(12) **United States Patent**
Divsalar et al.

(10) **Patent No.:** **US 7,089,477 B1**
(45) **Date of Patent:** **Aug. 8, 2006**

(54) **INTERLEAVED SERIAL CONCATENATION FORMING TURBO-LIKE CODES**

(75) Inventors: **Dariush Divsalar**, Pacific Palisades, CA (US); **Robert J. McEliece**, Pasadena, CA (US); **Hui Jin**, Glen Gardner, NJ (US); **Fabrizio Pollara**, Lacanada, CA (US)

(73) Assignee: **California Institute of Technology**, Pasadena, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 749 days.

(21) Appl. No.: **09/922,852**

(22) Filed: **Aug. 18, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/149,871, filed on Aug. 18, 1999.

(51) **Int. Cl.**
H03M 13/29 (2006.01)
(52) **U.S. Cl.** **714/755**
(58) **Field of Classification Search** 714/755
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,392,299 A	*	2/1995	Rhines et al.	714/756
5,751,739 A	*	5/1998	Seshadri et al.	714/746
5,881,093 A	*	3/1999	Wang et al.	375/130
6,014,411 A	*	1/2000	Wang	375/259
6,023,783 A	*	2/2000	Divsalar et al.	714/792
6,031,874 A	*	2/2000	Chennakeshu et al.	375/262
6,032,284 A	*	2/2000	Bliss	714/792
6,437,714 B1	*	8/2002	Kim et al.	341/81
2001/0025358 A1	*	9/2001	Eidson et al.	714/752

OTHER PUBLICATIONS

Wiberg et al., "Codes and Iterative Decoding on General Graphs", 1995 Intl. Symposium on Information Theory, Sep. 1995, p. 506.*

Divsalar, D., et al. Multiple Turbo Codes for Deep-Space Communications , The Telecommunications and Data Acquisition Progress Report 42-121 for NASA and California Institute of Technology Jet Propulsion Laboratory, Joseph H. Yuen, ed.,pp. 60-77, May 15, 1995.

Divsalar, D., et al. On the Design of Turbo Codes , The Telecommunications and Data Acquisition Progress Report 42-123 for NASA and California Institute of Technology Jet Propulsion Laboratory, Joseph H. Yuen, ed.,pp. 99-121, Nov. 15, 1995.

Divsalar, D., et al., Low-Rate Turbo Codes for Deep Space Communications , Proceedings from the 1995 IEEE International Symposium on Information Theory, Whistler, British Columbia, Canada, pp. 35, Sep. 17-22, 1995.

(Continued)

Primary Examiner—Stephen M. Baker
(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

A turbo-like code is formed by repeating the signal, coding it, and interleaving it. A serial concatenated coder is formed of an inner coder and an outer coder separated by an interleaver. The outer coder is a coder which has rate greater than one e.g. a repetition coder. The interleaver rearranges the bits. An outer coder is a rate one coder.
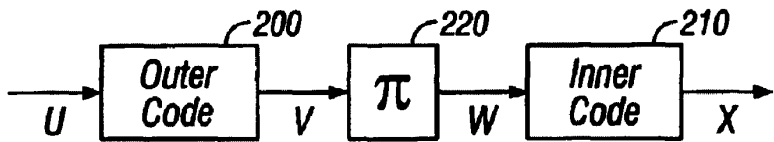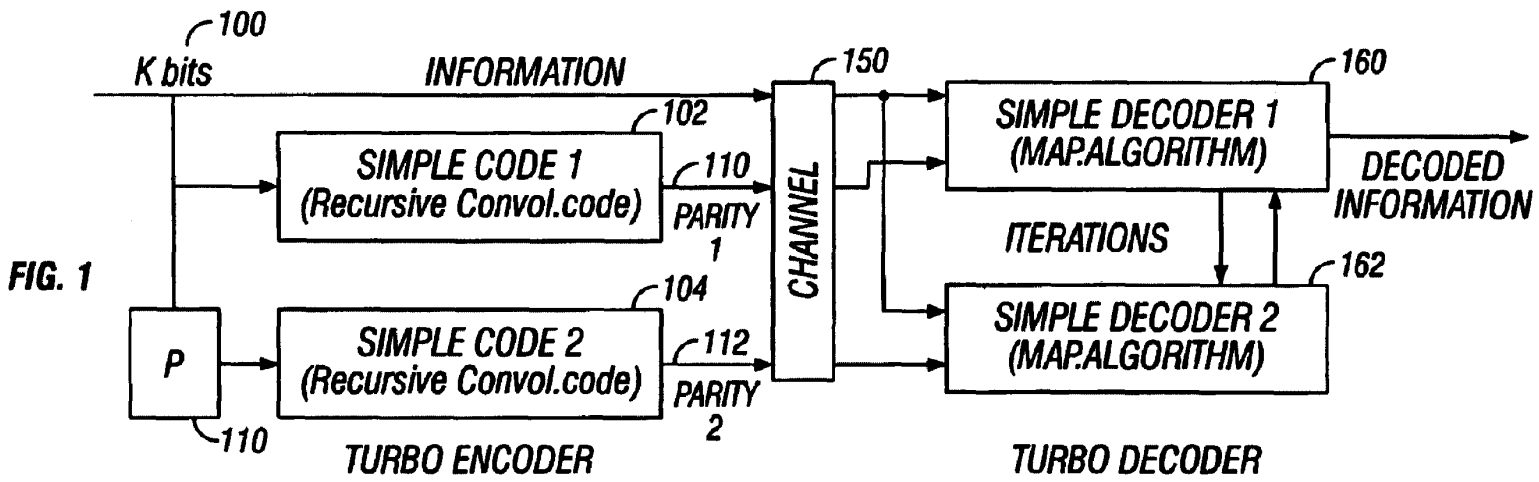
46 Claims, 6 Drawing Sheets
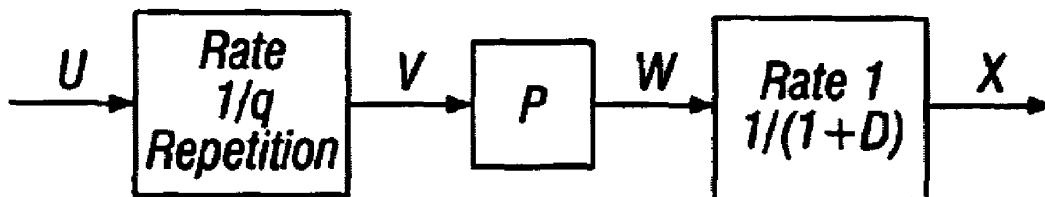
OTHER PUBLICATIONS

Benedetto, S., et al., Bandwidth efficient parallel concatenated coding schemes , Electronics Letters, vol. 31, No. 24, pp. 2067-2069, Nov. 23, 1995.

Divsalar, D., et al., Turbo Codes for PCS Applications , IEEE ICC 95, Seattle, WA, pp. 54-59, Jun. 1995.

Divsalar, D., et al., Multiple Turbo Codes , MILCOM 95, San Diego, CA, pp. 279-285, Nov. 5-6, 1995.

Benedetto, S., et al. Soft-Output Decoding Algorithms in Iterative Decoding of Turbo Codes , The Telecommunications and Data Acquisition Progress Report 42-124 for NASA and California Institute of Technology Jet Propulsion Laboratory, Joseph H. Yuen, ed.,pp. 63-87, Feb. 15, 1996.

Divsalar, D., et al., Effective free distance of turbo codes , Electronic Letters, vol. 32, No. 5, pp. 445-446, Feb. 29, 1996.

Benedetto, S., et al. Serial Concatenation of Interleaved Codes: Performance Analysis, Design, and Iterative Decoding , The Telecommunications and Data Acquisition Progress Report 42-126 for NASA and California Institute of Technology Jet Propulsion Laboratory, Joseph H. Yuen, ed.,pp. 1-26, Aug. 15, 1996.

Benedetto, S., et al. A Soft-Input Soft-Output Maximum A Posteriori (MAP) Module to Decode Parallel and Serial Concatenated Codes , The Telecommunications and Data Acquisition Progress Report 42-127 for NASA and California Institute of Technology Jet Propulsion Laboratory, Joseph H. Yuen, ed.,pp. 1-20, Nov. 15, 1996.

Benedetto, S., et al., Parallel Concatenated Trellis Coded Modulation , ICC 96, pp. 974-978, Jun. 1996.

Benedetto, S., et al., A Soft-Input Soft-Output APP Module for Iterative Decoding of Concatenated Codes , IEEE Communication Letters, vol. 1, No. 1, pp. 22-24, Jan. 1997.

Divsalar, D., et al., Hybrid Concatenated Codes and Iterative Decoding , Proceedings from the IEEE 1997 International Symposium on Information Theory, Ulm, Germany, p. 10, Jun. 29-Jul. 4, 1997.

Benedetto, S., et al., Serial Concatenation of interleaved codes: performance analysis, design, and iterative decoding, Proceedings from the IEEE 1997 International Symposium on Information Theory, Ulm, Germany, p. 106, Jun. 29-Jul. 4, 1997.

Benedetto, S., et al., Serial Concatenated Trellis Coded Modulation with Iterative Decoding , Proceedings from the IEEE 1997 International Symposium on Information Theory, Ulm, Germany, p. 8, Jun. 29-Jul. 4, 1997.

Benedetto, S., et al., Design of Serially Concatenated Interleaved Codes , ICC 97, Montreal, Canada, pp. 710-714, Jun. 1997.
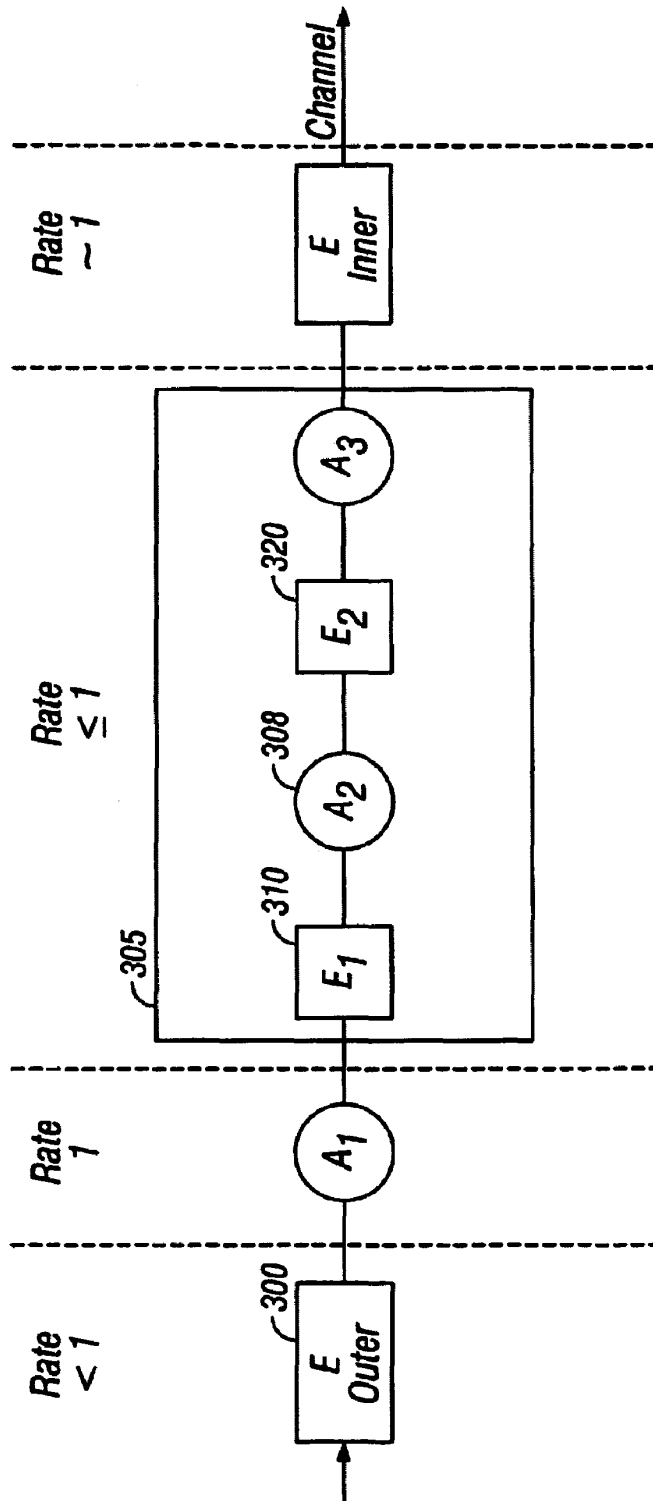
* cited by examiner

FIG. 1

100

K bits   INFORMATION

102

SIMPLE CODE 1
(Recursive Convol.code)

110

PARITY
1

P

110

104

SIMPLE CODE 2
(Recursive Convol.code)

112

PARITY
2

TURBO ENCODER

150

CHANNEL

160

SIMPLE DECODER 1
(MAP.ALGORITHM)

DECODED
INFORMATION

ITERATIONS

162

SIMPLE DECODER 2
(MAP.ALGORITHM)

TURBO DECODER

200

Outer
Code

U   V

220

π
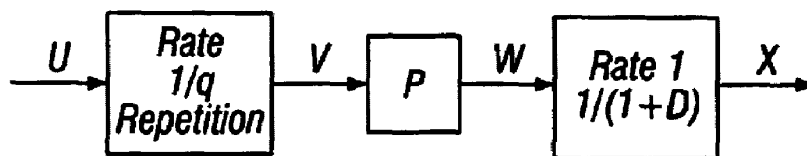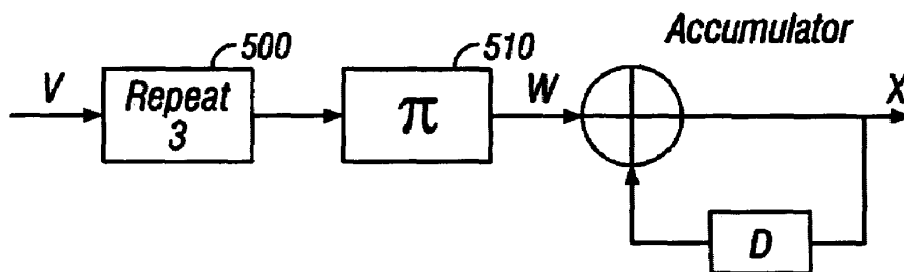
W

210

Inner
Code

X
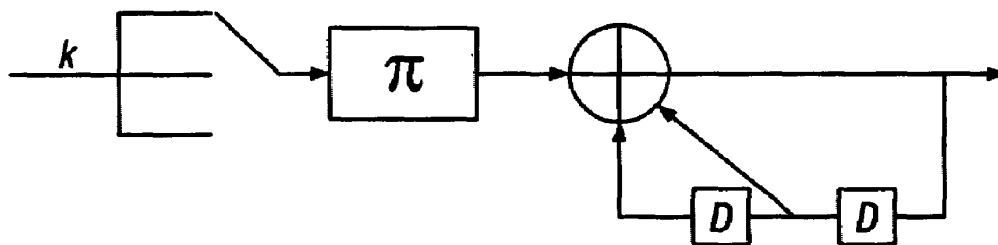
FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.