

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

(10) **Patent No.:** **US 7,421,032 B2**
(45) **Date of Patent:** **Sep. 2, 2008**

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

(75) **Inventors:** **Hui Jin**, Glen Gardner, NJ (US); **Aamod Khandekar**, Pasadena, CA (US); **Robert J. McEliece**, Pasadena, 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 0 days.

(21) **Appl. No.:** **11/542,950**

(22) **Filed:** **Oct. 3, 2006**

(65) **Prior Publication Data**

US 2007/0025450 A1 Feb. 1, 2007

Related U.S. Application Data

(63) Continuation of application No. 09/861,102, filed on May 18, 2001, now Pat. No. 7,116,710, and a continuation-in-part of application No. 09/922,852, filed on Aug. 18, 2000, now Pat. No. 7,089,477.

(60) Provisional application No. 60/205,095, filed on May 18, 2000.

(51) **Int. Cl.**
H04L 5/12 (2006.01)

(52) **U.S. Cl.** **375/262; 375/265; 375/348; 714/755; 714/786; 714/792; 341/52; 341/102**

(58) **Field of Classification Search** **375/259, 375/262, 265, 285, 296, 341, 346, 348; 714/746, 714/752, 755, 756, 786, 792, 794-796; 341/51, 341/52, 56, 102, 103**

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,392,299 A	2/1995	Rhines et al.	
5,530,707 A *	6/1996	Lin	714/792
5,751,739 A	5/1998	Seshadri et al.	
5,802,115 A *	9/1998	Meyer	375/341
5,881,093 A	3/1999	Wang et al.	
6,014,411 A	1/2000	Wang	
6,023,783 A	2/2000	Divsalar et al.	
6,031,874 A	2/2000	Chennakeshu et al.	
6,032,284 A	2/2000	Bliss	
6,044,116 A	3/2000	Wang	
6,094,739 A *	7/2000	Miller et al.	714/792

(Continued)

OTHER PUBLICATIONS

Appendix A.1 "Structure of Parity Check Matrices of Standardized LDPC Codes," Digital Video Broadcasting (DVB) User guidelines for the second generation system for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2) ETSI TR 102 376 V1.1.1. (Feb. 2005) Technical Report, pp. 64.

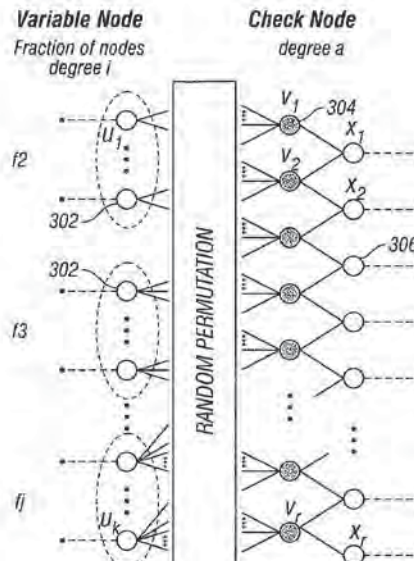
(Continued)

Primary Examiner—Dac V. Ha
(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

A serial concatenated coder includes an outer coder and an inner coder. The outer coder irregularly repeats bits in a data block according to a degree profile and scrambles the repeated bits. The scrambled and repeated bits are input to an inner coder, which has a rate substantially close to one.

23 Claims, 5 Drawing Sheets



U.S. PATENT DOCUMENTS

6,396,423 B1 5/2002 Laumen et al.
 6,437,714 B1 8/2002 Kim et al.
 6,859,906 B2* 2/2005 Hammons et al. 714/786
 2001/0025358 A1 9/2001 Eidson et al.

OTHER PUBLICATIONS

Benedetto et al., "A Soft-Input Soft-Output Maximum A Posteriori (MAP) Module to Decode Parallel and Serial Concatenated Codes," The Telecommunications and Data Acquisition (TDA) 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 et al., "Bandwidth efficient parallel concatenated coding schemes," *Electronics Letters* 31(24): 2067-2069 (Nov. 23, 1995).

Benedetto et al., "Design of Serially Concatenated Interleaved Codes," ICC 97, Montreal, Canada, pp. 710-714, (Jun. 1997).

Benedetto et al., "Parallel Concatenated Trellis Coded Modulation," ICC '96, IEEE, pp. 974-978, (Jun. 1996).

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

Benedetto et al., "Serial Concatenation of Interleaved Codes: Performance Analysis, Design, and Iterative Decoding," The Telecommunications and Data Acquisition (TDA) 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 et al., "Serial Concatenation of interleaved codes: performance analysis, design, and iterative decoding," Proceedings from the IEEE 1997 International Symposium on Information Theory (ISIT), Ulm, Germany, p. 106, Jun. 29-Jul. 4, 1997.

Benedetto et al., "Soft-output decoding algorithms in iterative decoding of turbo codes," The Telecommunications and Data Acquisition (TDA) Progress Report 42-124 for NASA and California Institute of Technology Jet Propulsion Laboratory, Joseph H. Yuen, Ed., pp. 63-87 (Feb. 15, 1996).

Benedetto, S. et al., "A Soft-Input Soft-Output APP Module for Iterative Decoding of Concatenated Codes," *IEEE Communications Letters* 1(1): 22-24 (Jan. 1997).

Berrou et al., "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo Codes," ICC pp. 1064-1070 (1993).

Digital Video Broadcasting (DVB) User guidelines for the second generation system for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2) ETSI TR 102 376 V1.1.1. (Feb. 2005) Technical Report, pp. 1-104 (Feb. 15, 2005).

Divsalar et al., "Coding Theorems for 'Turbo-Like' Codes," Proceedings of the 36th Annual Allerton Conference on Communication, Control, and Computing, Sep. 23-25, 1998, Allerton House, Monticello, Illinois, pp. 201-210 (1998).

Divsalar et al., "Effective free distance of turbo codes," *Electronics Letters* 32(5): 445-446 (Feb. 29, 1996).

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

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

Divsalar, D. et al., "Multiple Turbo Codes for Deep-Space Communications," The Telecommunications and Data Acquisition (TDA) 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., "Multiple Turbo Codes," MILCOM 95, San Diego, CA pp. 279-285 (Nov. 5-6, 1995).

Divsalar, D. et al., "On the Design of Turbo Codes," The Telecommunications and Data Acquisition (TDA) Progress Report 42-123 for NASA and California Institute of Technology Jet Propulsion Laboratory, Joseph H. Yuen, Ed., pp. 99-131 (Nov. 15, 1995).

Divsalar, D. et al., "Serial Turbo Trellis Coded Modulation with Rate-1 Inner Code," Proceedings from the IEEE 2000 International Symposium on Information Theory (ISIT), Italy, pp. 1-14 (Jun. 2000).

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

Jin et al., "Irregular Repeat—Accumulate Codes," 2nd International Symposium on Turbo Codes & Related Topics, Sep. 4-7, 2000, Brest, France, 25 slides, (presented on Sep. 4, 2000).

Jin et al., "Irregular Repeat—Accumulate Codes," 2nd International Symposium on Turbo Codes & Related Topics, Sep. 4-7, 2000, Brest, France, pp. 1-8 (2000).

Richardson et al., "Design of capacity approaching irregular low density parity check codes," *IEEE Trans. Inform. Theory* 47: 619-637 (Feb. 2001).

Richardson, T. and R. Urbanke, "Efficient encoding of low-density parity check codes," *IEEE Trans. Inform. Theory* 47: 638-656 (Feb. 2001).

Wilberg, et al., "Codes and Iterative Decoding on General Graphs", 1995 Intl. Symposium on Information Theory, Sep. 1995, p. 468.

* cited by examiner

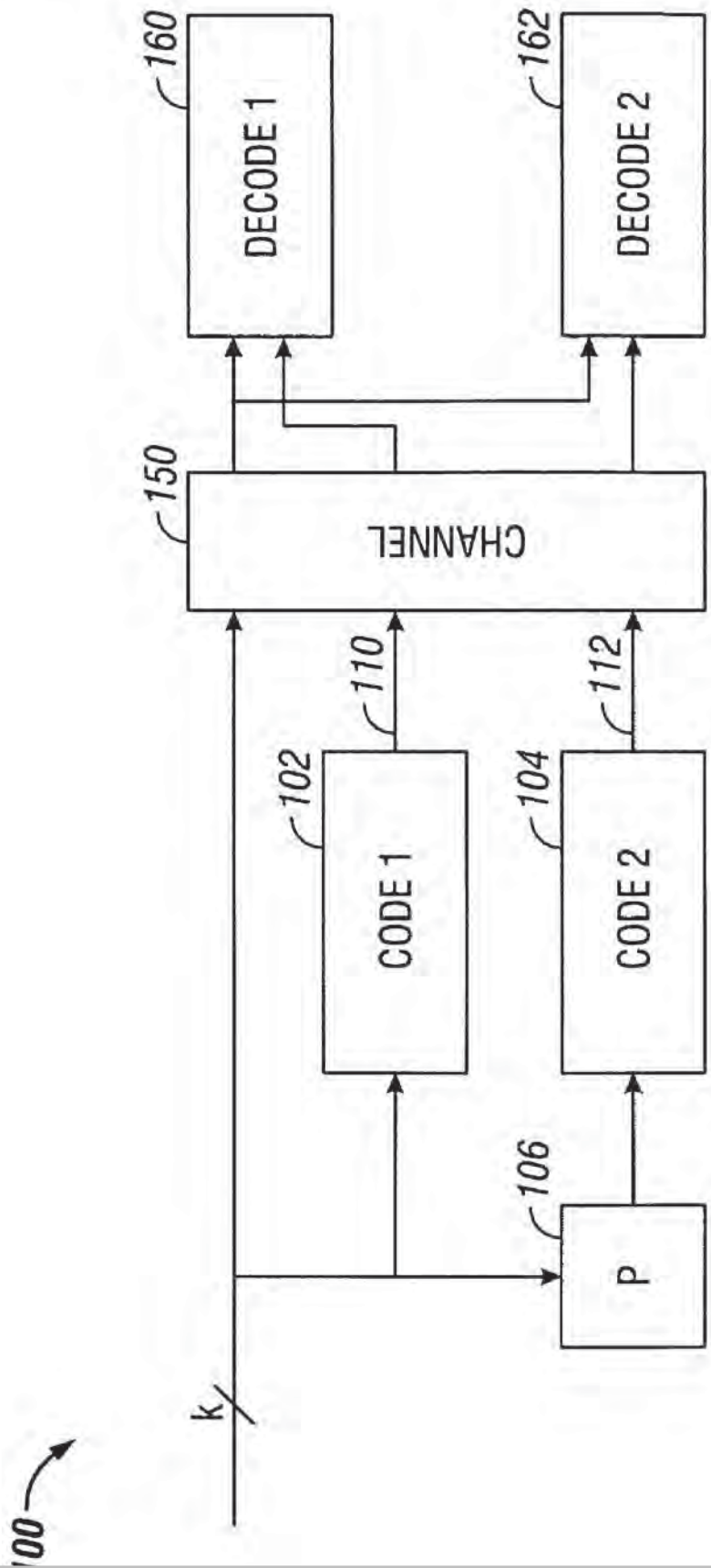


FIG. 1
(Prior Art)

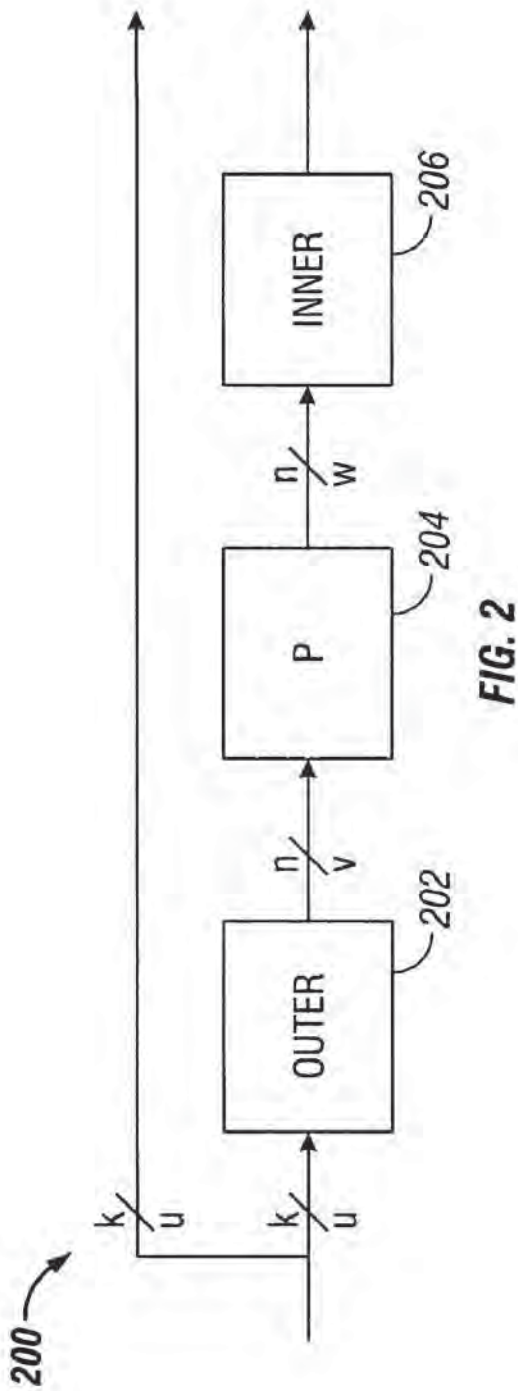


FIG. 2

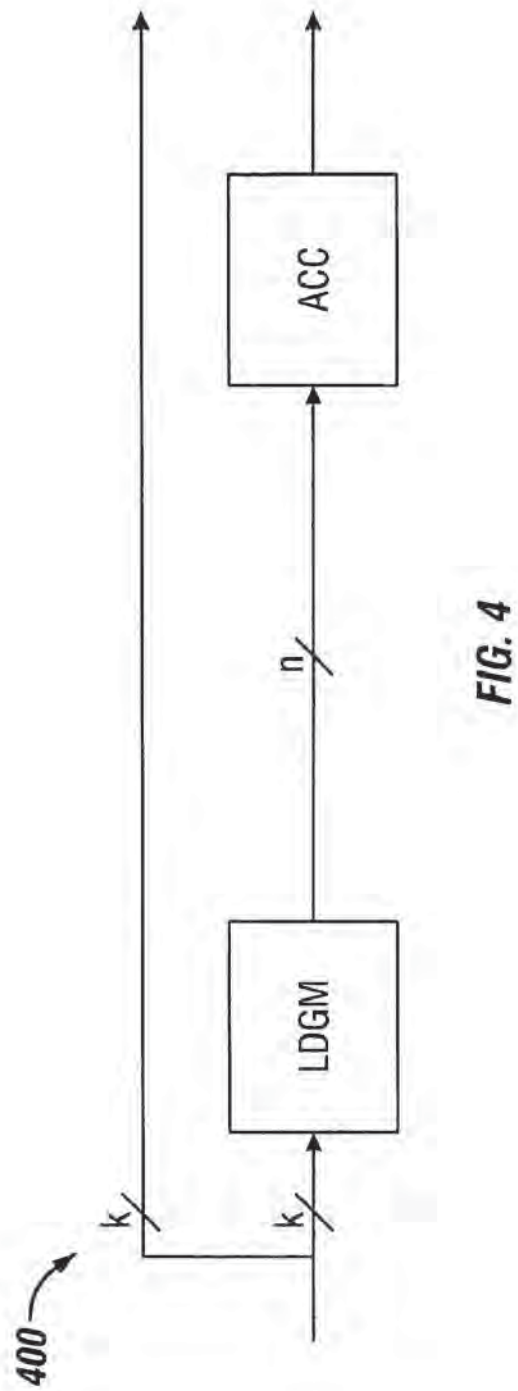


FIG. 4

Variable Node

Fraction of nodes
degree i

Check Node

degree a

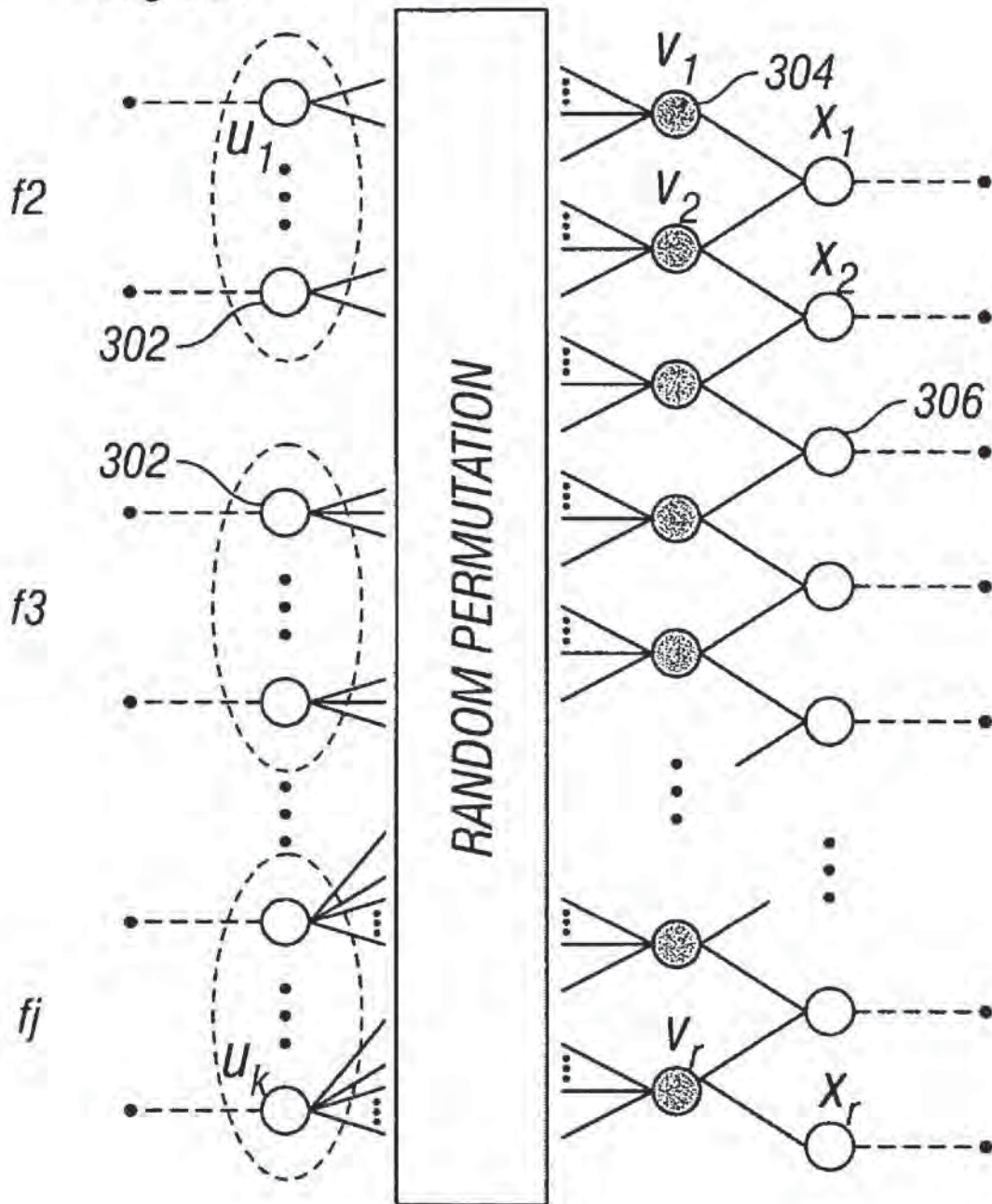


FIG. 3

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.