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**Jin et al.**

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

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(51) **Int. Cl.**  
**H04B 1/66** (2006.01)

(52) **U.S. Cl.** ..... 375/240; 375/262; 375/265; 375/341; 341/51; 341/102; 714/752

(58) **Field of Classification Search** ..... 375/259, 375/262, 265, 285, 296, 341, 346, 348; 714/746, 714/752, 755, 756, 786, 792, 794, 795, 796; 341/51, 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.  
5,751,739 A \* 5/1998 Seshadri et al. .... 714/746

5,881,093 A 3/1999 Wang et al.  
6,014,411 A \* 1/2000 Wang ..... 375/259  
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  
6,396,423 B1 \* 5/2002 Laumen et al. .... 341/95  
6,437,714 B1 \* 8/2002 Kim et al. .... 341/81  
2001/0025358 A1 9/2001 Eidson et al.

**OTHER PUBLICATIONS**

Wiberg et al., "Codes and Iterative Decoding on General Graphs", 1995 Intl. Symposium on Information Theory, Sep. 1995, p. 506.\* 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. (2005-02) Technical Report. pp. 64.

Benedetto et al., "Bandwidth efficient parallel concatenated coding schemes," Electronics Letters 31(24):2067-2069 (Nov. 23, 1995). 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).

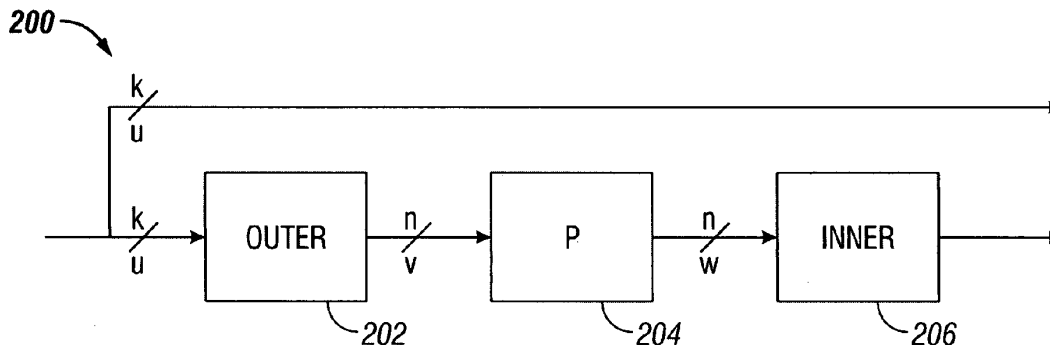
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(57) **ABSTRACT**

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.

**33 Claims, 5 Drawing Sheets**



## OTHER PUBLICATIONS

- 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., "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., "Parallel Concatenated Trellis Coded Modulation," ICC '96, IEEE, pp. 974-978, (Jun. 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).
- 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., "Serial Concatenated Trellis Coded Modulation with Iterative Decoding," Proceedings from IEEE 1997 International Symposium on Information Theory (ISIT), Ulm, Germany, p. 8, Jun. 29-Jul. 4, 1997.
- Benedetto et al., "Design of Serially Concatenated Interleaved Codes," ICC 97, Montreal, Canada, pp. 710-714, (Jun. 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 36<sup>th</sup> Annual Allerton Conference on Communication, Control, and Computing, Sep. 23-25 1998, Allerton House, Monticello, Illinois, pp. 201-210 (1998).
- 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., "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., "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, p. 35.
- Divsalar, D. et al., "Turbo Codes for PCS Applications," ICC 95, IEEE, 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).
- 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., "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).
- Jin et al., "Irregular Repeat - Accumulate Codes," 2<sup>nd</sup> 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," 2<sup>nd</sup> 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).

\* cited by examiner

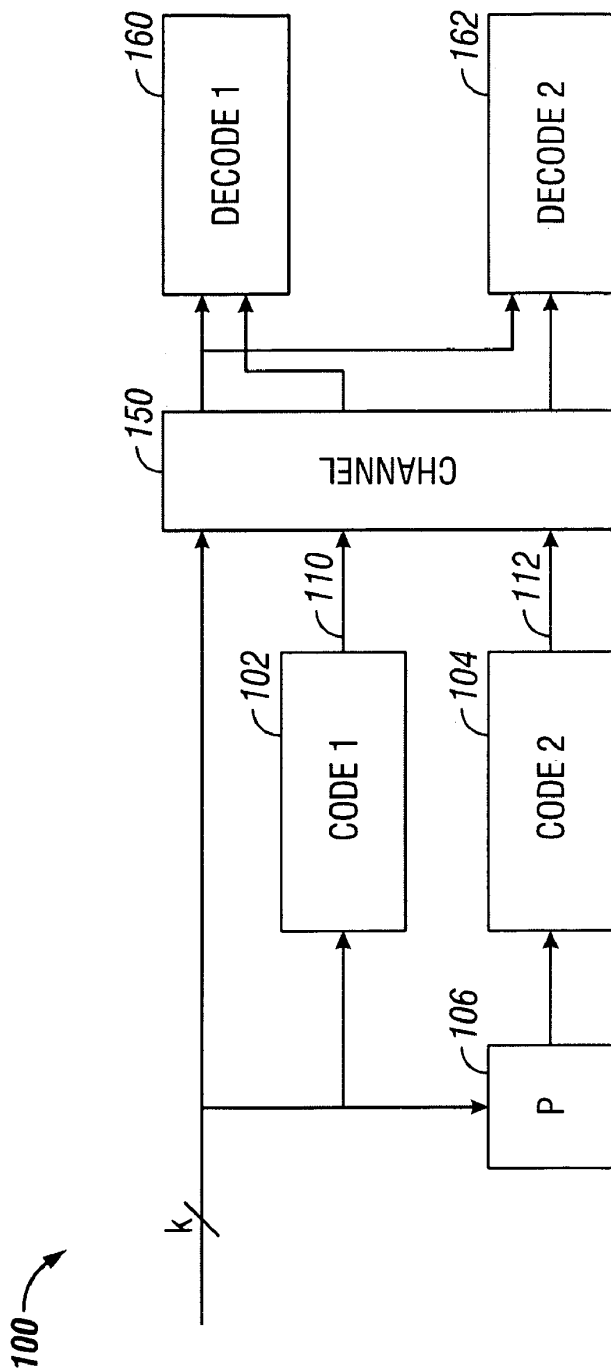
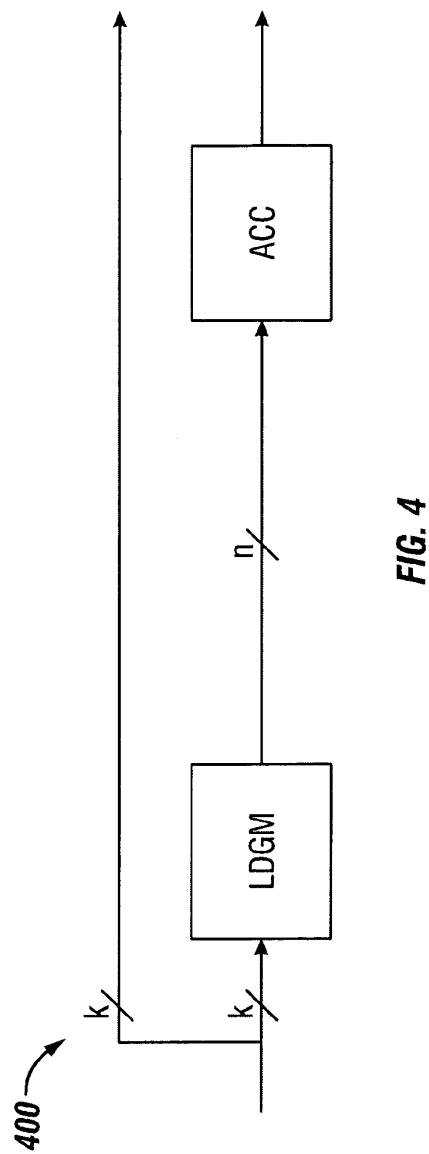
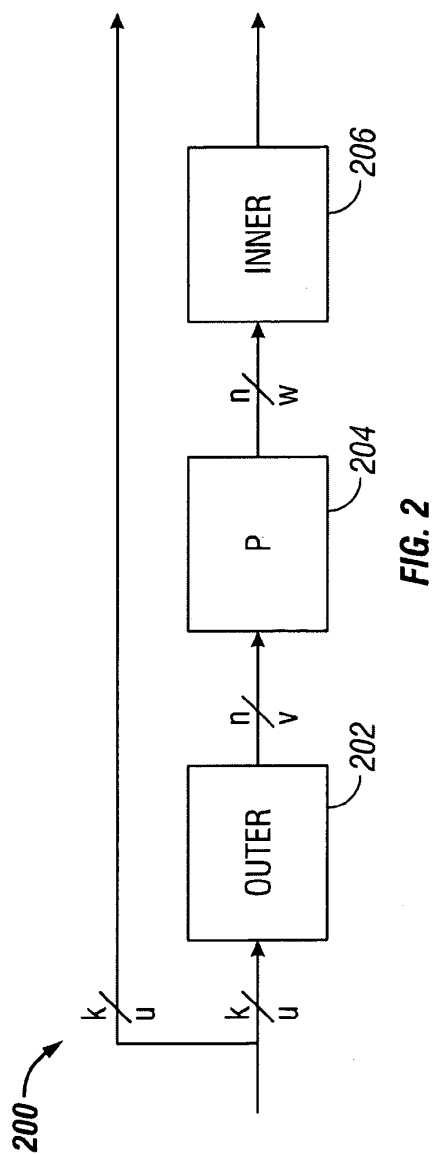


FIG. 1  
(Prior Art)



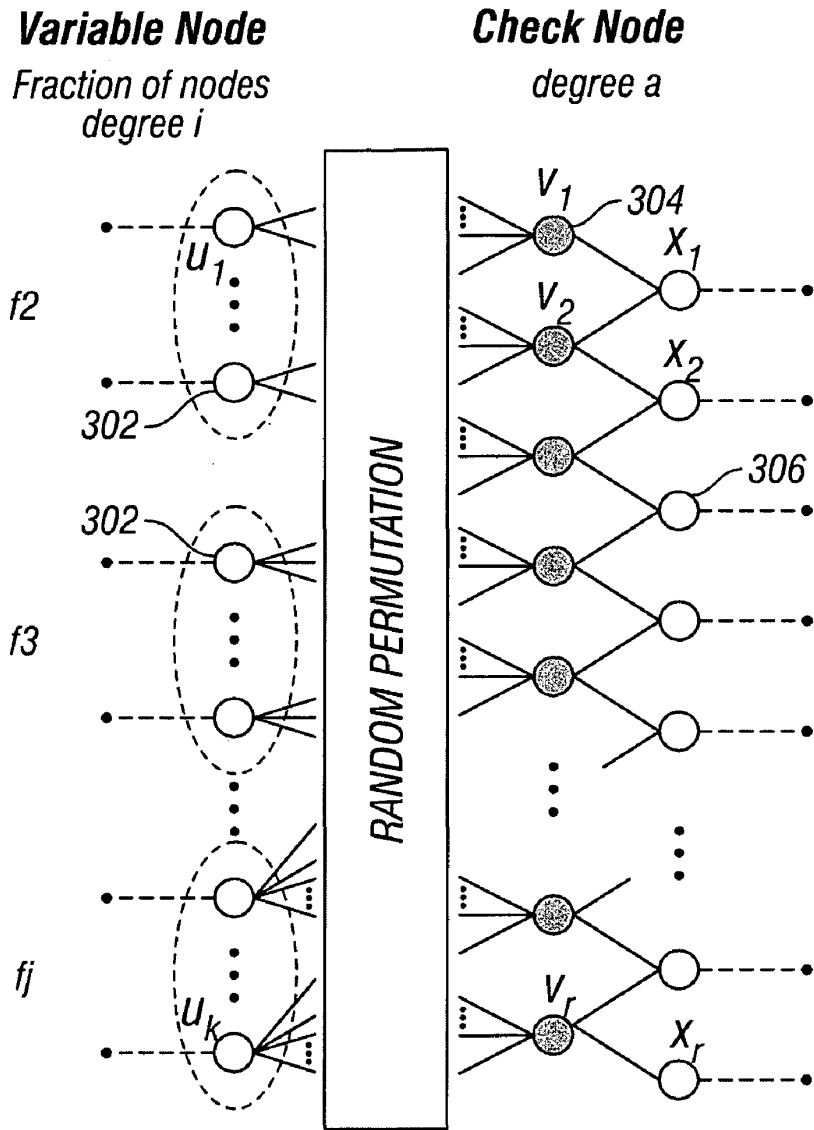


FIG. 3

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