and Leonard E. Miller, 1998 Artech House, ISBN 0-89006-990-5. Excellent treatment of CDMA basics and deeper theory, cell and system design principles, system performance optimization and capacity issues. Highly recommended.

"Applications of CDMA in Wireless/Personal Communications" by Garg, Smolik & Wilkes. 360 pp., Prentice Hall, 1997, ISBN 0-13-572157-1 $65. Good CDMA treatment. Excellent treatment of IS-95/JStd. 008 as well as W-CDMA. More than just theoretical text, includes chapters on IS-41 networking, radio engineering, and practical details of CDMA signaling, voice applications, and data applications.

"CDMA RF System Engineering" by Samuel C. Yang, 1998 Artech House, ISBN 0-89006-991-3. Good general treatment of CDMA capacity considerations from mathematical viewpoint.

"CDMA: Principles of Spread Spectrum Communication" by Andrew J. Viterbi**. 245 p. Addison-Wesley 1995. ISBN 0-201-63374-4, $65. Definitive very deep CDMA Theory. You can design CDMA chipsets after reading it, but beware lots of triple integrals; not very relevant to operations. Prestige collector's item among CDMA faithful.**

"Mobile Communications Engineering" 2nd. Edition by William C. Y. Lee. 689 pp. McGraw Hill 1998 $65. ISBN 0-07-037103-2 Lee's latest/greatest reference work on all of wireless; very complete and well done.

"Spread Spectrum Communications Handbook" by Simon, Omura, Scholtz, and Levitt. 1227 pp., 15 illus., McGraw-Hill # 057629-7, $99.50 Definitive technical reference on principles of Spread Spectrum including direct sequence as used in commercial IS-95/JStd008 CDMA. Heavy theory.

Bibliography (concluded)

"Wireless and Personal Communications Systems" by Garg, Smolik & Wilkes. 445 pp., Prentice Hall, 1996, $68. ISBN 0-13-234-626-5 $68. This is the little brother of "The Mobile Communications Handbook". Good explanation of each technology for a technical newcomer to wireless, but without quite as much authoritative math or deep theoretical insights. Still contains solid theory and discussion of practical network architecture.

"Voice and Data Communications Handbook" by Bates and Gregory 699 pp, 360 illus., McGraw-Hill # 05147-X, $65 Good authoritative reference on Wireless, Microwave, ATM, Sonet, ISDN, Video, Fax, LAN/WAN

"Communication Electronics" by Louis E. Frenzel, 2nd. Ed., list price $54.95. Glencoe/MacMillan McGraw Hill, April, 1994, 428 pages hardcover, ISBN 0028018427. All the basic principles of transmission and their underlying math. If you didn't take signals & systems in school, this is your coach in the closet.

"Digital Communications: Fundamentals and Applications" by Bernard Sklar. 771 pp., Prentice Hall, 1988. $74 ISBN# 0-13-211939-0 Excellent in depth treatment of modulation schemes, digital processing theory, noise.

"Wireless Personal Communications Services" by Rajan Kuruppillai. 424 pp., 75 illus., McGraw-Hill # 036077-4, $55 Introduction to major PCS technical standards, system/RF design principles and process, good technical reference

"PCS Network Deployment" by John Tsakalakis. 350 pp, 70 illus., McGraw-Hill #0065342-9, $65 Tops-down view of the startup process in a PCS network. Includes good traffic section.

"The ARRL Handbook for Radio Amateurs (1997)" published by the American Radio Relay League (phone 800-594-0200). 1100+ page softcopy ($44); useful exposure to nuts-and-bolts practical ideas for the RF-unfamiliar. Solid treatment of the practical side of theoretical principles such as Ohm's law, receiver and transmitter architecture and performance, basic antennas and transmission lines, and modern circuit devices. Covers applicable technologies from HF to high microwaves. If you haven't had much hands-on experience with real RF hardware, or haven't had a chance to see how the theory you learned in school fits with modern-day communications equipment, this is valuable exposure to real-world issues. Even includes some spread-spectrum information in case you're inclined to play and experiment at home. At the very least, this book will make dealing with hardware more comfortable. At best, it may motivate you to dig deeper into theory as you explore why things behave as they do.