SLIDE 322

Objectives

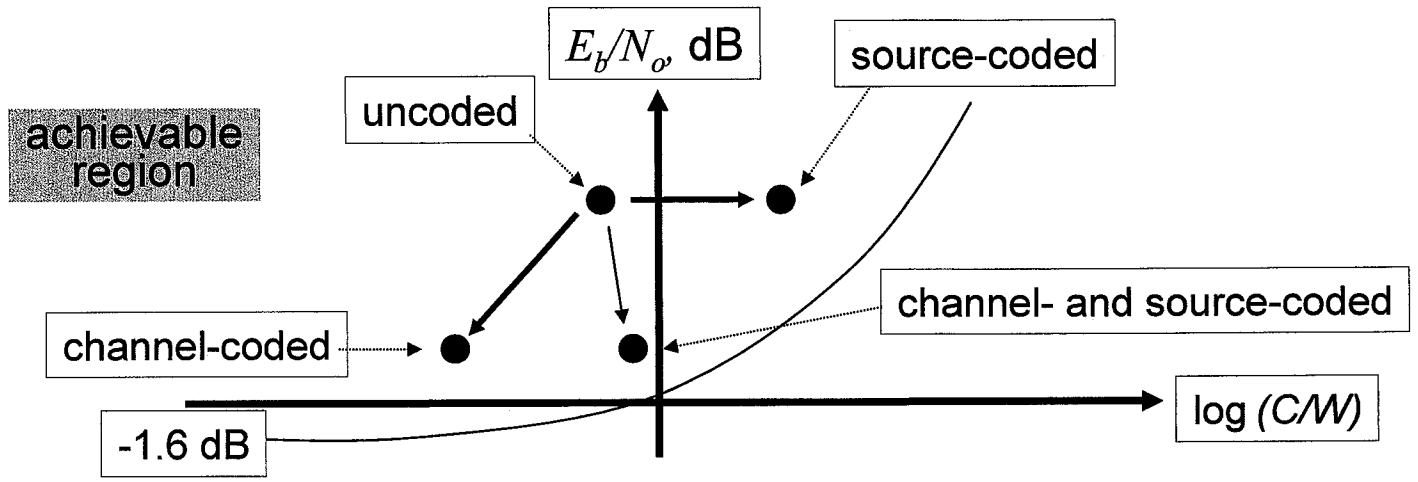
- Review some fundamental limits in Digital Communications Theory
- Present the W-CDMA and cdma2000 voice coding standards
- Discuss Error Correction Techniques, including convolutional and Turbo codes
- Introduce the variable length Orthogonal spreading codes
- Describe Pseudorandom Noise Codes, including m-sequences and Gold codes

SLIDE 344

Applications of Shannon's Theorem

$$C = W\log_2(1+\frac{S}{N}) \longrightarrow \frac{E_b}{N_o} = \frac{2^{C/W}-1}{C/W}$$

C is capacity in bps
W is bandwidth in Hz
S/N is signal-to-noise ratio



SLIDE 366

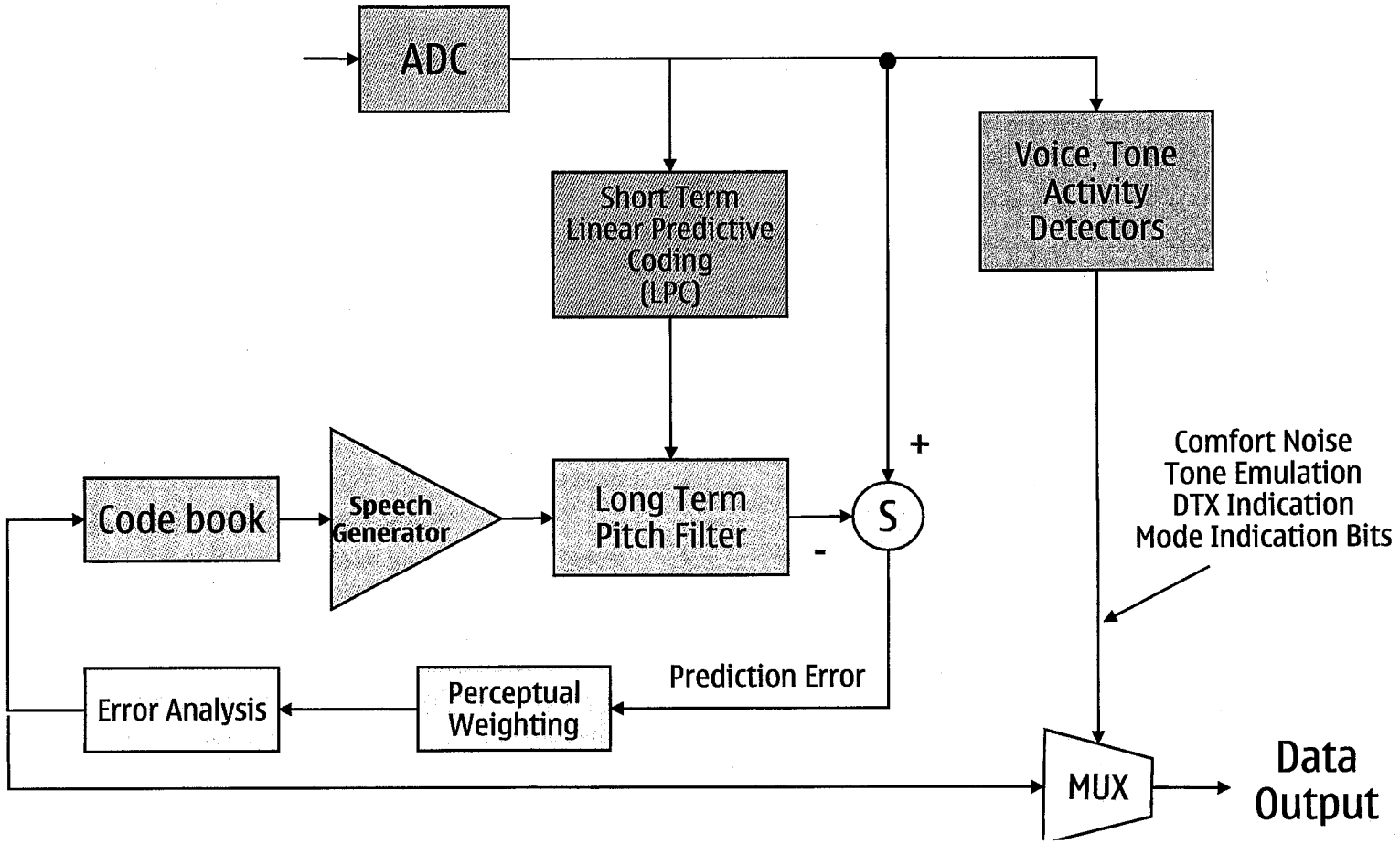
Source Coding

- Efficient description of information sources
- The goal of source coding of digital sources is to reduce the data rate:
  - Lossless compression: the source bit sequence must be exactly reproduced at the receiver
  - Lossy compression: data mismatch is allowed. Some other performance criteria is employed
- Source coding techniques depend on:
  - Statistics of source information
  - Measure of quality of source information
  - Application

Coding in 3G CDMA

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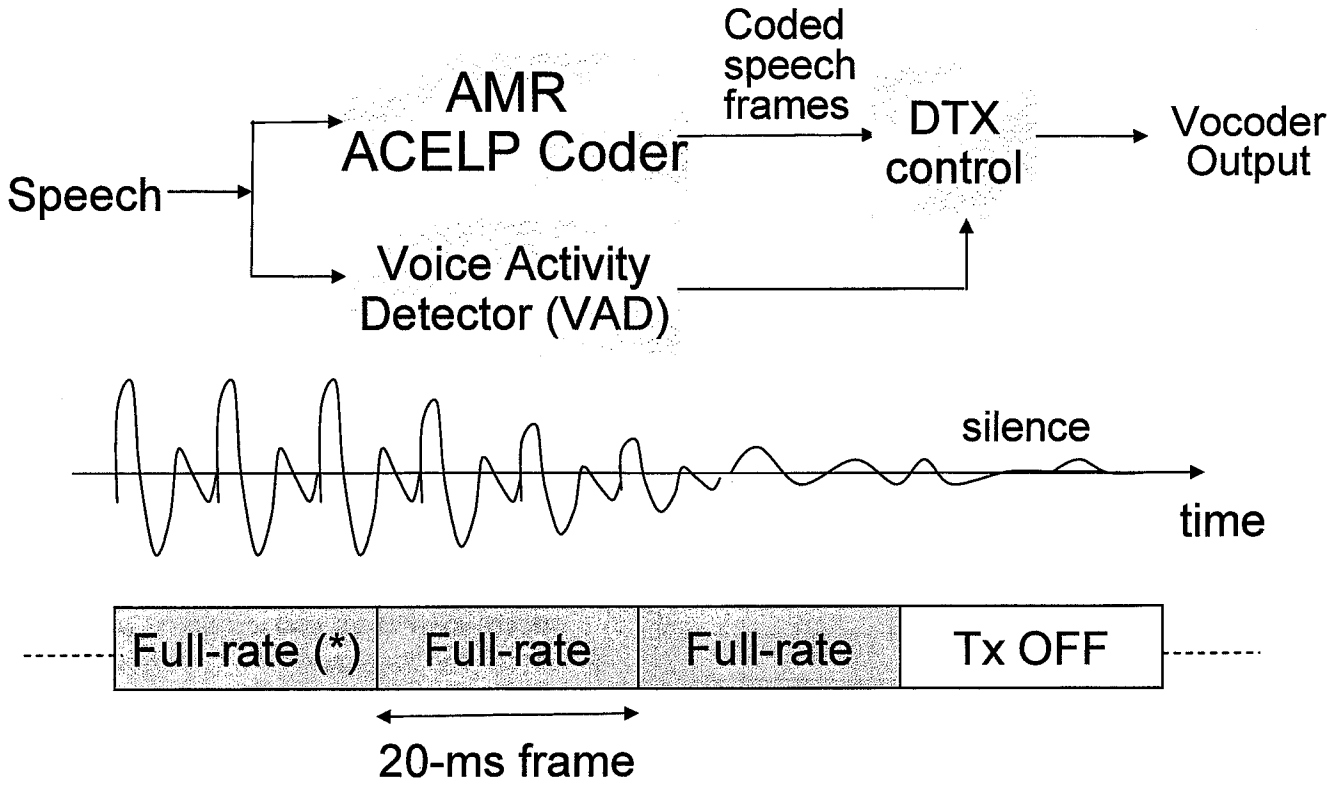
Speech Analysis-by-Synthesis



Coding in 3G CDMA

SLIDE 3100

W-CDMA AMR DTX



(*) Full-rate can be one of 8 possible rates

SLIDE 3122

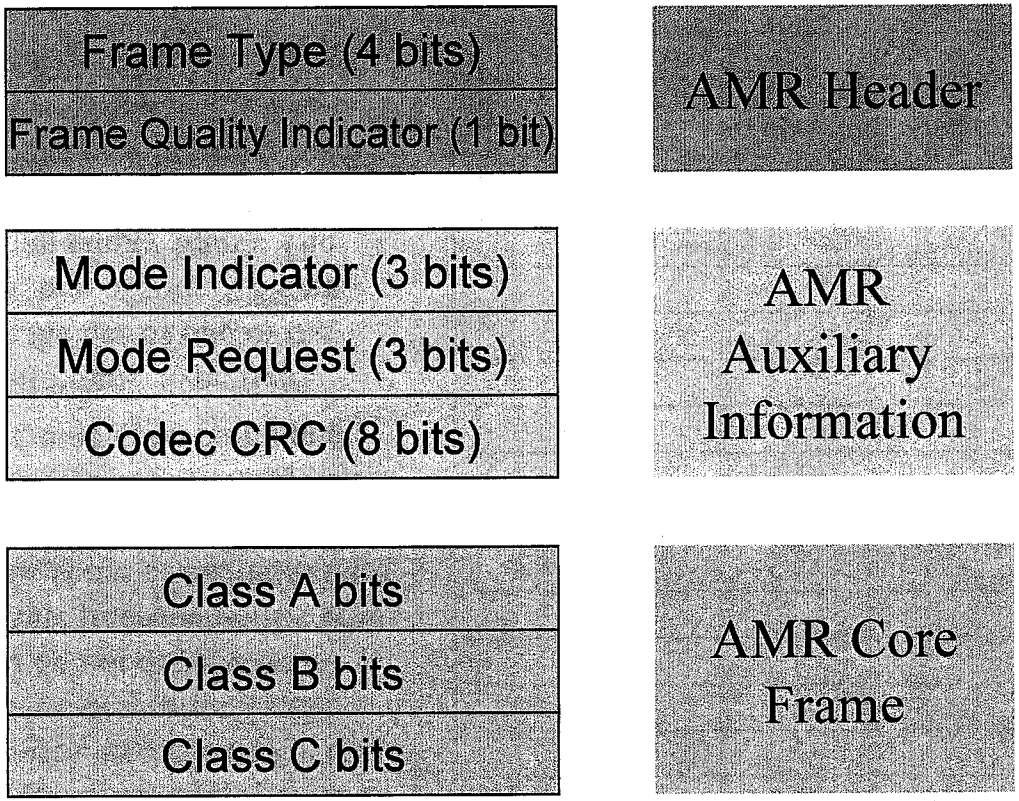
W-CDMA Adaptive Multi-rate (AMR) codec

Frame Type	Contents
0	4,75 kbit/s
1	5,15 kbit/s
2	5,90 kbit/s
3	6,70 kbit/s (PDC-EFR)
4	7,40 kbit/s (IS-641)
5	7,95 kbit/s
6	10,2 kbit/s
7	12,2 kbit/s (GSM EFR)
8	AMR Comfort Noise Frame
9	GSM-EFR Comfort Noise Frame
10	IS-641 Comfort Noise frame
11	PDC-EFR Comfort Noise Frame
12-14	For future use
15	No transmission/No reception

Coding in 3G CDMA

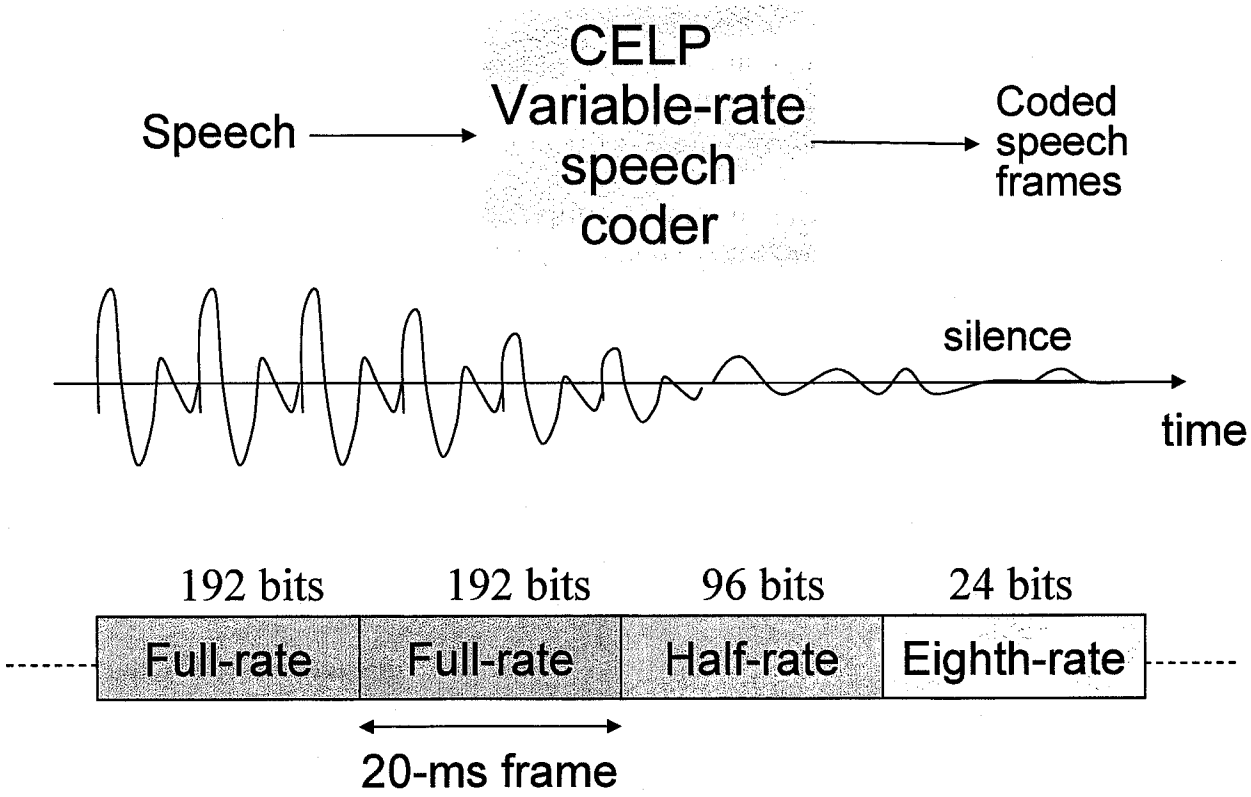
SLIDE 3144

Generic AMR Structure



SLIDE 3166

cdma2000 Variable Rate Speech Coder



SLIDE 3188

cdma2000 Voice Codecs

Name	Speech Rate	Frame Rate	Variable Rate
Rate Set 1	8.55 kbps	9.6 kbps	1, 1/2, 1/4, 1/8
Rate Set 2	13.35 kbps	14.4 kbps	1, 1/2, 1/4, 1/8
EVRC	8.55 kbps	9.6 kbps	1, 1/2, 1/8

Coding in 3G CDMA

SLIDE 3280

Channel Coding in 3G CDMA

Channel Codes in 3G CDMA

- Block Codes (CRC)
- Convolutional Codes
- Turbo Codes

SLIDE 3222

Convolutional Codes in cdma2000 and W-CDMA

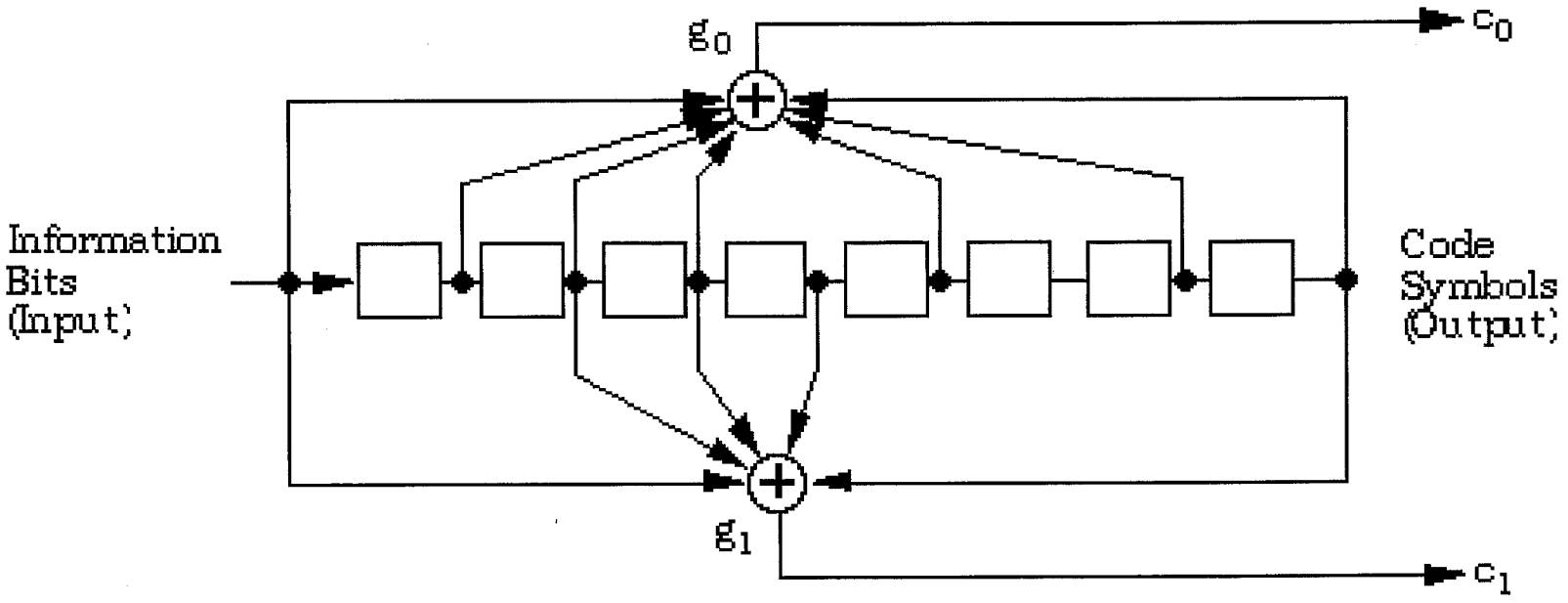
Rate	Constraint Length	Tap Generators (octal)
1/2	9	753 561
1/3	9	711 633 557
1/4 (*)	9	765 671 513 473
1/6 (*)	9	457 755 557 637 625 727

(*) cdma2000 only

Coding in 3G CDMA

SLIDE 3274

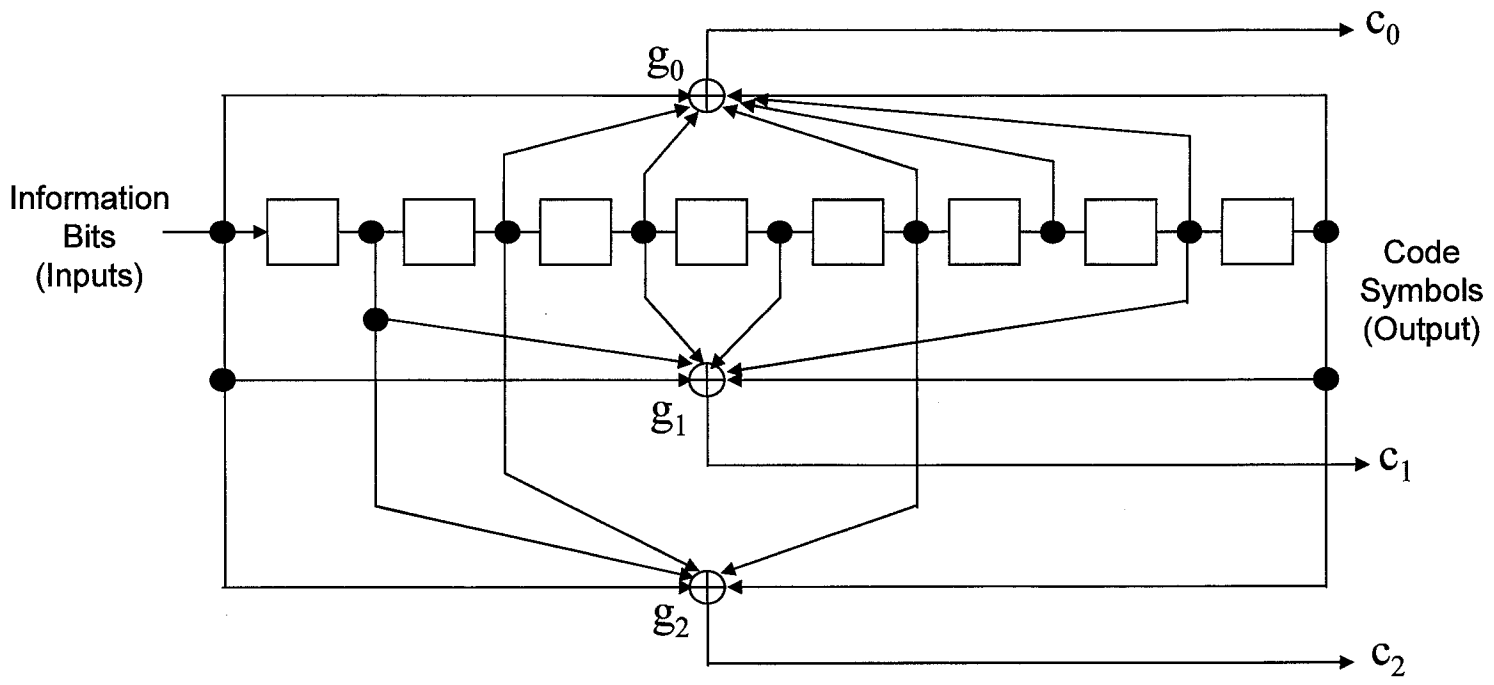
Convolutional Encoder Length 9, Rate 1/2



Coding in 3G CDMA

SLIDE 3226

Convolutional Encoder Rate 1/3



SLIDE 3288

Convolutional Codes Free Distance

Rate 1/2 Codes				Rate 1/3 Codes				
K	d_f	Tap Generator(Octal) G_1	G_2	K	d_f	Tap Generator(Octal) G_1	G_2	G_3
3	5	7	5	3	8	7	7	5
4	6	17	15	4	10	17	15	13
5	7	35	23	5	12	37	33	25
6	8	75	53	6	13	75	53	47
7	10	171	133	7	15	171	165	133
8	10	371	274	8	16	367	331	225
9	12	753	561	9	18	711	633	557
10	13	1545	1167	10	20	1633	1365	1117

Convolutional Codes Free Distance

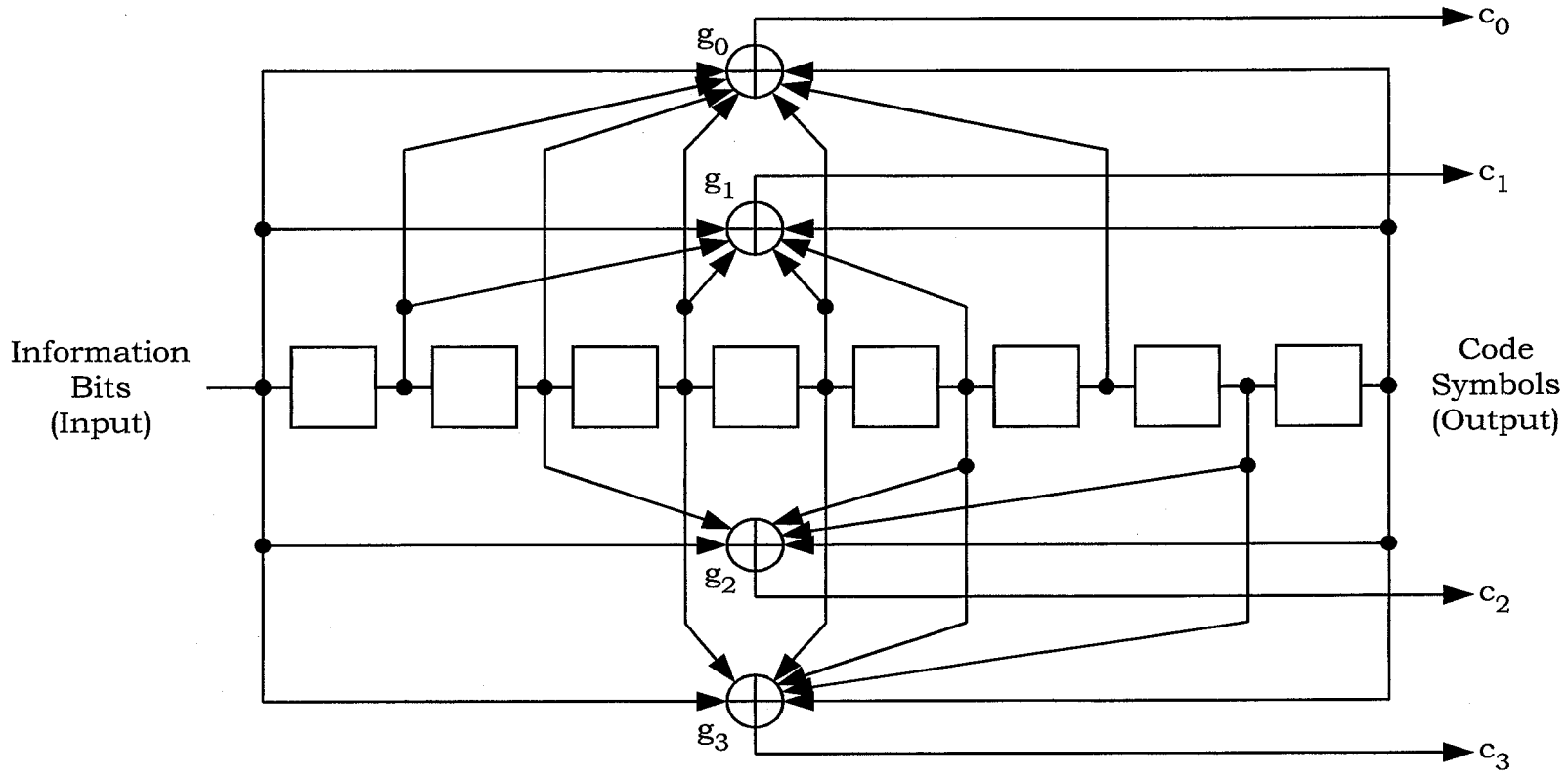
SLIDE 3380

Convolutional Codes

- Code performance is a function of rate and constraint length
- Optimal decoder is the MLSE
- Viterbi algorithm performs MLSE with reduced complexity
- Soft decoding instead of hard decoding:
  - significantly improves code performance
  - low increase in computation
- Tail bits needed to "flush out" encoder

SLIDE 3332

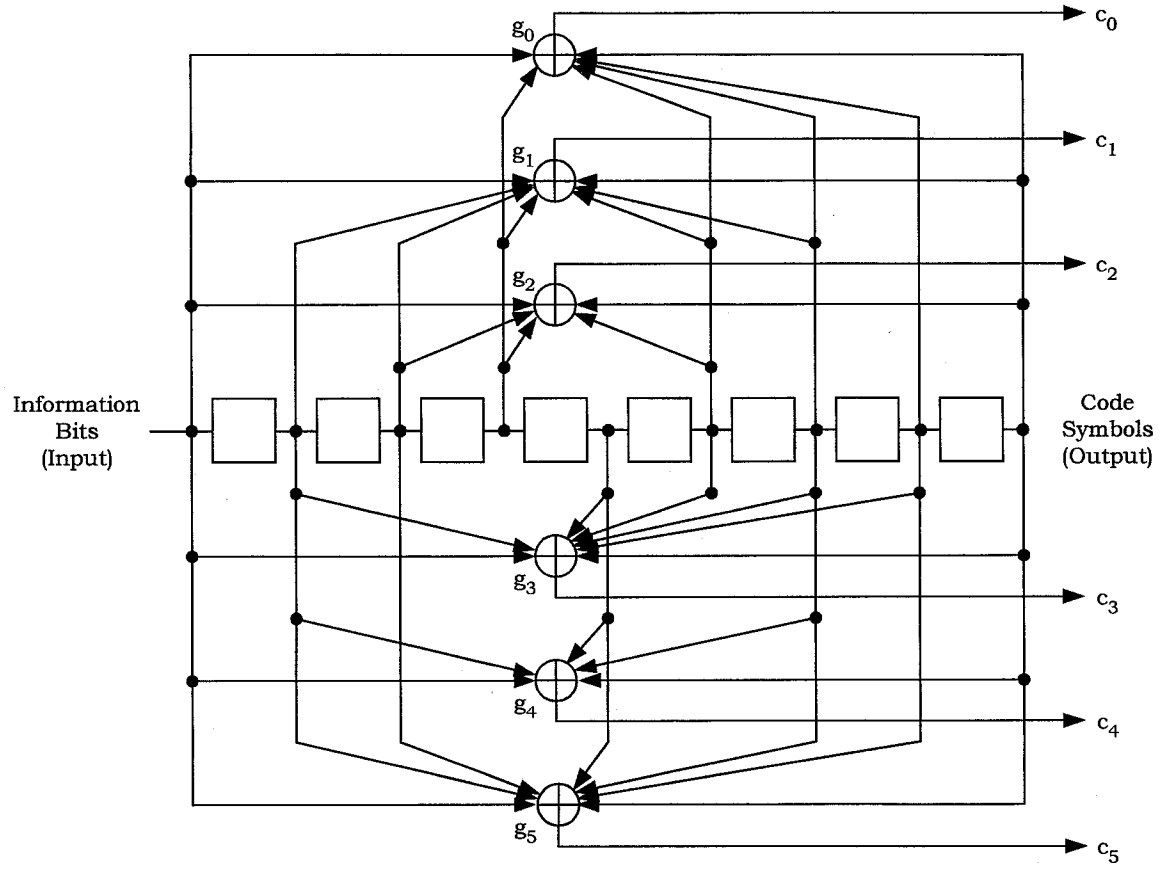
K = 9, Rate 1/4 Convolutional Encoder



Coding in 3G CDMA

SLIDE 3344

K = 9, Rate 1/6 Convolutional Encoder



SLIDE 3386

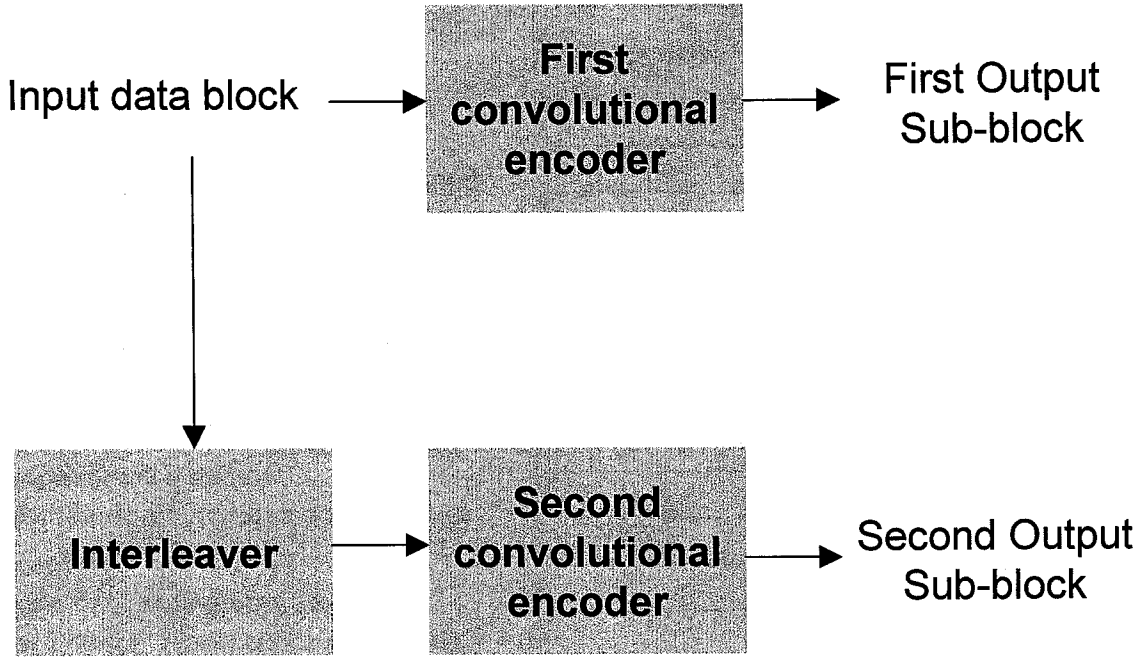
Turbo Codes

- Introduced by Berrou *et. al.* in 1993.
- Turbo codes are actually the concatenation of two feedback convolutional encoders
- Effective over long blocks (several hundred of bits or more).
- Named after the analogy with the "feedback" in a turbo-charged engine.
- Iterative decoding: suboptimal! Even so, turbo codes provide 2-3 dB more than convolutional codes of same rate and comparable decoding complexity.
- As opposed to most known codes, turbo codes do not seek directly an increase in d_{free}, but instead a reduction in the number of "nearest neighbor"sequences.

Coding in 3G CDMA

SLIDE 3408

Turbo Code Example

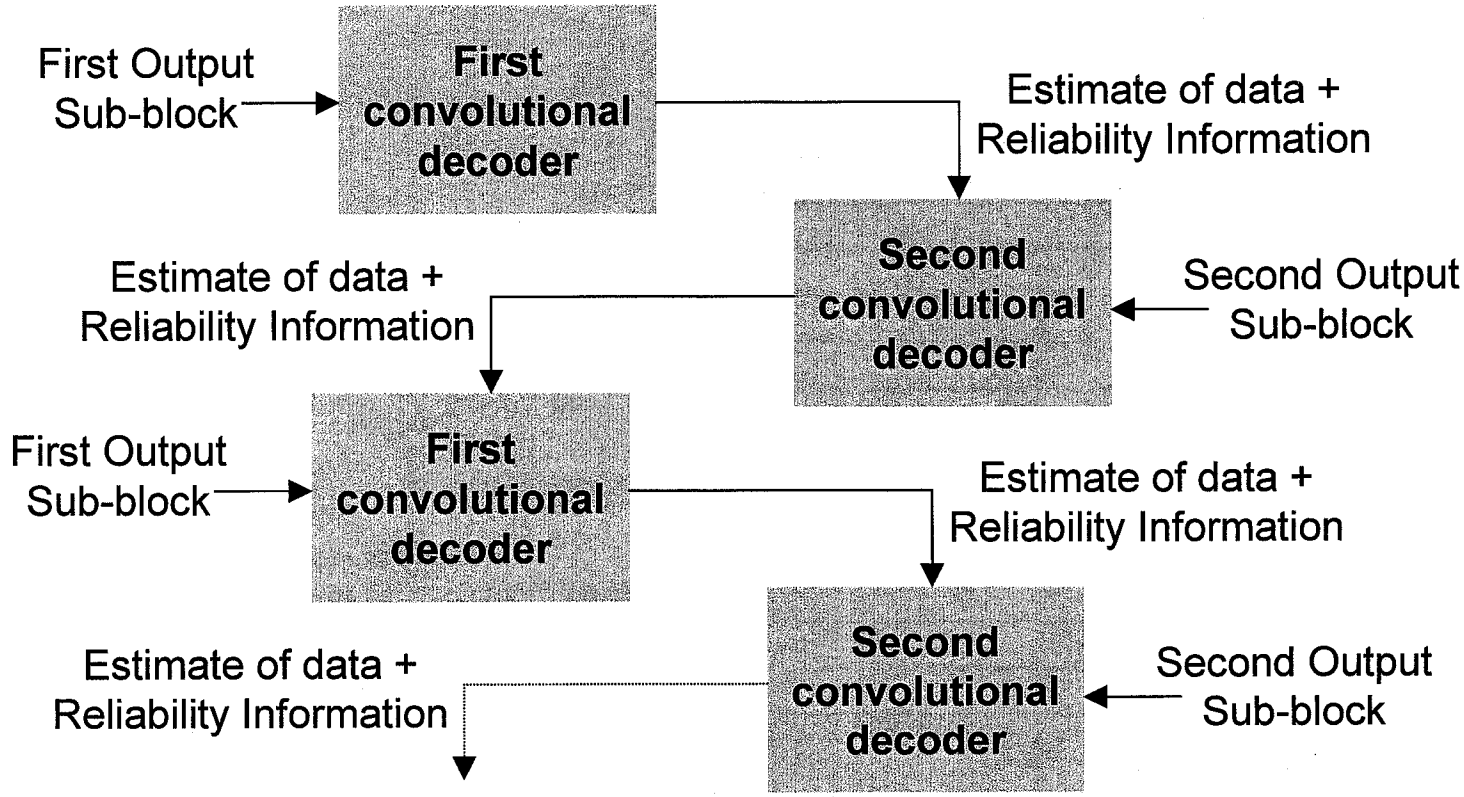


Turbo coder with parallel concatenation

Coding in 3G CDMA

SLIDE 3480

Iterative Decoding

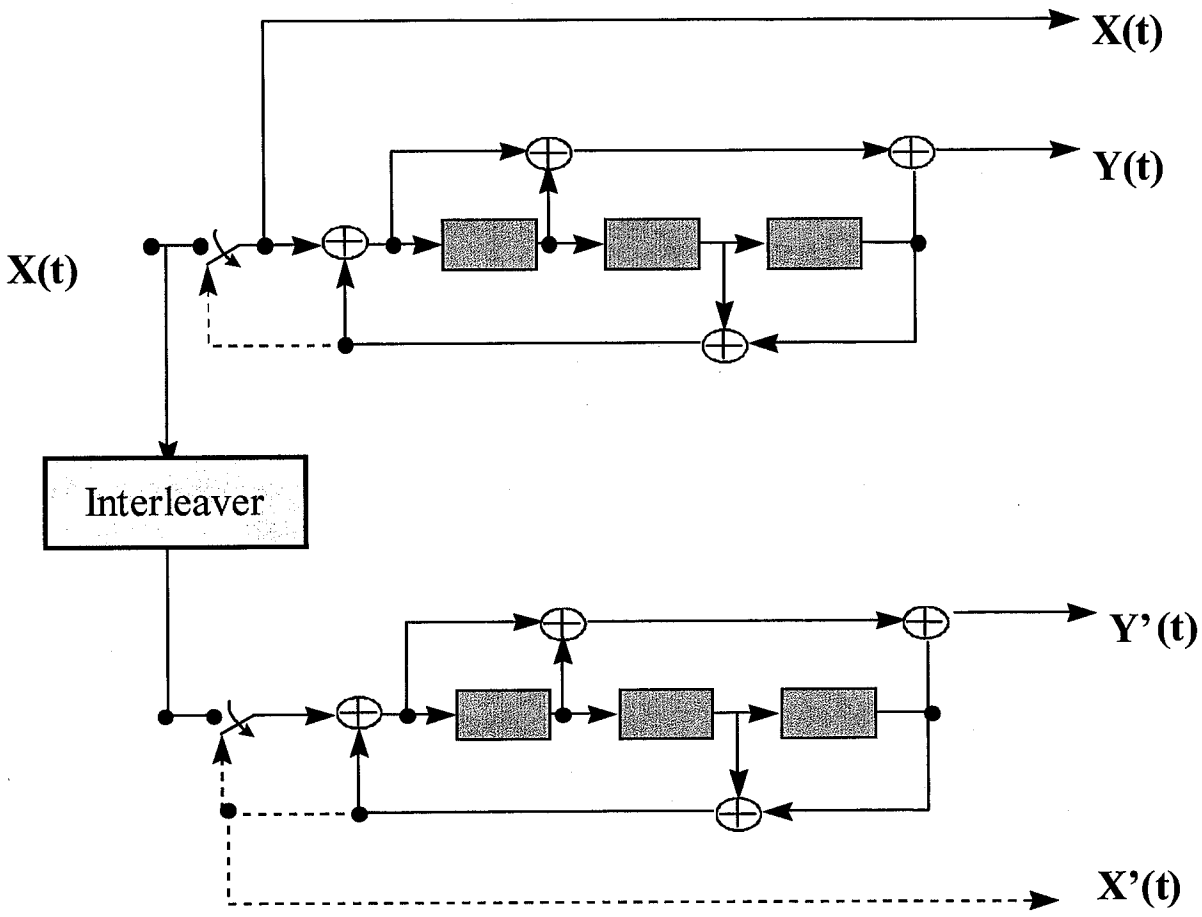


(for previous example)

Coding in 3G CDMA

SLIDE 3402

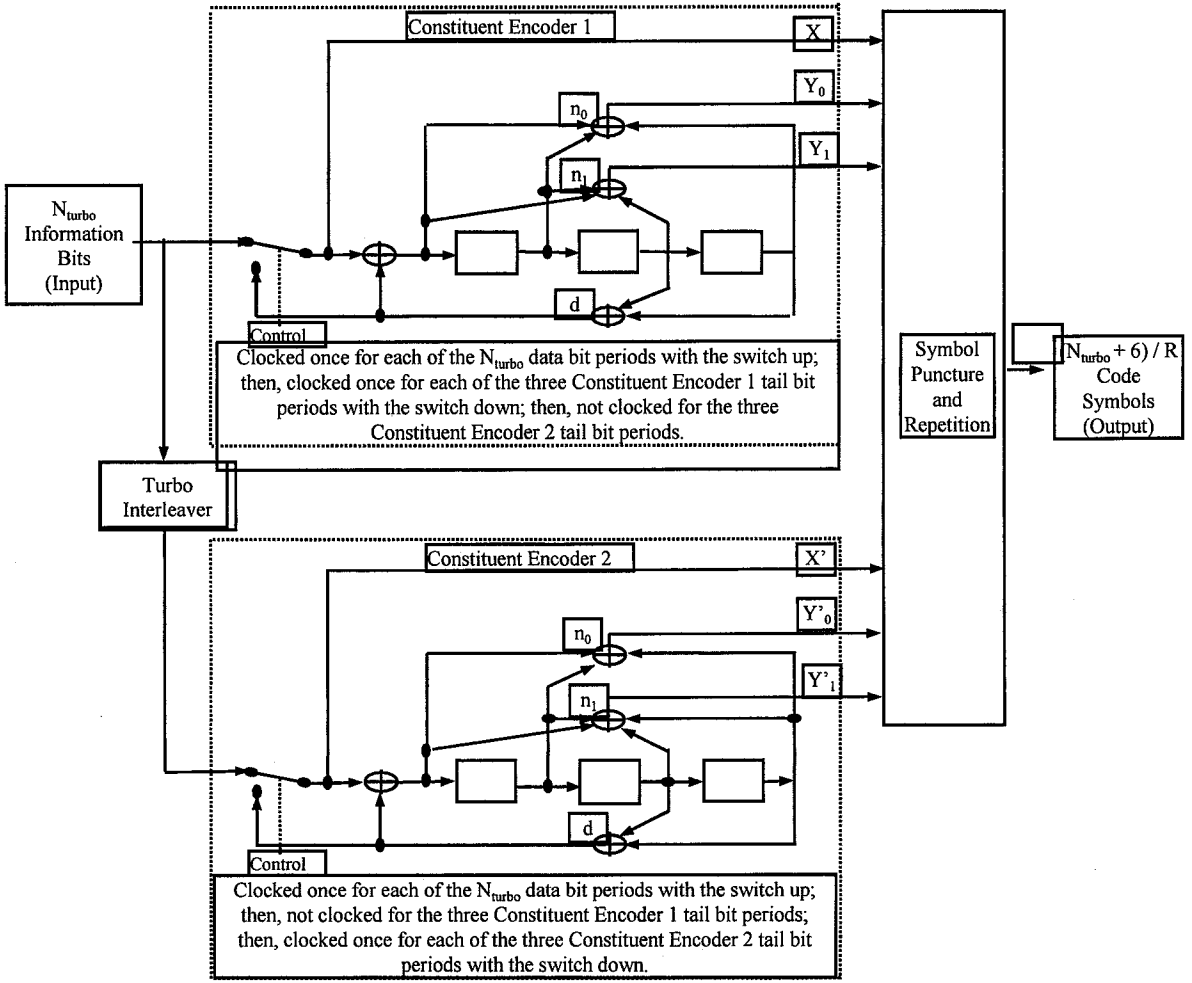
WCDMA Turbo Code



Coding in 3G CDMA

SLIDE 3444

cdma2000 Turbo Codé



SLIDE 3486

Puncturing Patterns for cdma2000 Turbo Code

	Code Rate		
Output	**1/2**	**1/3**	**1/4**
X	11	11	11
Y_0	10	11	11
Y_1	00	00	10
X'	00	00	00
Y'_0	01	11	01
Y'_1	00	00	11

Note: For each rate the puncturing table shall be read first from top to bottom and then from left to right.

SLIDE 3468

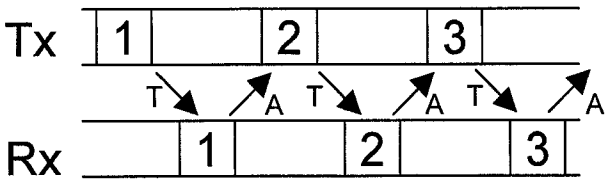
Interleaving

- Used to spread errors in order to improve channel coding performance
- Interleaver depth is a function of block size
- Deeper interleaver is more effective, but it also increases delay
  - Voice applications generally use short interleaving (in theorder of 20 ms)
  - Non-real time data applications can afford deeper interleaving (up to 80 ms)
- Interleaving on a bit by bit basis used in combination with convolutional coders, and as part of turbo codes.
- Multistage interleaving may be used (WCDMA)

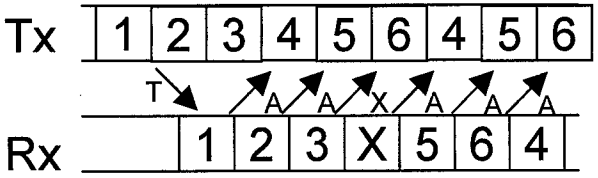
Coding in 3G CDMA

SLIDE 3560

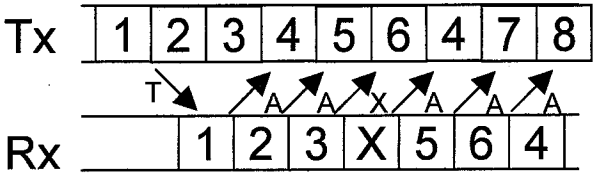
Automatic Repeat Request (ARQ)



Stop and Wait (half duplex)



Go-back-N

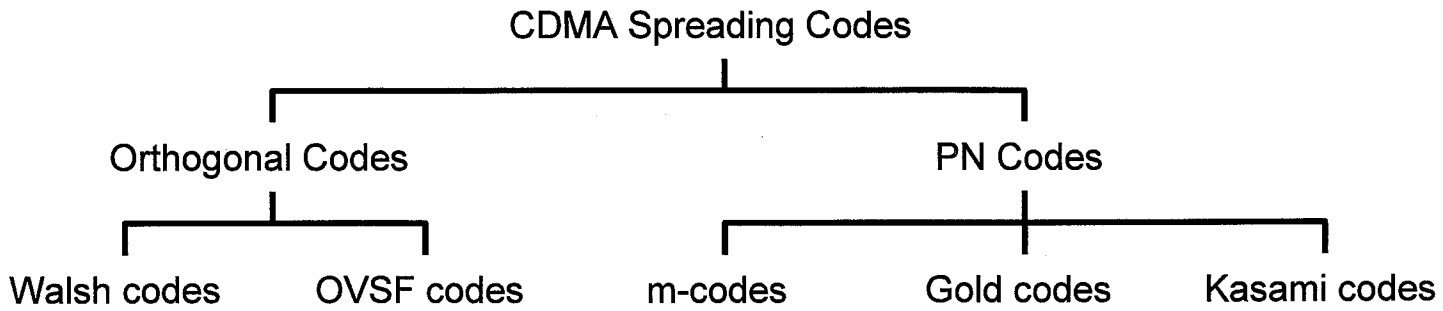


Selective Repeat

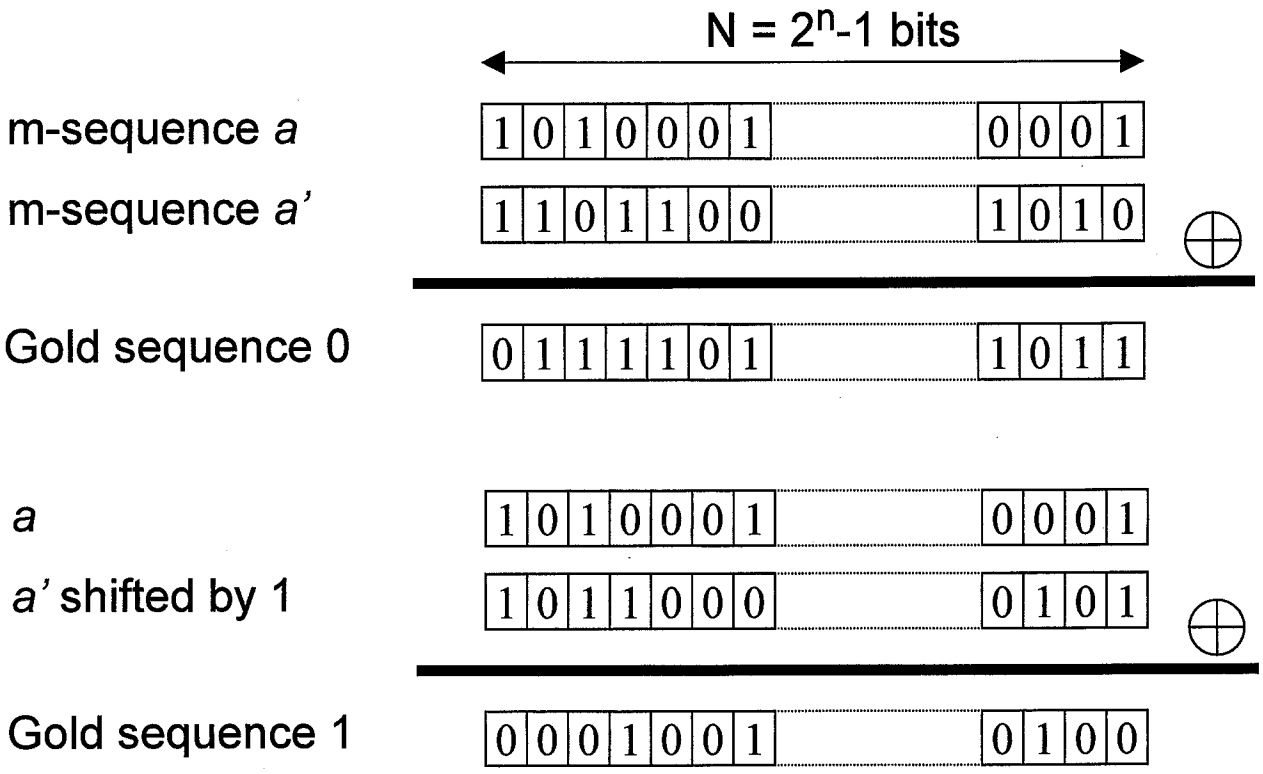
Coding in 3G CDMA

SLIDE 3652

CDMA Spreading Codes



Gold Sequences



Number of Gold Sequences: N+2 (including *a* and *a'*)

SLIDE 3566

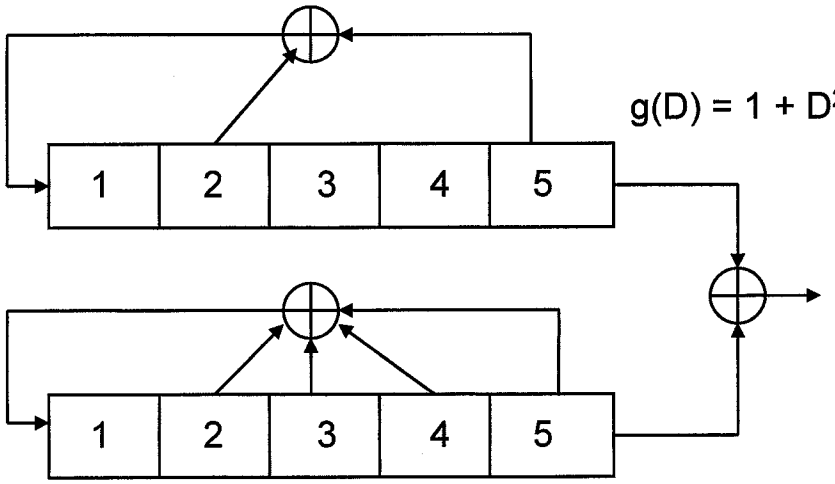
Gold Sequences

- Generated from certain pairs of m-sequences called *preferred pairs*
- Same period as the generating m-sequences
- Good cross-correlation properties
- Large families easily obtained
- Example:
  - there are 630 m-sequences with n=13 ($N = 2^{13}-1 = 8191$ bits), with a maximum cross-correlation value of 703
  - preferred pairs from this set generate N+1=8193 Gold sequences with a maximum cross-correlation of 129.

Coding in 3G CDMA

SLIDE 3568

Gold Sequence Example



$g_t(D) = 1 + D^2 + D^3 + D^4 + D^5$

Sequence 1:	11111000110111010100001001011 00
Sequence 2:	11111001001100001011010001110
0 shift combination	00000001111011011111011101000 10
1 shift combination	00001010101111000010100001100 01

SLIDE 3660

Properties of Gold Sequences

- The cross correlation spectrum between a preferred pair is three valued, where those values are -t(n), -1, t(n)-2 where
  - $t(n) = 1 + 2^{(n+1)/2}$ for n odd
  - $t(n) = 1 + 2^{(n+2)/2}$ for n even
- if $g_t(D)$ is the minimal polynomial of $a^{t(n)}$ where a is the root of g(D) then the coefficients of $g_t(D)$ provides the selection of connections for the shift register.
- Gold codes are not maximal sequences, hence their auto correlations are not two-valued.
- The cross correlation between any pairs of binary sequences of period N in a set of M sequences is approximately lower bounded by square root of N for N large (Welch lower bound) while Gold codes lower bound is better than this by a factor of 2 (for n even) and by a factor of square root of 2 for n odd.

Coding in 3G CDMA

SLIDE 3662

Code use in CDMA

Function	IS-95 Downlink	IS-95 Uplink	cdma2000™ Downlink	cdma2000™ Uplink	WCDMA Downlink	WCDMA Uplink
Cell Identification	Different offsets of two (I and Q) m-sequences of 2^{15} chips	N/A	Different offsets of two (I and Q) m-sequences of 2^{15} chips	N/A	One of 8192 Gold codes of 2^{18}-1 chips truncated to 10 ms	N/A
Channel-ization	Walsh orthogonal sequences of length 64	N/A	OVSF codes, QOF codes	OVSF codes,	OVSF codes	OVSF codes
User Identification	Walsh orthogonal sequences of length 64	Different offsets of one m-sequence of 2^{42}-1 chips	OVSF codes, QOF codes	Different offsets of one m-sequence of 2^{42}-1 chips (*)	OVSF codes	One 2^{24}-1 chip Gold code (truncated= 10 ms) (MUD option: 256-chip VL Kasami code)
Privacy	Different offsets of one m-sequence of 2^{42}-1 chips	Same as user identification	Different offsets of one m-sequence of 2^{42}-1 chips (*)	Same as user identification	N/A	Same as user identificatio

(*) Three times longer for the 3X standard

END OF SECTION