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16 October 2014

(54) **Title**: SYSTEMS AND METHODS FOR ENCODING AND DECODING OF CHECK-IRREGULAR NON-SYSTEMATIC IRA CODES

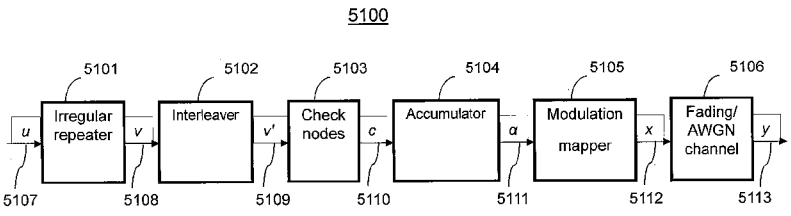

Fig. 1

(57) **Abstract**: Systems and methods for encoding and decoding check-irregular non-systematic IRA codes of messages in any communication or electronic system where capacity achieving coding is desired. According to these systems and methods, improved IRA coding strategies, including ones that employ capacity-approaching non-systematic IRA codes that are irregular and that exhibit a low error floor, are employed. These non-systematic IRA codes are particularly advantageous in scenarios in which up to half of coded bits could be lost due to channel impairments and/or where complementary coded bits are desired to transmit over two or more communications sub-channels. An encoder includes information bit repeaters and encoders, one or more interleavers, check node combiners, a check node by-pass and an accumulator. A decoder includes a demapper, one or more check node processors, an accumulator decoder, a bit decoder, and one or more interleavers/deinterleavers.

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INTERNATIONAL SEARCH REPORT

~~013/072900 11.07.2014~~
International application No.
PCT/US 13/72900

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H03M 13/00 (2014.01)
USPC - 714/758
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 714/758; IPC: H03M 13/00 (2014.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 714/758, 786, 780, 755, 791; 375/262, 298; IPC: H03M* (keyword limited; terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase; Google Scholar; Google Patents
Keywords: encoding, check-irregular, non-systematic irregular codes; interleaver; accumulator; decoder; check node; degree

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Johnson, Sarah J., and Steven R. Weller. "Constructions for irregular repeat-accumulate codes." Information Theory, 2005. ISIT 2005. Proceedings. International Symposium on. IEEE, 2005. Retrieved online on 07 June 2014 at <http://sigpromu.org/reports/EE05045.pdf>	1 - 30
A	Wang, Guangsong, Ingmar Land, and Alex Grant. "Irregular repeat accumulate codes with few iterations for the binary adder channel." Turbo Codes and Iterative Information Processing (ISTC), 2012 7th International Symposium on. IEEE, 2012. Published in: Turbo Codes and Iterative Information Processing (ISTC), 2012 7th International Symposium on Date of Conference: 27-31 Aug. 2012; Page(s): 215 ? 219; Retrieved online on 07 June 2014 at <https://www.itr.un```isa.edu.au/itrusers/landi/public_html/Ingmar_Land/publications_files/paper_iteropt_ISTC2012.pdf>	1 - 30
A	US 2005/0111564 A1 (KRAMER et al.) 26 May 2005 (26.05.2005), entire document, especially; para [0038]	1 - 30
A	US 2010/0174963 A1 (KIENLE et al.) 08 July 2010 (08.07.2010), entire document, especially; para [0019], [0044], [0048], [0049], [0053], [0063], [0064], [0079]	1 - 30
A	US 2005/0132260 A1 (KYUNG et al.) 16 June 2005 (16.06.2005), entire document, especially; para [0059], [0060], [0077], [0082], [0115]	1 - 30
A	Jin, Hui, Aamod Khandekar, and Robert McEliece. "Irregular repeat-accumulate codes." Proc. 2nd Int. Symp. Turbo codes and related topics. 2000. Retrieved online on 07 June 2014 at <http://www.ee.caltech.edu/EE/Faculty/rjm/papers/Brest00.pdf.	1 - 30

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 June 2014 (07.06.2014)	11 JUL 2014
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 13/72900

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions that are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-8 and 20-27 directed to a system for encoding check-irregular non-systematic irregular repeat accumulate codes, the system comprising:
a. a plurality of information bit repeaters that produce a set of first stage coded bits;
b. an interleaver that interleaves said set of first stage coded bits;
c. two or more sets of check node combiners of different degrees, each degree being greater than or equal to 2, wherein a check node combiner of degree M produces a set of second stage coded bits from said interleaved set of first stage coded bits, wherein at least one of said check node combiners includes one or more modulo-2 adders;
d. a check node by-pass that passes said set of first stage coded bits to a further encoding stage as second stage coded bits; and
e. an accumulator decoder that encodes the second stage coded bits from the check node combiners and from the check node bypass.
See Continuation Sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

Continuation of Box No. III, Observations where unity of invention is lacking:

Group II: claims 9-19 and 28-30 directed to a system for decoding check-irregular non-systematic irregular repeat accumulate codes, the system comprising:
a. a demapper for soft-demodulating a received noisy symbol sequence to produce Log-Likelihood Ratios of a first set of coded bits from received distorted channel symbols and that outputs said LogLikelihood Ratios to an accumulator decoder;
b. a first check node processor that:
i. receives from the accumulator decoder incoming messages corresponding to a second set of coded bits,
ii. receives from a second check node processor a priori information corresponding to a third set of coded bits received, and
iii. produces outgoing messages corresponding to the third set of coded bits;
c. wherein the second check node processor receives from an interleaver interleaved extrinsic information corresponding to the third set of code bits and:
i. passes said interleaved extrinsic information as a priori information corresponding to the third set of coded bits to the first check node processor, and
ii. produces extrinsic information for the second set of coded bits that are passed to the accumulator decoder as a priori information for the second set of coded bits;
d. wherein the accumulator decoder produces, outgoing messages corresponding to the second set of coded bits obtained from:
i. the Log-Likelihood Ratios of the first set of coded bits produced by said demapper, and
ii. the a priori information corresponding to the second set of coded bits obtained from said second check node processor;
e. a bit decoder that processes deinterleaved messages corresponding to the third set of coded bits obtained from a deinterleaver to produce extrinsic information for the third set of coded bits and information bits soft outputs, said bit decoder comprising a repetition bit decoder;
f. wherein the interleaver interleaves extrinsic information for the third set of coded bits produced by the bit decoder and its output is supplied to said second check node processor; and
g. wherein the deinterleaver deinterleaves the outgoing messages corresponding to the third set of coded bits obtained from said first check node processor and passes said deinterleaved messages to the bit decoder.

The inventions listed as Groups I - II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical feature of Group I invention is directed to encoding check-irregular non-systematic irregular repeat accumulate codes, the system comprising plurality of information bit repeaters; two or more sets of check node combiners; and a check node by-pass, not required by the claims of Group II.

The special technical feature of Group II invention is directed to decoding check-irregular non-systematic irregular repeat accumulate codes, the system comprising a demapper for soft-demodulating a received noisy symbol sequence to produce Log-Likelihood Ratios of a first set of coded bits from received distorted channel symbols and that outputs said LogLikelihood Ratios; a first check node processor; a second check node processor; a bit decoder, not required by the claims of Group I.

Groups I-II share the technical feature of check-irregular non-systematic irregular repeat accumulate codes, an accumulator decoder and an interleaver.

However, these common technical features are anticipated by US 7,418,051 B2 to Kramer et al. (26 August 2008) the check-irregular non-systematic irregular repeat accumulate codes (col 3, ln 21-23), and accumulator decoder (col 6, ln 31-55)and an interleaver (col 3, ln 65).

Therefore, Groups I-II all lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.