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**Jin et al.**

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<sup>a</sup>(54) **SERIAL CONCATENATION OF INTERLEAVED CONVOLUTIONAL CODES FORMING TURBO-LIKE CODES**

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 424 days.

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(63) Continuation of application No. 11/542,950, filed on Oct. 3, 2006, now Pat. No. 7,421,032, which is a continuation of application No. 09/861,102, filed on May 18, 2001, now Pat. No. 7,116,710, which is a continuation-in-part of application No. 09/922,852, filed on Aug. 18, 2000, now Pat. No. 7,089,477.

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

(52) **U.S. Cl.** ..... **375/240**; 375/285; 375/296; 714/801; 714/804

(58) **Field of Classification Search** ..... 375/240, 375/240.24, 254, 285, 295, 296, 260; 714/755, 714/758, 800, 801, 804, 805

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,181,207	A *	1/1993	Chapman	714/755
5,392,299	A	2/1995	Rhines et al.	
5,530,707	A	6/1996	Lin	
5,751,739	A	5/1998	Seshadri et al.	
5,802,115	A	9/1998	Meyer	
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.	
6,195,396	B1 *	2/2001	Fang et al.	375/261
6,396,423	B1	5/2002	Laumen et al.	
6,437,714	B1	8/2002	Kim et al.	
6,732,328	B1 *	5/2004	McEwen et al.	714/795
6,859,906	B2	2/2005	Hammons et al.	
7,089,477	B1	8/2006	Divsalar et al.	

(Continued)

OTHER PUBLICATIONS

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.

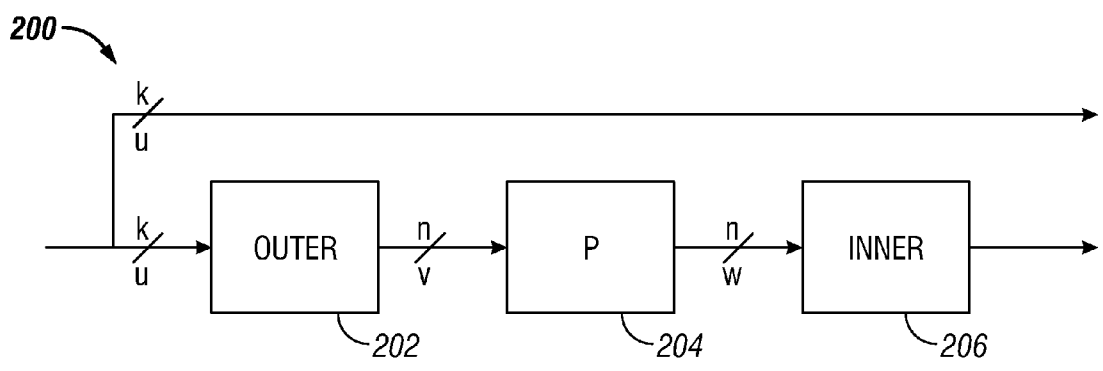
(Continued)

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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.

**22 Claims, 5 Drawing Sheets**



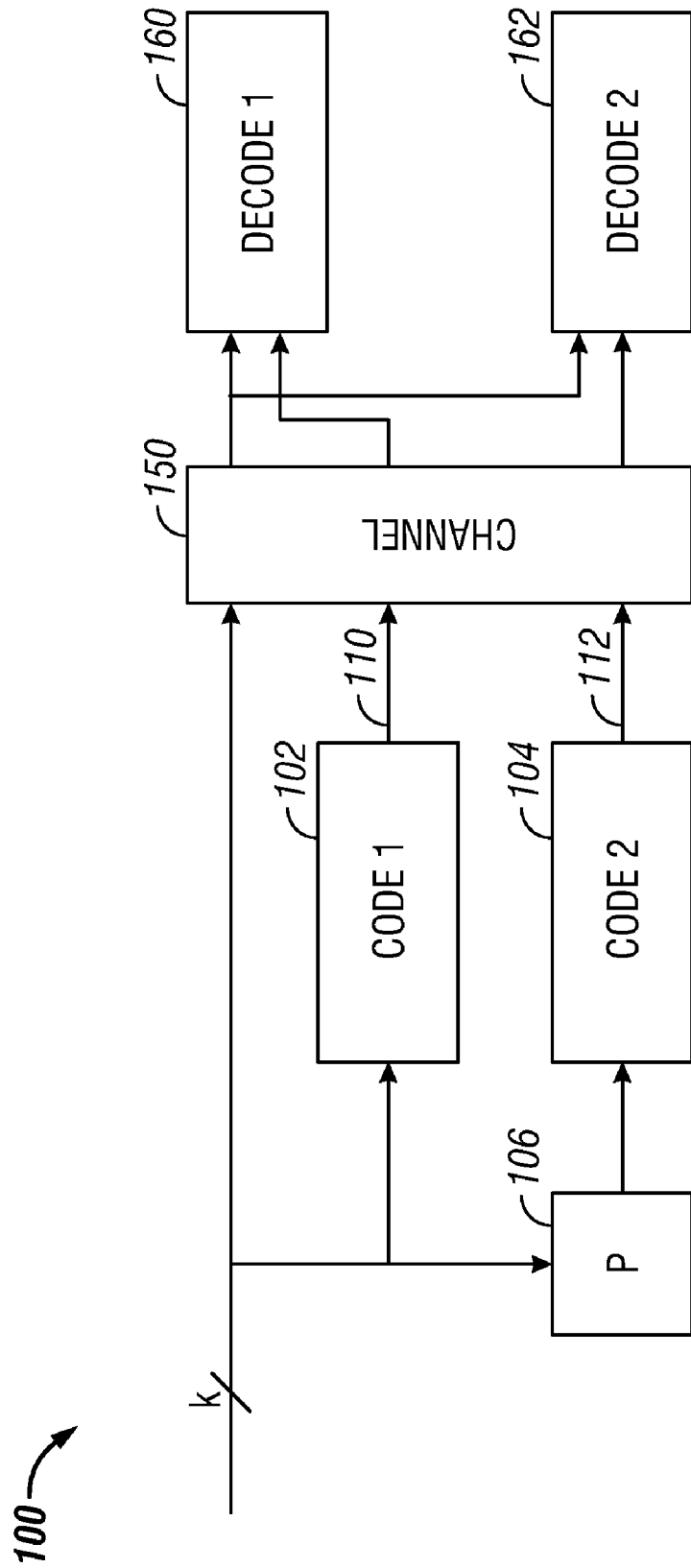
## U.S. PATENT DOCUMENTS

2001/0025358 A1 9/2001 Eidson et al.

## OTHER PUBLICATIONS

- 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 (TDA PR 42-127)*, pp. 1-20, Nov. 1996.
- Benedetto, S., et al., "Bandwidth efficient parallel concatenated coding schemes," *Electronics Letters*, 31(24):2067-2069, Nov. 1995.
- Benedetto, S., et al., "Design of Serially Concatenated Interleaved Codes," *ICC 97*, vol. 2, pp. 710-714, Jun. 1997.
- Benedetto, S., et al., "Parallel Concatenated Trellis Coded Modulation," *ICC 96*, vol. 2, pp. 974-978, Jun. 1996.
- Benedetto, S., et al., "Serial Concatenated Trellis Coded Modulation with Iterative Decoding," *Proceedings 1997 IEEE International Symposium on Information Theory (ISIT)*, Ulm, Germany, p. 8, Jun. 29-Jul. 4, 1997.
- Benedetto, S., et al., "Serial Concatenation of Interleaved Codes: Performance Analysis, Design, and Iterative Decoding," *The Telecommunications and Data Acquisition Progress Report (TDA PR 42-126)*, pp. 1-26, Aug. 1996.
- Benedetto, S., et al., "Serial concatenation of interleaved codes: performance analysis, design, and iterative decoding," *Proceedings 1997 IEEE International Symposium on Information Theory (ISIT)*, Ulm, Germany, p. 106, Jun. 29-Jul. 4, 1997.
- Benedetto, S., et al., "Soft-Output Decoding Algorithms in Iterative Decoding of Turbo Codes," *The Telecommunications and Data Acquisition Progress Report (TDA PR 42-124)*, pp. 63-87, Feb. 1996.
- Berrou, C., et al., "Near Shannon Limit Error—Correcting Coding and Decoding: Turbo Codes," *ICC 93*, vol. 2, pp. 1064-1070, May 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 Technical Report, pp. 1-104 (p. 64), Feb. 2005.
- Divsalar, D., et al., "Coding Theorems for 'Turbo-Like' Codes," *Proceedings of the 36<sup>th</sup> Annual Allerton Conference on Communication, Control, and Computing*, Monticello, Illinois, pp. 201-210, Sep. 1998.
- Divsalar, D., et al., "Effective free distance of turbo codes," *Electronics Letters*, 32(5):445-446, Feb. 1996.
- Divsalar, D., et al., "Hybrid Concatenated Codes and Iterative Decoding," *Proceedings 1997 IEEE 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 1995 IEEE International Symposium on Information Theory (ISIT)*, Whistler, BC, Canada, p. 35, Sep. 1995.
- Divsalar, D., et al., "Multiple Turbo Codes for Deep-Space Communications," *The Telecommunications and Data Acquisition Progress Report (TDA PR 42-121)*, pp. 66-77, May 1995.
- Divsalar, D., et al., "Multiple Turbo Codes," *MILCOM '95*, vol. 1, pp. 279-285, Nov. 1995.
- Divsalar, D., et al., "On the Design of Turbo Codes," *The Telecommunications and Data Acquisition Progress Report (TDA PR 42-123)*, pp. 99-121, Nov. 1995.
- Divsalar, D., et al., "Serial Turbo Trellis Coded Modulation with Rate-1 Inner Code," *Proceedings 2000 IEEE International Symposium on Information Theory (ISIT)*, Sorrento, Italy, pp. 194, Jun. 2000.
- Divsalar, D., et al., "Turbo Codes for PCS Applications," *IEEE ICC '95*, Seattle, WA, USA, vol. 1, pp. 54-59, Jun. 1995.
- Jin, H., et al., "Irregular Repeat—Accumulate Codes," *2<sup>nd</sup> International Symposium on Turbo Codes*, Brest, France, 25 pages, Sep. 2000.
- Jin, H., et al., "Irregular Repeat—Accumulate Codes," *2<sup>nd</sup> International Symposium on Turbo Codes & Related Topics*, Brest, France, p. 1-8, Sep. 2000.
- Richardson, T.J., et al., "Design of Capacity-Approaching Irregular Low-Density Parity-Check Codes," *IEEE Transactions on Information Theory*, 47(2):619-637, Feb. 2001.
- Richardson, T.J., et al., "Efficient Encoding of Low-Density Parity-Check Codes," *IEEE Transactions on Information Theory*, 47(2):638-656, Feb. 2001.
- Wiberg, N., et al., "Codes and Iterative Decoding on General Graphs," *Proceedings 1995 IEEE International Symposium on Information Theory (ISIT)*, Whistler, BC, Canada, p. 468, Sep. 1995.
- Aji, S.M., et al., "The Generalized Distributive Law," *IEEE Transactions on Information Theory*, 46(2):325-343, Mar. 2000.
- Tanner, R.M., "A Recursive Approach to Low Complexity Codes," *IEEE Transactions on Information Theory*, 27(5):533-547, Sep. 1981.

\* cited by examiner



**FIG. 1**  
*(Prior Art)*

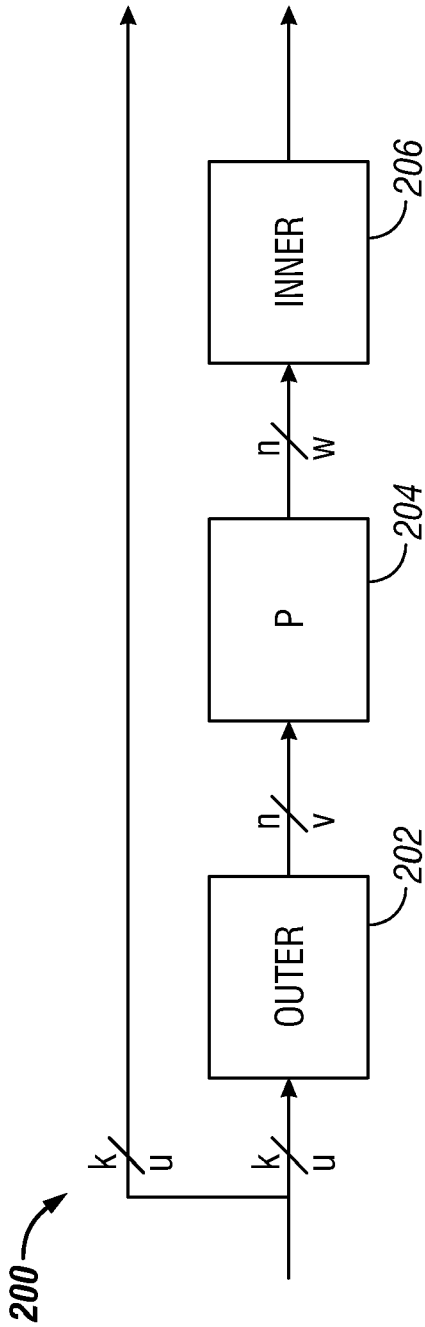


FIG. 2

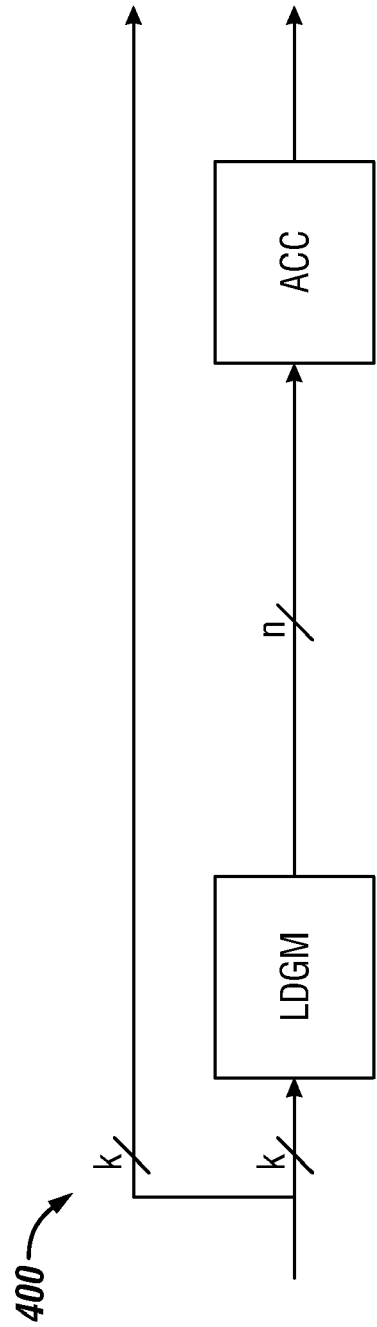


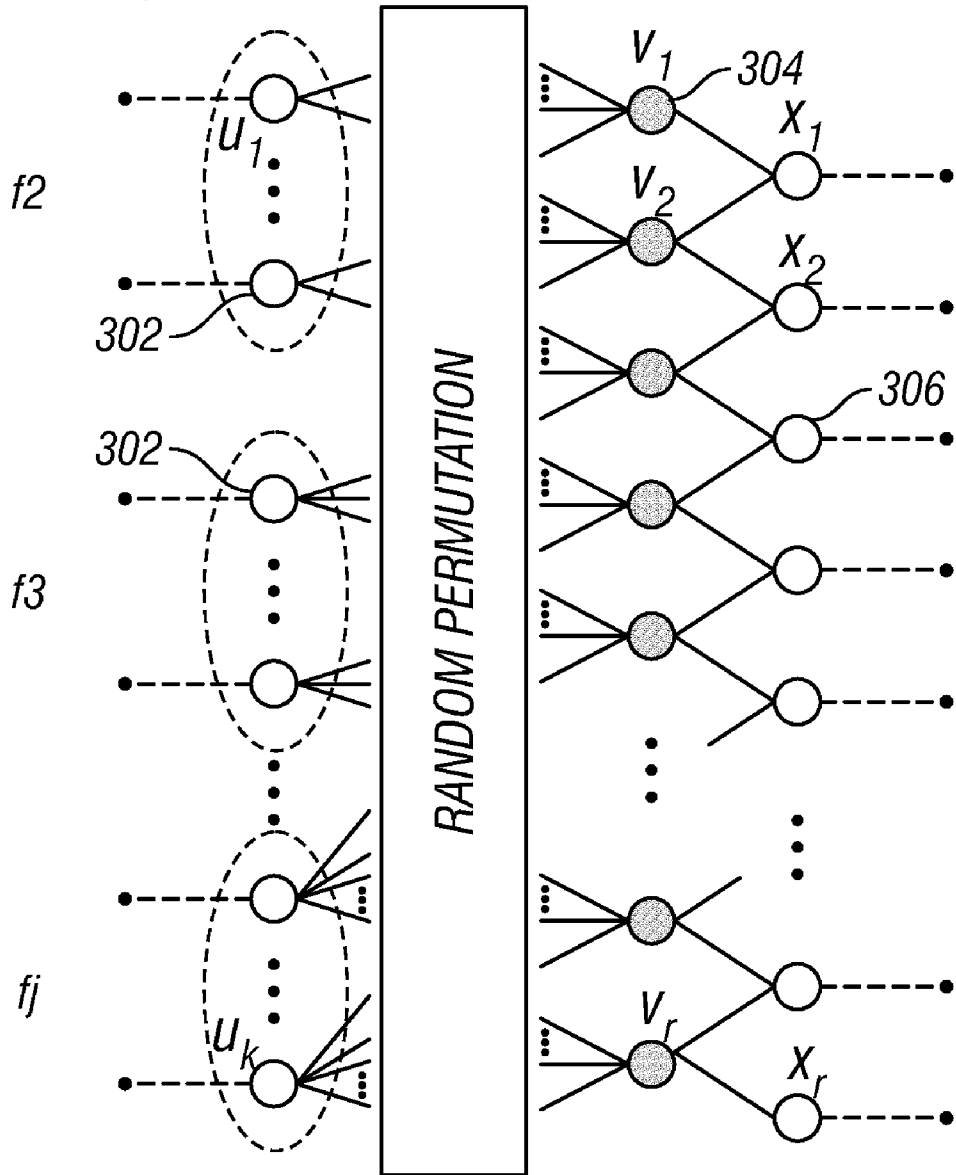
FIG. 4

**Variable Node**

Fraction of nodes  
degree  $i$

**Check Node**

degree  $a$



**FIG. 3**

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