Method and system for generating channel codes, in particular for a frame-header

US009692542B2

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

(10) **Patent No.: US 9,692,542 B2**
(45) **Date of Patent: Jun. 27, 2017**

(54) **METHOD AND SYSTEM FOR GENERATING CHANNEL CODES, IN PARTICULAR FOR A FRAME-HEADER**

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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 0 days.

(21) Appl. No.: **14/430,865**

(22) PCT Filed: **Sep. 24, 2013**

(86) PCT No.: **PCT/EP2013/069871**
§ 371 (c)(1),
(2) Date: **Mar. 24, 2015**

(87) PCT Pub. No.: **WO2014/048928**
PCT Pub. Date: **Apr. 3, 2014**

(65) **Prior Publication Data**

US 2015/0244491 A1 Aug. 27, 2015

(30) **Foreign Application Priority Data**

Sep. 25, 2012 (IT) TO2012A0829

(51) **Int. Cl.**
H04L 12/28 (2006.01)
H04J 13/10 (2011.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04J 13/10*** (2013.01); ***H03M 13/251*** (2013.01); ***H03M 13/2906*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H04L 47/365; H04L 7/042; H04L 1/007; H04L 45/00; H04L 12/28; H04L 29/0653;
(Continued)

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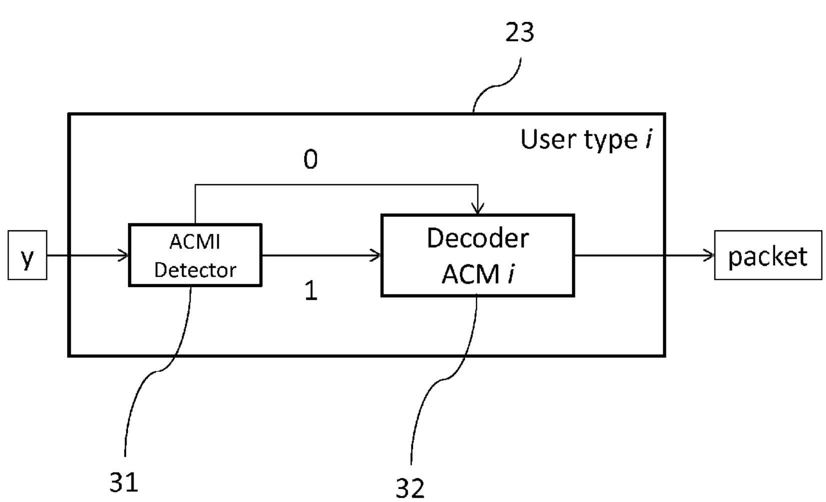
Primary Examiner — Andrew Lee
(74) *Attorney, Agent, or Firm* — Workman Nydegger

(57) **ABSTRACT**

A method for generating a channel code, in particular for a frame-header, wherein at least a code-word of the channel code is obtained by means of at least a concatenation of code-words of two constituent codes and such concatenation is performed on subsets of code-words of a first constituent code, having maximum length, with code-words of a second constituent code.

17 Claims, 16 Drawing Sheets



(51) **Int. Cl.**

H04L 1/00	(2006.01)
H03M 13/25	(2006.01)
H03M 13/29	(2006.01)
H03M 13/35	(2006.01)
H04L 29/06	(2006.01)
H04W 72/04	(2009.01)
H03M 13/13	(2006.01)

(52) **U.S. Cl.**
CPC ***H03M 13/356*** (2013.01); ***H04L 1/001*** (2013.01); ***H04L 1/0003*** (2013.01); ***H04L 1/0057*** (2013.01); ***H04L 1/0064*** (2013.01); ***H04L 69/22*** (2013.01); ***H04W 72/0466*** (2013.01); *H03M 13/136* (2013.01); *H04L 1/007* (2013.01)

(58) **Field of Classification Search**
CPC . H04L 2012/5652; H04B 3/54; H04M 13/136
See application file for complete search history.

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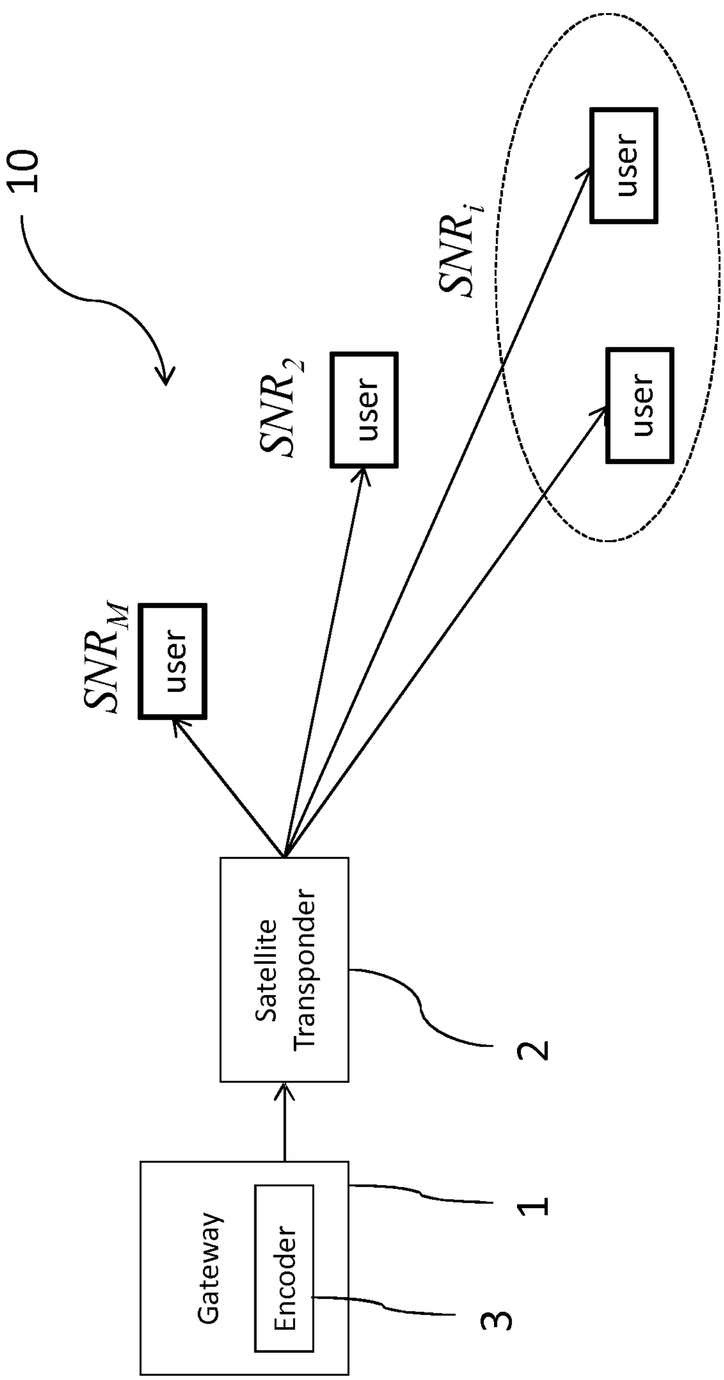
10
Gateway
Encoder
Satellite Transponder
user
user
user
user
SNR_M
SNR_2
SNR_i
1
2
3

Fig. 1

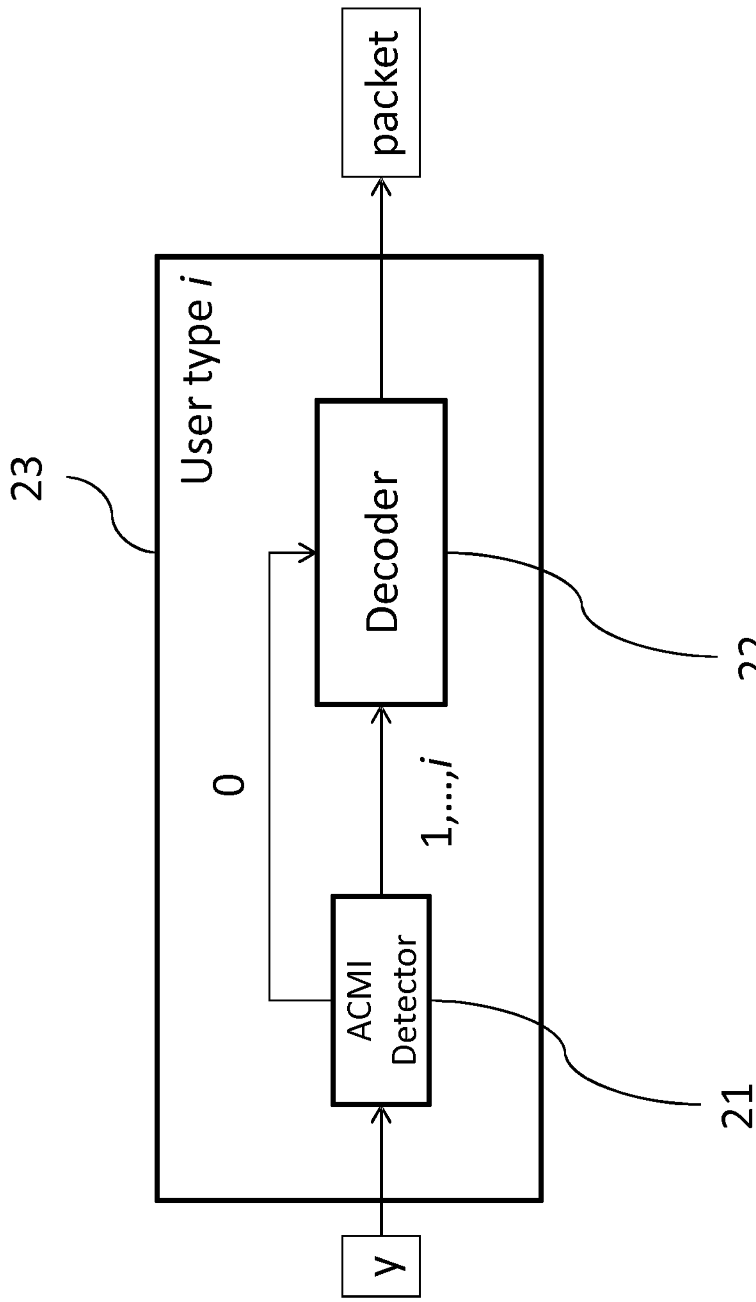

Fig. 2

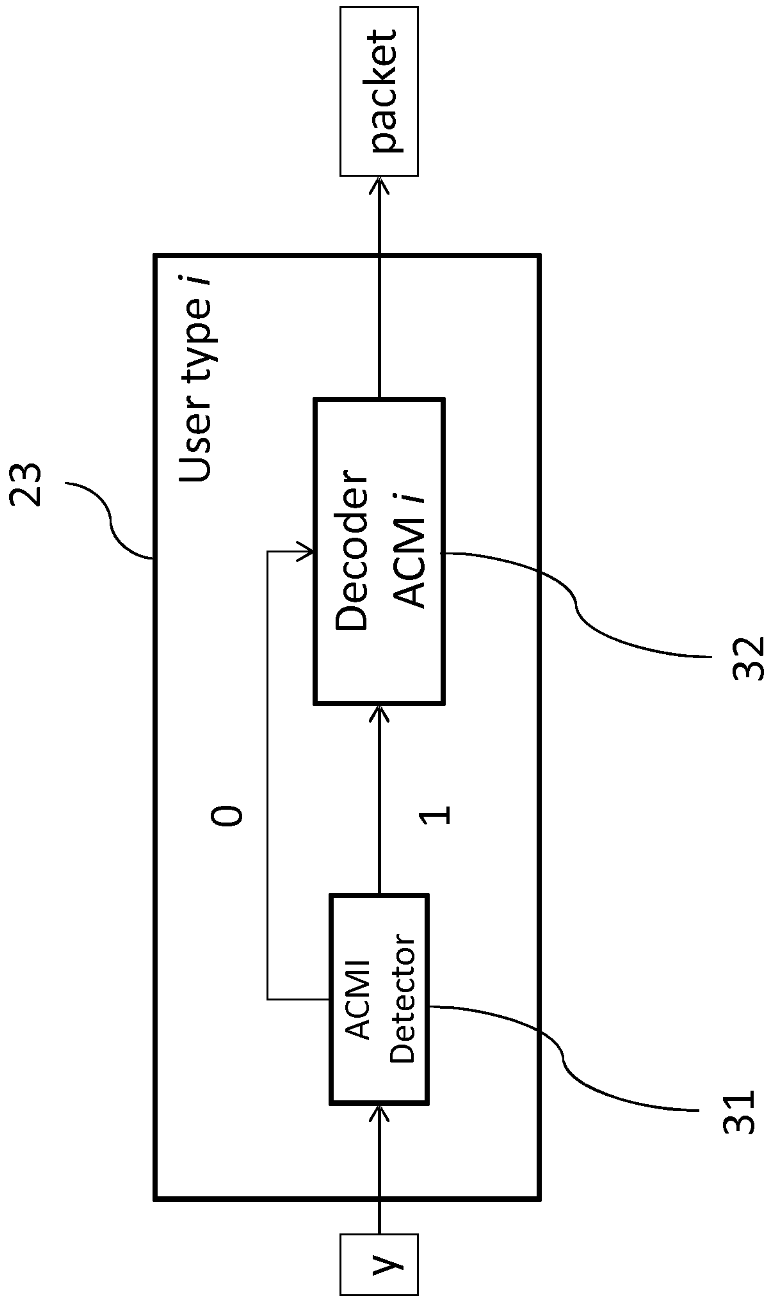

Fig. 3

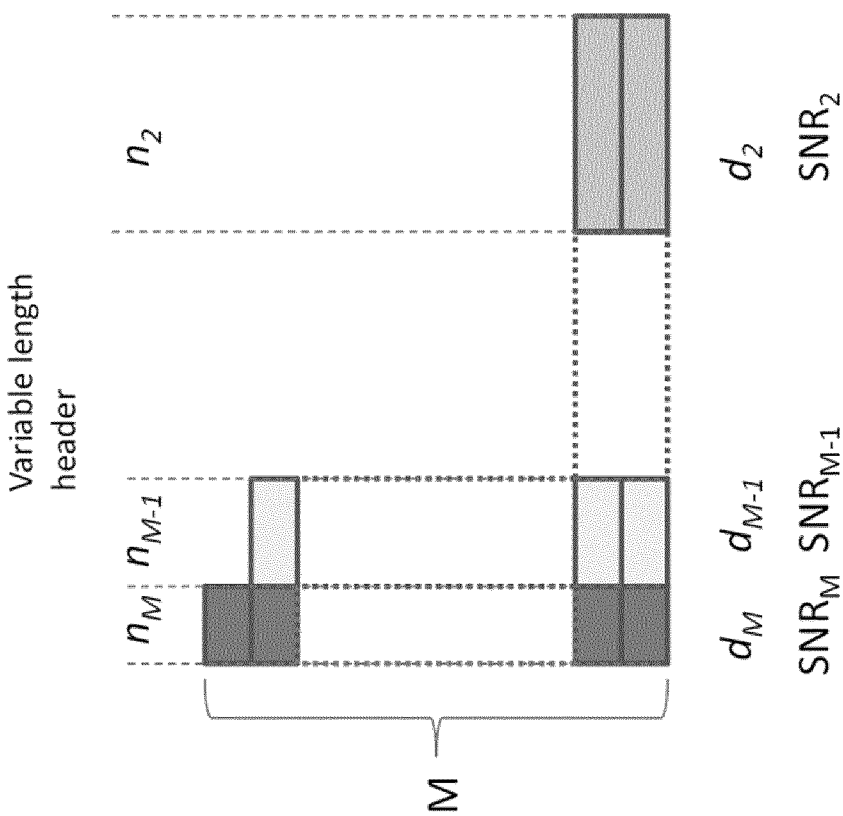

Fig. 4

i	SNR_i	n_i	k_i	d_i	d_T	N_i	$i \cdot N_i$
32	15	5	5	1	1	5	160
31	14	0	5	0	1	5	155
30	13	0	5	0	1	5	150
29	12	0	5	0	1	5	145
28	11	5	5	1	2	10	280
27	10	0	5	0	2	10	270
26	9	0	5	0	2	10	260
25	8	5	5	1	3	15	375
24	7	0	5	0	3	15	360
23	6	5	5	1	4	20	460
22	5	5	5	1	5	25	550
21	4	5	5	1	6	30	630
20	3	6	5	2	8	36	720
19	2	5	5	1	9	41	779
18	1	8	5	3	12	49	882
17	0	6	5	2	14	55	935
16	-1	7	4	4	18	62	992
15	-2	7	4	4	22	69	1035
14	-3	10	4	6	28	79	1106
13	-4	12	4	7	35	91	1183
12	-5	15	4	9	44	106	1272
11	-6	14	4	10	54	120	1320
10	-7	19	4	14	68	139	1390
9	-8	21	4	16	84	160	1440
8	-9	27	3	21	105	187	1496
7	-10	31	3	26	131	218	1526
6	-11	37	3	31	162	255	1530
5	-12	45	3	39	201	300	1500
4	-13	50	2	46	247	350	1400
3	-14	57	2	54	301	407	1221
2	-15	57	1	57	358	464	928
						$E\{N_i\} = 119$	$E\{i \cdot N_i\} = 853.226$

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Fig. 5

i	SNR_i	n_i	k_i	d_i	d_T	N_i	$i \cdot N_i$
32	15	5	5	1	1	5	160
31	14	0	5	0	1	5	155
30	13	0	5	0	1	5	150
29	12	0	5	0	1	5	145
28	11	5	5	1	2	10	280
27	10	0	5	0	2	10	270
26	9	0	5	0	2	10	260
25	8	5	5	1	3	15	375
24	7	0	5	0	3	15	360
23	6	5	5	1	4	20	460
22	5	5	5	1	5	25	550
21	4	5	5	1	6	30	630
20	3	6	5	2	8	36	720
19	2	5	5	1	9	41	779
18	1	9	5	3	12	50	900
17	0	6	5	2	14	56	952
16	-1	8	4	4	18	64	1024
15	-2	8	4	4	22	72	1080
14	-3	12	4	6	28	84	1176
13	-4	14	4	7	35	98	1274
12	-5	19	4	9	44	117	1404
11	-6	20	4	10	54	137	1507
10	-7	27	4	14	68	164	1640
9	-8	30	4	16	84	194	1746
8	-9	38	3	21	105	232	1856
7	-10 0	46	3	26	131	278	1946
6	-11 0	55	3	31	162	333	1998
5	-12 0	69	3	39	201	402	2010
4	-13 0	69	2	46	247	471	1884
3	-14 0	81	2	54	301	552	1656
2	-15 0	57	1	57	358	609	1218
						$E\{N_i\} = 149$	$E\{i \cdot N_i\} = 985.968$

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Fig. 6

i	SNR_i	n_i	k_i	d_i	d_T	N_i	$i \cdot N_i$	N_i ([3])
48	13.46	6	6	1	1	6	288	64
47	13.61	0	6	0	1	6	282	64
46	12.33	6	6	1	2	12	552	64
45	12.33	0	6	0	2	12	540	64
44	11.95	0	6	0	2	12	528	64
43	11.95	0	6	0	2	12	516	64
42	11.37	0	6	0	2	12	504	64
41	11.37	0	6	0	2	12	492	64
40	9.96	0	6	0	2	12	480	64
39	9.96	0	6	0	2	12	468	64
38	8.71	6	6	1	3	18	684	64
37	8.71	0	6	0	3	18	666	64
36	6.55	7	6	2	5	25	900	64
35	6.55	0	6	0	5	25	875	64
34	4.79	7	6	2	7	32	1088	96
33	4.79	0	6	0	7	32	1056	96
32	1.90	14	5	6	13	46	1472	96
31	1.90	0	5	0	13	46	1426	96
30	0.73	10	5	4	17	56	1680	96
29	0.73	0	5	0	17	56	1624	96
28	-0.16	9	5	3	20	65	1820	96
27	-0.16	0	5	0	20	65	1755	96
26	-1.91	21	5	10	30	86	2236	128
25	-1.91	0	5	0	30	86	2150	128
24	-2.28	6	5	2	32	92	2208	192
23	-3.17	15	5	7	39	107	2461	192
22	-3.17	0	5	0	39	107	2354	192
21	-4.93	40	5	20	59	147	3087	288
20	-6.18	39	5	19	78	186	3720	384
19	-6.18	0	5	0	78	186	3534	384
18	-7.94	75	5	38	116	261	4698	576
17	-7.94	0	5	0	116	261	4437	576
16	-9.19	71	4	37	153	332	5312	768
15	-9.19	0	4	0	153	332	4980	768
14	-10.16	71	4	37	190	403	5642	960
13	-10.16	0	4	0	190	403	5239	960
12	-11.62	139	4	73	263	542	6504	1344
11	-11.62	0	4	0	263	542	5962	1344
10	-12.71	134	4	71	334	676	6760	1728
9	-12.71	0	4	0	334	676	6084	1728
8	-13.59	123	3	70	404	799	6392	2112
7	-13.59	0	3	0	404	799	5593	2112
6	-14.63	174	3	99	503	973	5838	2688
5	-14.63	0	3	0	503	973	4865	2688
4	-15.72	188	2	125	628	1161	4644	3456
3	-15.72	0	2	0	628	1161	3483	3456
2	-16.79	124	1	124	752	1285	2570	4416
						$E\{N_i\} = 301$	$E\{i \cdot N_i\} = 2775.51$	$E\{N_i\} = 750$

Fig. 7

74 73 72 71

i	SNR_i	n_i	k_i	d_i	d_T	N_i	$i \cdot N_i$
32	15	39	5	19	19	39	1248
31	14	0	5	0	19	39	1209
30	13	0	5	0	19	39	1170
29	12	0	5	0	19	39	1131
28	11	0	5	0	19	39	1092
27	10	0	5	0	19	39	1053
26	9	0	5	0	19	39	1014
25	8	0	5	0	19	39	975
24	7	0	5	0	19	39	936
23	6	0	5	0	19	39	897
22	5	0	5	0	19	39	858
21	4	0	5	0	19	39	819
20	3	0	5	0	19	39	780
19	2	0	5	0	19	39	741
18	1	0	5	0	19	39	702
17	0	0	5	0	19	39	663
16	-1	177	4	94	113	216	3456
15	-2	0	4	0	113	216	3240
14	-3	0	4	0	113	216	3024
13	-4	0	4	0	113	216	2808
12	-5	0	4	0	113	216	2592
11	-6	0	4	0	113	216	2376
10	-7	0	4	0	113	216	2160
9	-8	0	4	0	113	216	1944
8	-9	49	3	28	141	265	2120
7	-10 0	60	3	34	175	325	2275
6	-11 0	168	3	96	271	493	2958
5	-12 0	0	3	0	271	493	2465
4	-13 0	213	2	142	413	706	2824
3	-14 0	0	2	0	413	706	2118
2	-15 0	85	1	85	498	791	1582
						$E\{N_i\} = 216$	$E\{i \cdot N_i\} = 1717.1$

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Fig. 8

i	SNR_i	n_i	k_i	d_i	d_T	N_i	$i \cdot N_i$	N_i ([3])
48	13.46	17	6	7	7	17	816	64
47	13.61	0	6	0	7	17	799	64
46	12.33	0	6	0	7	17	782	64
45	12.33	0	6	0	7	17	765	64
44	11.95	0	6	0	7	17	748	64
43	11.95	0	6	0	7	17	731	64
42	11.37	0	6	0	7	17	714	64
41	11.37	0	6	0	7	17	697	64
40	9.96	0	6	0	7	17	680	64
39	9.96	0	6	0	7	17	663	64
38	8.71	0	6	0	7	17	646	64
37	8.71	0	6	0	7	17	629	64
36	6.55	0	6	0	7	17	612	64
35	6.55	0	6	0	7	17	595	64
34	4.79	0	6	0	7	17	578	96
33	4.79	0	6	0	7	17	561	96
32	1.9	62	5	32	39	79	2528	96
31	1.9	0	5	0	39	79	2449	96
30	0.73	0	5	0	39	79	2370	96
29	0.73	0	5	0	39	79	2291	96
28	-0.16	0	5	0	39	79	2212	96
27	-0.16	0	5	0	39	79	2133	96
26	-1.91	0	5	0	39	79	2054	128
25	-1.91	0	5	0	39	79	1975	128
24	-2.28	0	5	0	39	79	1896	192
23	-3.17	0	5	0	39	79	1817	192
22	-3.17	0	5	0	39	79	1738	192
21	-4.93	148	5	76	115	227	4767	288
20	-6.18	0	5	0	115	227	4540	384
19	-6.18	0	5	0	115	227	4313	384
18	-7.94	0	5	0	115	227	4086	576
17	-7.94	0	5	0	115	227	3859	576
16	-9.19	277	4	147	262	504	8064	768
15	-9.19	0	4	0	262	504	7560	768
14	-10.1 6	0	4	0	262	504	7056	960
13	-10.1 6	0	4	0	262	504	6552	960
12	-11.6 2	0	4	0	262	504	6048	1344
11	-11.6 2	0	4	0	262	504	5544	1344
10	-12.7 1	132	4	70	332	636	6360	1728
9	-12.7 1	0	4	0	332	636	5724	1728
8	-13.5 9	119	3	68	400	755	6040	2112
7	-13.5 9	0	3	0	400	755	5285	2112
6	-14.6 3	171	3	97	497	926	5556	2688
5	-14.6 3	0	3	0	497	926	4630	2688
4	-15.7 2	174	2	116	613	1100	4400	3456
3	-15.7 2	0	2	0	613	1100	3300	3456
2	-16.7 9	139	1	139	752	1239	2478	4416
						$E\{N_i\} = 285$	$E\{i \cdot N_i\} = 2992.36$	$E\{N_i\} = 750$

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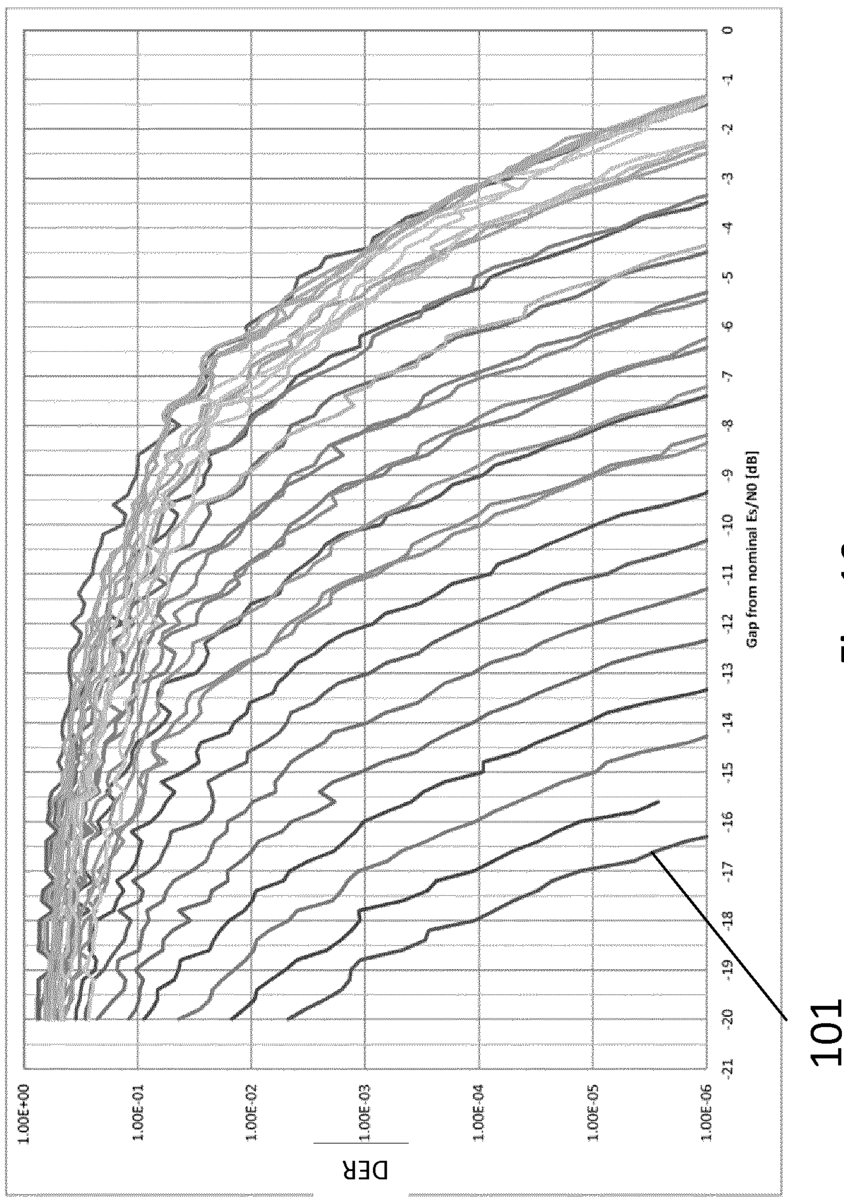
Fig. 9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1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
Gap from nominal Es/N0 [dB]
-21
-20
-19
-18
-17
-16
-15
-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
101

Fig. 10

j	N_j	c_j
0	39	111100000000111101001010110010110101001
1	39	011010011001011111100000011000011111100
2	39	101001010101101011010100101100101011010
3	39	001111001100001001111111000011000000111
4	39	110000110011110100110011001011001100110
5	39	010110101010010110011001100001100110011
6	39	100101100110100010101101010101010010101
7	39	000011111111100000000001111111111000000
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10	39	101010100101010011010011010100101100101
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12	39	110011000011001100110100110011001011001
13	39	010101011010101110011110011001100001100
14	39	100110010110011010101010101101010101010
15	39	000000001111111000000000000111111111111
16	216	111100001111000101001010110101001010110 10100101011011010011001011011110011000011110000110011110011010011001011011110011000011111- 000011001111001101001100101101111001100001111000011001111001101001100101101101001100101100
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18	216	101001011010010011010100101011010100101 011010100101101101010100101110011110011001100110000110011101101010100101110011110011001 1- 001100001100111011010101001011100111100110011001100001100111011010101001011011010101001 01
19	216	001111000011110001111110000000111111000000 001111110000000111111110000000000011111111111111100000000000011111110000000000011111111- 111111000000000000111111110000000000011111111111111000000000000011111110000000011111110000
20	216	110000111100001100110011001100110011001 100110011001110011010011001111100001111001100001111000011110011010011001111100001111 0011- 000011110000111100110100110011111000011110011000011110000111100110100110011100110100110 01
21	216	010110100101101110011001100110011001100 1100110011000110011110011000011110000111111100001111000000110011110011000011110000111111- 1100001111000000110011110011000011110000111111100001111000000110011110011000110011110011 00
22	216	100101101001011010101101010010101101010 010101101010101010110101010110011001100111100110011001100101010110101010110011001100111 1- 001100110011001010101101010101100110011001111001100110011001010101101010101010101101010 10
23	216	000011110000111000000111111000000111111 000000111111000000001111111100000000000000011111111111111100000000111111110000000000000000011- 111111111111100000000111111110000000000000000111111111111111100000000111111110000000011111111
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Fig. 11a

j	N_j	c_j
27	493	001100110011001001111001111001111001111 0011110011110001111000011110000001111111100000000111111110001111000011110000001111111100- 0000001111111100011110000111100000011111111000000001111111100011110000111100011110000111 1 0001111000111100011110001111000111100000011111111 00000111111000111100011110001111000111100011110000001111111 0001111000111100011110001111000111100000011111111000111100011110001111000111100011110000- 00111111110001111000111100011110001111000111100000011111111000111100000011111111
28	706	110011001100110100110100110100110100110 1001101001101100110011001101111000011110000111100001111001100110011001101111000011110000- 1111000011110011001100110011011110000111100001111000011110011001100110011011001100110 0110 1100110110011011001101100110110011011110000111100 110100110101100110110011011001101100110110011011110000111100 1100110110011011001101100110110011011110000111100110011011001101100110110011011001101111- 00001111001100110110011011001101100110110011011110000111100110011011110000111100 1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111- 111111111111111111111111111111111111111111111111111111000000000000000000000000000000000 0- 0000000000000000000000000000000000000
29	706	010101010101010110011110011110011110011 1100111100110110011001100110011110000111100001111000011110110011001100110011110000111100- 0011110000111101100110011001100111100001111000011110000111101100110011001101100110011 0011 0110011011001101100110110011011001100111100001111 01111001111011001101100110110011011001101100110011110000 1111 0110011011001101100110110011011001100111100001111011001101100110110011011001101100110011- 11000011110110011011001101100110110011011001100111100001111011001100111100001111 1111111111111111111111111111111111111111111111111111111111111111111111110000000000000000- 0000000000000000000000000000000000000000000000000000001111111111111111111111111111111111- 1111111111111111111111111111111111111
30	791	100110011001100010101010101010101010101 0101010101011010101010101011100110011001100110011001100111010101010101011100110011001100- 11001100110011101010101010101110011001100110011001100110011101010101010101101010101010101 1010101101010110101011010101101010111001100110011 101010101011010101101010110101011010101101010111001100110011 1010101101010110101011010101101010111001100110011101010110101011010101101010110101011100- 11001100111010101101010110101011010101101010111001100110011101010111001100110011 0000000000000000000000000000000000000000000000000000000000000000000000001111111111111111- 1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111- 1111111111111111111111111111111111111 1111111111111111111111111111111111111111111111111111111111111111111111111111111111111

Fig. 11b

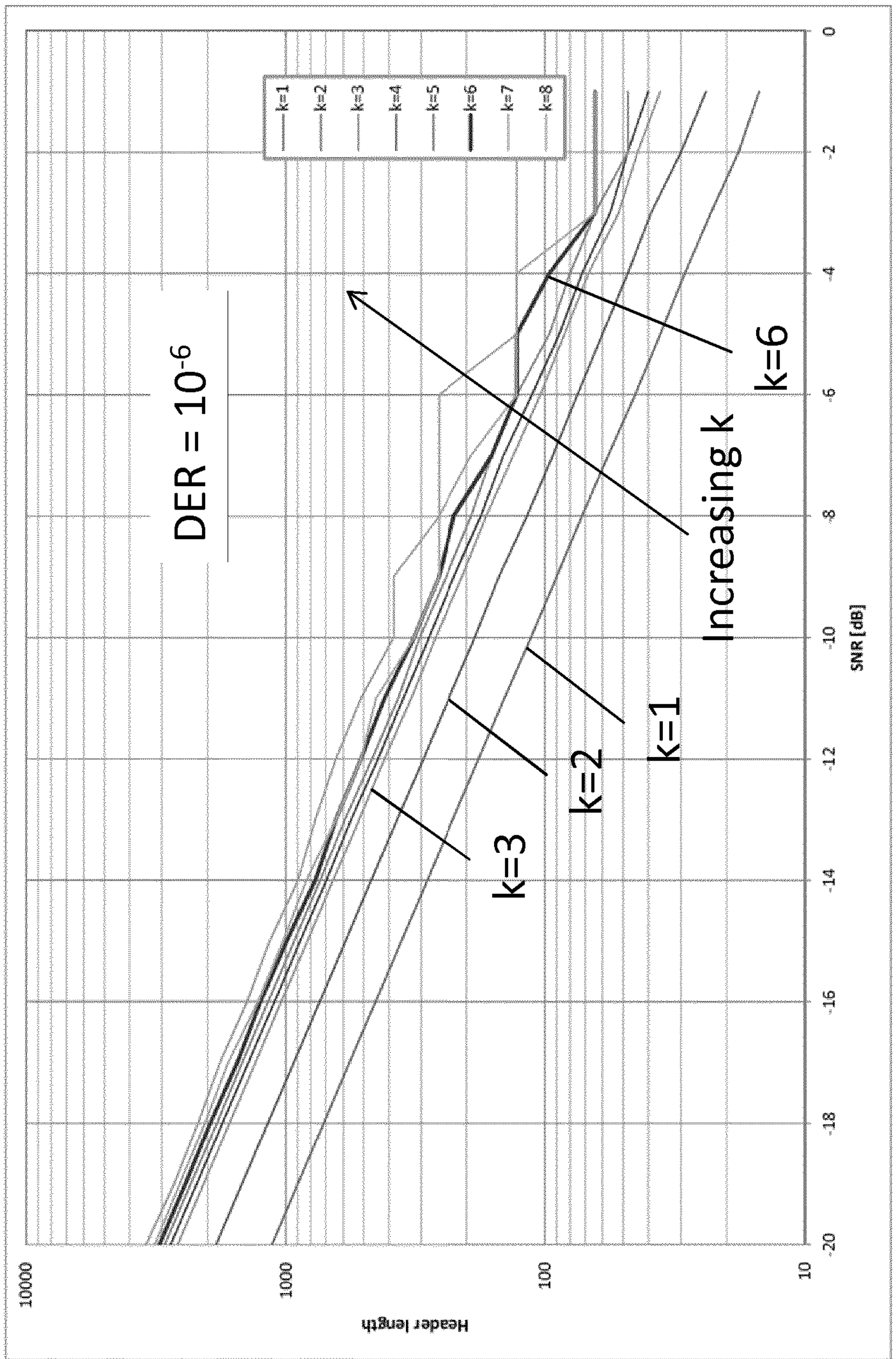
DER = 10^{-6}
Increasing k
k=6
k=1
k=2
k=3
k=1
k=2
k=3
k=4
k=5
k=6
k=7
k=8
Header length
10000
1000
100
10
SNR [dB]
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0

Fig. 12

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SNR	k=1	k=2	k=3	k=4	k=5	k=6	k=7	k=8	k=9
-20.0	1130	1854	2608	2776	2928	3072	3200	3456	3584
-19.0	898	1473	2072	2200	2320	2432	2560	2688	2816
-18.0	713	1170	1644	1752	1840	1952	2048	2176	2304
-17.0	567	930	1308	1392	1472	1536	1664	1792	1792
-16.0	450	738	1040	1104	**1168**	**1248**	1280	1408	1536
-15.0	358	588	824	880	928	992	1024	1152	1280
-14.0	284	468	656	696	736	768	832	896	1024
-13.0	226	372	520	560	592	640	640	768	768
-12.0	180	294	416	440	464	512	512	640	768
-11.0	143	234	328	352	368	416	448	512	512
-10.0	113	186	264	280	304	320	320	384	512
-9.0	90	150	208	224	240	256	256	384	512
-8.0	72	117	168	176	192	224	256	256	256
-7.0	57	93	132	144	160	160	192	256	256
-6.0	45	75	104	112	128	128	128	256	256
-5.0	36	60	84	88	96	128	128	128	256
-4.0	29	48	68	72	80	96	128	128	256
-3.0	23	39	52	56	64	64	64	128	256
-2.0	18	30	44	48	48	64	64	128	256
-1.0	15	24	36	40	48	64	64	128	256

Fig. 13

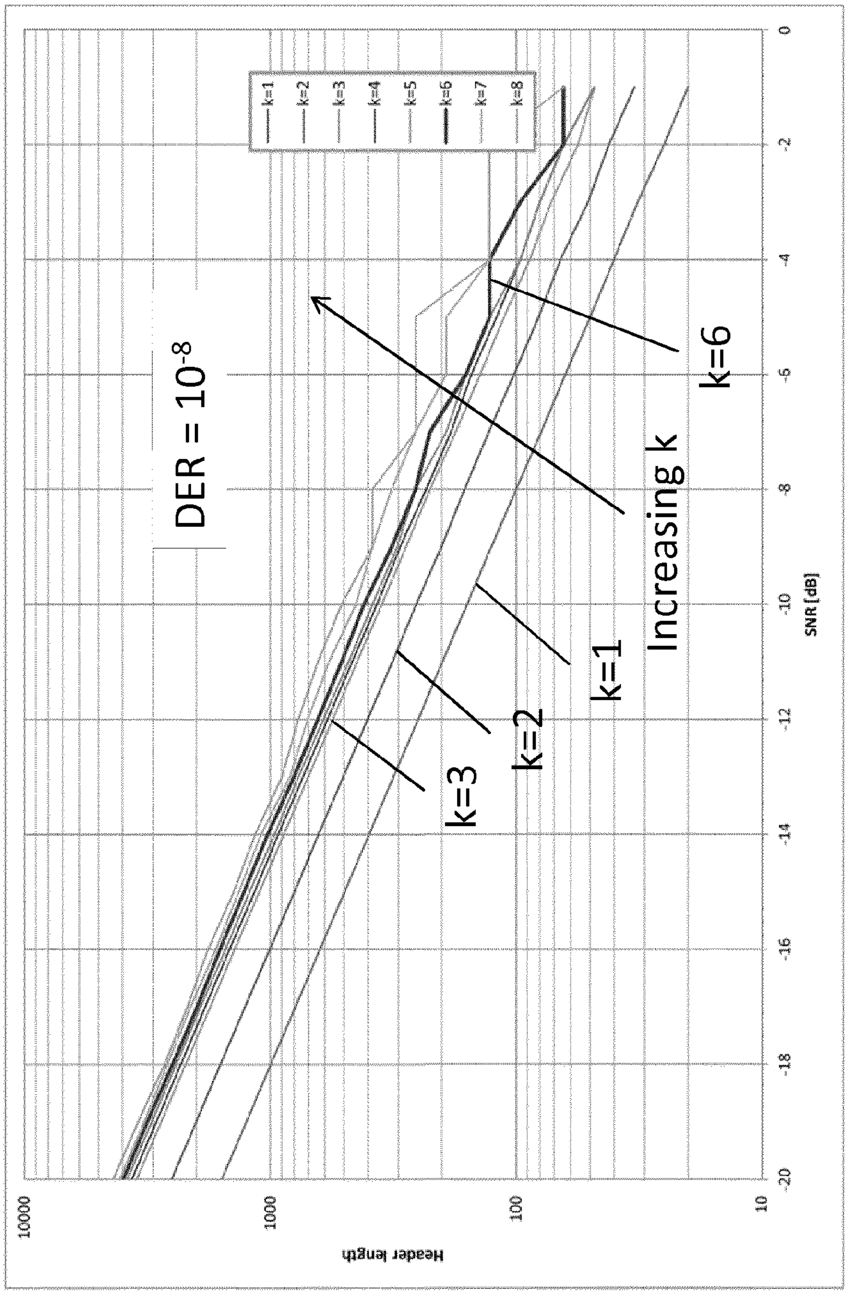
DER = 10^{-8}
Increasing k
k=1
k=2
k=3
k=6
k=1
k=2
k=3
k=4
k=5
k=6
k=7
k=8
Header length
SNR [dB]
10000
1000
100
10
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0

Fig. 14

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SNR	k=1	k=2	k=3	k=4	k=5	k=6	k=7	k=8	k=9
-20.0	1575	2523	3500	3664	3824	3968	4096	4352	4608
-19.0	1251	2004	2780	2912	3040	3168	3264	3456	3584
-18.0	994	1593	2208	2312	2416	2496	2624	2688	2816
-17.0	790	1266	1756	1840	1920	1984	2112	2176	2304
-16.0	627	1005	1396	1464	**1520**	**1600**	1664	1792	1792
-15.0	498	798	1108	1160	1216	1280	1344	1408	1536
-14.0	396	636	880	928	960	1024	1088	1152	1280
-13.0	315	504	700	736	768	800	832	896	1024
-12.0	250	402	556	584	608	640	704	768	768
-11.0	199	318	444	464	480	512	576	640	768
-10.0	158	255	352	368	384	416	448	512	512
-9.0	126	201	280	296	304	320	384	384	512
-8.0	100	162	224	232	256	256	320	384	512
-7.0	79	129	176	184	192	224	256	256	256
-6.0	63	102	140	152	160	160	192	256	256
-5.0	50	81	112	120	128	128	192	256	256
-4.0	40	66	88	96	96	128	128	128	256
-3.0	32	51	72	80	80	96	128	128	256
-2.0	25	42	56	64	64	64	128	128	256
-1.0	20	33	48	48	48	64	64	128	256

Fig. 15

METHOD AND SYSTEM FOR GENERATING CHANNEL CODES, IN PARTICULAR FOR A FRAME-HEADER

FIELD OF THE INVENTION

The present invention relates to a method and a system for generating channel codes, in particular channel codes for a frame-header in an ACM ("Adaptive Coding and Modulation") communication system.

DESCRIPTION OF THE PRIOR ART

Real-time adaptation of transmission parameters according to the channel conditions is highly desirable feature in the communication systems where the channel parameters may change in time or from one receiver to another.

Time and/or user varying channel condition is an important characteristic of most communication systems such as satellite, network and broadcast systems.

According to the prior art, adaptive coding and modulation schemes have been proposed in such systems to provide significant capacity gains by real-time adaptation of the FEC ("Forward Error Correction") code rate/length and modulation constellation.

The main idea of an ACM scheme is to increase the capacity of a system communication by avoiding the waste of resources caused by adopting a fixed physical layer scenario by which the spectral efficiency must be sacrificed to guarantee a good performance for the user with the worst channel conditions.

By employing an ACM scheme, the transmitter is able to switch between several constellations and codes choosing the largest available modulation and code rate which ensures a target DER ("Detection Error Rate"), therefore insuring maximum spectral efficiency for each user. At the receiver, to successfully decode the message, each user should be able to decide whether the message is intended to him and/or to recognize the parameters of the constellation and code which has been used by the transmitter.

In general, each packet sent by the transmitter consists of two main parts.

The first part is called frame-header, or simply header, and contains the informations regarding the modulation and coding, hereinafter called ACMI ("Adaptive Coding and Modulation Indicator").

The second part contains the message which is encoded using the corresponding ACMI parameters.

Therefore each user should first decode the information in the frame-header in order to be able to decode the rest of the message.

In applications such as satellite broadcasting, the coding strategy is not trivial due to the wide dynamic range of the SNR ("Signal to Noise Ratio"), typically from −15 dB to 15 dB. Only the use of an ACM scheme may not be sufficient to ensure the radio link, a good spectral efficiency and a target probability of error to the receiver.

It is therefore important to improve the spectral efficiency through a generation of a code which allows to minimize the average and maximum length of a frame-header.

In the patent application no. US 2010/0128661, the code generation procedure is based on heuristic considerations without any attempt to minimize the frame-header length. The variable length code consists in the repetition of a single strong Reed-Muller code to cope with the different signal to noise ratio conditions.

However, such patent application does not teach to minimize a length of a frame-header. It is the main object of the present invention to indicate a method and a system for generating channel codes, in particular for a frame header, able to minimize an average and a maximal length of a frame-header of a data packet.

It is a further object of the present invention to indicate a method and a system for generating channel codes, in particular for a frame header, able to maximize the spectral efficiency of a communication system.

It is a further object of the present invention to indicate a method and a system for generating channel codes, in particular for a frame header, able to improve the correction capability of the generated channel code.

It is a further object of the present invention to indicate a method and a system for generating channel codes, in particular for a frame header, able to decrease the computational complexity of a decoder.

It is a further object of the present invention to indicate a method and a system for generating channel codes, in particular for a frame header, able to obtain a fixed length for all code-words in order to have a same complexity of the maximum likelihood decoder of a variable length code.

These and other objects of the invention are achieved by a method and a system for generating channel codes, in particular for a frame header, as claimed in the appended claims, which are intended to be an integral part of the present description.

SUMMARY OF THE INVENTION

In short, it is disclosed a method for generating a channel code, in particular for a frame-header, wherein at least a code-word of said channel code is obtained by means of at least a concatenation of code-words of two constituent codes and such concatenation is performed on subsets of code-words of a first constituent code, having maximum length, with code-words of a second constituent code.

The users are divided, for example, into a smaller set of M types according to their radio link quality. Each user type i is associated with an available signal to noise ratio SNR_i. It is assumed that for any two user types k and m, if k>m, then $SNR_k > SNR_m$.

A set of maximum ACM modes, ACM_i, are associated to the set of user types. Each user type i must be capable of detecting and decoding all packets encoded with ACM modes $j \leq i$, corresponding to signal to noise ratio SNR lower or equal to that associated to the user type i. Consequently, users of higher types, corresponding to high SNR values, must then be able to detect the ACM mode within a larger set than that of users of lower type.

This corresponds to the generation of a code which admits a sequence of subsets of code-words of such code with very large differences in the correction capabilities.

Further features of the invention are set out in the appended claims, which are intended to be an integral part of the present description.

BRIEF DESCRIPTION OF THE DRAWINGS

The above objects will become more apparent from the following detailed description of a method for generating channel codes, with particular reference to the annexed drawings, wherein:

FIG. **1** shows a block diagram of a communication system;

FIGS. **2** and **3** show modes of operation of an ACMI detector for a user type i;

FIG. **4** shows an example of the code generation using a variable length coding;

FIG. **5** shows parameters of codes for a variable length code with thirty-two modes using the method according to the present invention and the Hamming code bound with DER ("Detection Error Rate") equal to 10^{-6};

FIG. **6** shows parameters of codes for a variable length code with thirty-two modes using linear codes of the prior art with DER equal to 10^{-6};

FIG. **7** shows parameters of codes for a variable length code with forty-eight modes using linear optimal codes of the prior art with DER equal to 10^{-8};

FIGS. **8** and **9** show parameters of codes for a variable length code using the method according to the present invention and linear optimal codes of the prior art with DER equal to 10^{-8} with respectively thirty-two and forty-eight modes;

FIG. **10** shows a graph relating to data of FIG. **8**;

FIGS. **11***a* e **11***b* show code-words of the code of FIG. **8**;

FIGS. **12** and **13** show respectively required header packet length versus minimal signal to noise ratio SNR for some values of k bits when DER is fixed to 10^{-6} and data relating to FIG. **12**, thus corresponding to a straightforward worst case design of frame-header;

FIGS. **14** and **15** show respectively required header packet length versus minimal signal to noise ratio SNR for some values of k bits when DER is fixed to 10^{-8} and data relating to FIG. **14**, thus corresponding to a straightforward worst case design of frame-header.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIG. **1**, it is shown a communication system **10** used as an example of system scenario to explain the detailed description of the present invention. A plurality of users is served by a gateway **1** through a satellite transponder **2** and the gateway **1** comprises at least one encoder **3** that generate at least a code.

The users are divided into M types, for example M≤64, according to their current radio link quality and this subdivision is created by a designer during the design of the communication system **10**.

Each user type i is associated with an available signal to noise ratio SNR_i and it is assumed, with no loss of generality, that $SNR_i \leq SNR_{i+1} \leq \ldots \leq SNR_M$. This latter condition is typical of satellite communication systems. Thus, signal to noise ratio is different for each user type i. Furthermore, each user type i comprises at least one physical user.

A set of maximum ACM modes are associated to each user type i. Each user type i must be capable of detecting and decoding all packets encoded with modes ACM_j with j≤i. A feedback channel, not represented in FIG. **1**, allows the gateway **1** to know the type i of each user.

Furthermore, the gateway **1** has the possibility of choosing for each user type i an ACM mode with index j≤i. Choosing a value below the maximum allowed i, which in principle is suboptimal for the total system capacity, allows some flexibility at the gateway **1**. This additional system flexibility, however, requires that user type i detects and decodes all modes ACM_j with j≤i. This requirement then imposes a high detection complexity especially to users associated to high SNR values. In particular, users with the highest user type M must detect and decode all packets from a satellite. The filtering of the packets, according to the true intended destination, is deferred after the decoding process.

With reference to FIG. **2**, it is shown a mode of operation of a receiver **23** comprising an ACMI detector **21** for a user type i, and an input signal y, in the communication system **10** described in FIG. **1**. The ACMI detector **21** delivers an index $\hat{j}$ in the range [1, . . . , i] denoting an estimation of an ACM index in the allowed range, or the conventional symbol "0" to denote a failure in the detection, freezing a following decoder **22**.

In this example of communication system **10**, the following types of events for an ACMI are:

Detection error: $P_E=P(\hat{j}\neq j|j\leq i)$

This refers to the probability that $ACMI_{\hat{j}}$, estimated from the ACMI detector **21**, is transmitted to the decoder **22** from the ACMI detector **21** and it is not equal to the $ACMI_j$ received from gateway **1**, given that index j is less or equal to the index i of the user type. A packet that is potentially intended to the user type i is decoded with an uncorrect ACM mode and consequently not correctly delivered.

Useless decoding: $P_U=P(\hat{j}\neq 0|j>i)$

This refers to the probability that $ACMI_{\hat{j}}$, estimated from ACMI detector **21**, is transmitted to the decoder **22** from the ACMI detector **21** and it is not equal to zero, given that index j is greater than the index i of the user type. A packet that is not intended to users of type j is incorrectly decoded with the wrong format. The only cost is a useless decoding.

From that aforementioned, it is important to design and generate codes for minimizing the probability of the detection error P_E, given that the cost of useless decoding P_U is marginal.

With reference to FIG. **3**, it is worthwhile to notice that by removing the flexibility for the gateway **1** of choosing a mode j≤i, and thus imposing j=i at the gateway **1**, the only function of an ACMI detector **31** is to activate or to freeze a following decoder **32**.

An error of the ACMI detector **31** would only cause a useless decoding event. The number of useless decoding in this case can be drastically reduced also for users with good link quality.

In a first example of the present invention it is described a method for generating a channel code for minimizing the aforementioned detection error probability P_E, at which is associated a DER ("Detection Error Rate") of ϵ value, and with variable length code-words.

The set of code-words is generated with variable lengths according to the following algorithm, which is shown in FIG. **4**:

1. Fixing a set of M ordered SNR values SNR_i corresponding to the desired modes thresholds and a desired DER ϵ;
2. Setting a total distance $d_T=0$;
3. For all i decreasing from M to 2;
4. Computing the required incremental distance to achieve the desired DER ϵ at target SNR_i

$$d_i=d_{min}(\epsilon,SNR_i,i)-d_T \tag{1}$$

The minimum distance d_{min} or d_i depends on a signal to noise ratio SNR and on a detection error rate with ϵ value. Furthermore, the minimum distance d_i increases for each generated subset of code and it is computed for each user type i.

5. If $d_i=0$ repeat from step 3.
6. else generating a code with code-words having minimized length n_i, i code-words and minimum distance d_i
7. Setting the total distance $d_T=d_T+d_i$
8. Repeat from step 3.

9. The set of variable length code-words is finally obtained by concatenating a code-word from each of the constituent codes (see FIG. **4**). The code-word of the mode i is then obtained by concatenating code-words of constituent codes from M down to i and have total length N_i as follows:

$$N_i = \sum_{m=1}^{M} n_m \tag{2}$$

With reference to FIG. **4**, at least a code-word of constituent codes is encapsulated into a code-word of the channel code and at least a code-word of the channel code has length greater than remaining code-words of such channel code. Furthermore, the concatenation is performed on subsets of code-words of a first constituent code, having maximum length, with code-words of a second constituent code.

In the formula (1) it is defined the following function:

$$d_{min}(\epsilon, SNR, M) = \frac{Q^{-1}(\epsilon/(M-1))^2}{2 \cdot SNR} \tag{3}$$

where Q is the Q-function, i.e. the complementary cumulative distribution function of the random variable standards.

The formula (3) provides the required minimum distance d_{min} for a channel code with M code-words achieving a detection error rate ϵ at the signal to noise ratio SNR. This formula (3) is obtained by using the upper bound:

$$\epsilon \leq (M-1)Q\sqrt{2d_{min} \cdot SNR)} \tag{4}$$

which is rather accurate for small M and almost perfect codes.

In order to have a lower bound on what can be achieved is used, for example, the Hamming bound

$$M \leq \frac{2^n}{\sum_{i=0}^{t} \binom{n}{i}} \tag{5}$$

$$t = \left\lfloor \frac{d_{min} - 1}{2} \right\rfloor \tag{6}$$

where t is the maximum weight of error vectors that are surely correct from the minimum distance decoding, to find the minimal length n of a code with M code-words and minimum distance d_{min} required in step 6 of the previous algorithm.

With reference to FIG. **5**, it is shown a result of a channel code generation using the previous algorithm for a system with 32 modes, signal to noise ratio SNR ranging from +15 to −16 dB in steps of 1 dB, for a target DER $\epsilon=10^{-6}$.

The columns of the table of FIG. **5** indicate, from left to right, the number of code-words i, that is also the index of the user type, the corresponding signal to noise ratio SNR_i, the incremental length of code-word n_i of an header with index i, the number of bits k_i of code-word of an header at index i, the incremental minimum distance of code-word d_i of an header at index i, the total minimum distance d_T i.e. the sum, at index i, of preceding d_i, the total code-word length N_i of an header i.e. the sum, at index i, of preceding n_i and, in the last column, $i \cdot N_i$ that indicate the complexity of the decoding.

It is to be noted that in this case the maximal code-word length N_i is 464 symbols, indicated with the reference **51**, and the average header length $E\{N_i\}$, assuming that all modes have the same probability, is only 119 symbols, indicated with the reference **52**. Hamming bound is an upper bound to the number of code-words and there are few codes that achieve it.

With reference to FIG. **6**, it is reported a result of a channel code generation using optimal constituent linear codes noted in the prior art, taken from the tables found on M. Grassl, "Bounds on the minimum distance of linear codes and quantum codes", available online at http://www.codetables.de, published in 2007.

These constituent linear codes, noted in the prior art, have the additional constraint of having a number of code-words that is a power of two, i.e. 2^k, wherein k is the number of information bits. The use of these linear codes requires a maximal code-word length of 609 symbols, indicated with the reference **61**, and an average header length $E\{N_i\}$ of only 149 symbols, indicated with the reference **62**.

By comparing FIG. **5** and FIG. **6**, it is therefore clear that the channel code, generated using the previous algorithm according to the present invention, is able to minimize the average and the maximal length of a frame-header of a data packet.

With reference to FIG. **7**, it is compared an example of the generated code length according to the present invention for 48 modes with the required header length for the signaling scheme specified in D. Becker, N. Velayudhan, A. Loh, J. O'Neill, and V. Padmanabhan, "Efficient control signaling over shared communication channels with wide dynamic range", described in the U.S. patent application Ser. No. 12/621,203. The DER is fixed into $\epsilon=10^{-8}$.

It can be noticed that the channel code generation proposed according to the present invention allows to reduce considerably the header length for all modes. The average of header length $E\{N_i\}$ according to the U.S. patent application Ser. No. 12/621,203 is 750 (reference **71**), while the average of the header length $E\{N_i\}$ (reference **72**) is reduced to **301** according to this example of the present invention; in the same way the maximum header length is reduced from 4416 (reference **73**) to 1285 (reference **74**).

Therefore, using the method according to the present invention, by evaluating the average length $E\{N_i\}$, an improvement of about 60% is obtained.

The aforementioned algorithm, when applied to constituent linear codes, shows some weaknesses in the channel code length. This is mainly due to the fact that the number of code-words of a constituent linear code is always a power of 2.

In this case, for example, all modes from 32 to 17 in FIG. **6** share the same size. In such cases, it is useful to generate a single constituent code which guarantees a good minimum distance instead of using a completely incremental approach as described above.

It is therefore proposed an example of modified code generation algorithm as follows:

1. Fixing a set of M ordered SNR values SNR_i corresponding to the desired modes thresholds and a desired DER ϵ.
2. Setting $d_{T,M+1}=0$ and $N_{T,M+1}=0$.
3. For all i decreasing from M to 2
4. Setting $k=\lceil \log_2 i \rceil$
5. Computing the required minimum distance

$$d_{T,i}=d_{min}(\epsilon, SNR_i, i)$$

6. For all $i<j<2^k$ (modes with the same code dimension)
7. Computing the incremental distance

$$\delta_{i,j}=d_{T,i}-d_{T,j}$$

8. Generating a $(n_{i,j}, k, \delta_{i,j})$ linear code with minimal length $n_{i,j}$.

Notice that when the distance increment $\delta_{i,j}$ is zero, the code has length 0. In this case, k is the number of information bits and not the number of code-words.

9. Repeat from 6.
10. Picking from the previous set of codes the one with the minimal total length corresponding to $j^*=\arg\min_j n_{i,j}+N_{T,j}$
11. Setting $N_{T,j}=n_{T,j^*}$ and $d_{T,j}=d_{T,i}$, for all $i\leq j\leq j^*$
12. Repeat from 3.
13. The set of variable length code-words is finally obtained by concatenating code-words from each of the constituent codes (see FIG. **4**).

It can be noticed that, in this example, at each step are considered all the possible constituent codes with the same dimension k guaranteeing the minimum distance $d_{T,i}$. This generation allows at steps i of the iteration to change the codes generated in previous steps $j\geq i$, provided that $j<2^{[\log_2 i]}$.

With reference again to the case of FIG. **4**, at least a code-word of constituent codes is encapsulated into a code-word of the channel code and at least a code-word of the channel code has length greater than remaining code-words of such channel code. Furthermore, the concatenation is performed on subsets of code-words of a first constituent code, having maximum length, with code-words of a second constituent code.

The result of this new generation of codes are reported in FIG. **8** and FIG. **9** and the latter is compared with FIG. **7**. It is important to notice that this new generation of codes allows to slightly reduce both the average and the maximum length of header.

In fact, the maximum length of header of FIG. **9** is 1239 symbols, indicated with the reference **91**, which is lower than the maximum length of 1285 symbols of the header of FIG. **7**, indicated with the reference **74**; while the average length of header $E\{N_i\}$ is reduced from 301 symbols, indicated with the reference **72**, to 285 symbols, indicated with the reference **92**.

Furthermore, it should be noticed that the number of generated codes is reduced. An example of generated code is represented in FIG. **10** and in FIG. **11***a* and in FIG. **11***b* are shown relative code-words.

With reference to FIG. **10**, there are reported the simulation results relative to FIG. **8**. The abscissa of FIG. **10** indicates the gap in dB from the nominal SNR_i of each user type i. In this case many codes actually achieve the target DER with a very large margin.

For example, the curve of user type 32, indicated in the FIG. **10** with the reference number **101**, achieves the target DER $\epsilon=10^{-6}$ with a margin of about 16.3 dB. This is due to the fact that the same code (**39**,**5**,**19**) is used for all types ranging from 32 to 17, and the target DER is achieved with no margin only for the user type 17, corresponding to a nominal SNR of 0 dB.

It is also possible to evaluate the performances of the described above examples, according to the present invention, in term of detection error rate DER with respect to a worst case design.

The worst case design provides a coding example where all users are able to decode all ACMI headers. A Reed-Muller code class is chosen as constituent code and its parameters will be evaluated as a function of the required signal to noise ratio SNR range and number of modes M.

In the worst case design, the fact that each user type i can be associated to a code with different code-word lengths or protection is not exploited. The code design is such that each user type i is capable to retrieve the ACMI from the header. Remembering that the user type i decides to proceed with decoding only if the detected $ACMI_{\hat{j}}$ is less than or equal to its type, i.e., $\hat{j}\leq i$. In this case, the channel code generation is rather simple and strictly depends on the minimal signal to noise ratio SNR allowed in the system.

Taking the asymptotic expression of the DER ϵ for a code with minimum distance d_{min}, number of nearest neighbours A and repeating it R times, is achieved:

$$\epsilon = AQ\left(\sqrt{2d_{min}R\cdot SNR}\right)\rightarrow Rd_{min}=\frac{Q^{-1}(\epsilon/A)^2}{2\cdot SNR} \tag{7}$$

It is considered the class of Reed-Muller codes as a solution for worst case design. The Reed-Muller codes have the parameters $(n=2^m, k=m+1)$, with $d_{min}=2^{m-1}$ and $A=2^k-2$.

With reference to FIG. **12** and FIG. **13**, there is reported the required header length Rn to achieve a DER ϵ**32** 10^{-6} versus the minimal target SNR. The different curves in FIG. **12** refer to the use of Reed-Muller codes with k=1 to 8. The number of the needed repetitions can be easily computed given the length of the corresponding Reed-Muller. The curve indicated with k=6 is the one that should be considered for a system with 64 ACM modes. It can be noticed that, in order to design a channel code working at −16 dB with 32 modes and DER $\epsilon=10^6$, a header length of 1168 (reference **131**) is required with a worst case design, while the maximum header length of the examples of variable length coding according to the present invention described above is 464 (reference **51**) shown in FIG. **5**, using Hamming bound, and **609** (reference **61**) shown in FIG. **6**, using in our construction linear codes of the prior art.

With reference to FIG. **14** and FIG. **15**, there is reported the required header length Rn achieved setting a DER $\epsilon=10^{-8}$. In this latter case, the maximum header length at −16 dB with 32 modes and DER $\epsilon=10^{-8}$ is 1520 (reference **151**), while the maximum header length of the examples of variable length coding of the present invention described above is 791 (reference **81**) shown in FIG. **8**.

It is clear from this comparison that the header length decreases when using the method according to the present invention.

With reference to FIG. **10**, there are shown simulation results using a maximum likelihood decoder, i.e. to maximize the probability $P(\bar{y}|\bar{c})$. It is done by calculating the correlation of a received signal $\bar{y}$ with all the code-words of $\bar{c}$ code and then choosing the code-word with largest correlation. It is important to notice that the user type i needs to calculate the correlation between only the first N_i elements of the received signal $\bar{y}$ and only for the i code-words associated to SNR's which are smaller or equal to its nominal SNR (SNR_i).

Therefore, the decoding complexity is different for each user type i and is equal to $N_i\times i$ sums and i comparisons. The average decoding complexity can be calculated as $E\{N_i\times i\}$. In FIGS. **5** to **9** the last column shows $N_i\times i$ results with their average values, assuming a uniform distribution over all the users.

Since in the examples described above the linear constituent codes are chosen to be optimal for the given parameters and no other particular structure is assumed, the best optimal decoding strategy is to compute the correlation of the received signal $\overline{y}$ (N_i sums) with all the i candidate code-words.

The complexity of this exhaustive decoder is affordable because it is dealing with small codes and short average lengths.

The complexity of the correlations is further reduced by using constituent codes which admit faster decoding algorithms, as the Hadarmard transform used for Reed-Muller or maximal length codes. In particular, for a given set of parameters (n, k, d) where n and k are sufficiently small, repetition of maximal length codes yields codes with almost optimal performances.

The main goal of UEP ("Unequal Error Protection") is to design a code which offer a larger error protection to some bits, symbols or code-words than others. In the literature the same name is used for all three cases.

Hereinafter it is described a further example of the present invention, only addressing the code-word UEP, which uses a modification of the variable length channel code generation described above to generate a fixed length code.

The variable length code also has code-words with different error protection capabilities.

In fact, one way to generate a block UEP code is to extend all the code-words of the code obtained for variable length codes by zero to have a fixed length for all code-words (to equalize the length of all code-words), thus at least a code-word comprises a sequence of bits having values equal to zero. In this case all code-words will have the length equal to the longest code-word in the starting code.

It can be noticed that for this strategy to work, one should not use the all zero code-words in the construction of the starting variable length code.

It is important to notice that in the example of variable length coding described above it should be considered the average length as the effective length of the code.

As for the complexity of the maximum likelihood correlator decoder for the generated code by zero padding, it has in principle the same complexity as the corresponding variable length coding and therefore the aforementioned description about decoding complexity is valid also for these codes.

The features of the present invention, as well as the advantages thereof, are apparent from the above description.

A first advantage of the method for generating channel codes according to the present invention is that the average and the maximal length of a frame-header of a data packet is minimized.

A second advantage of the method of the present invention is that the spectral efficiency of a communication system is maximized.

A further advantage of the method of the present invention is that the correction capability of the generated channel code is improved.

A further advantage of the method of the present invention is that the computational complexity of a decoder is decreased.

A further advantage of the method of the present invention is to possibly also obtain a fixed length for all code-words in order to have a same complexity of the maximum likelihood decoder of a variable length code.

The method and the system for generating channel codes in particular for a frame-header described herein by way of example may be subject to many possible variations without departing from the novelty spirit of the inventive idea; it is also clear that in the practical implementation of the invention the illustrated details may have different shapes or be replaced with other technically equivalent elements.

For example, the method and the system for generating channel codes in particular for a frame-header can be applied in any communication system in which it is possible to vary the spectral efficiency and/or in communication systems that do not use an ACM scheme.

It can therefore be easily understood that the present invention is not limited to a method and a system for generating channel codes in particular for a frame-header, but may be subject to many modifications, improvements or replacements of equivalent parts and elements without departing from the inventive idea, as clearly specified in the following claims.

The invention claimed is:

1. A method for generating a channel code for a frame-header of a packet, the method comprising:

obtaining a code-word of said channel code, with an encoder, by means of at least a concatenation of code-words of two constituent codes, wherein said concatenation is performed on subsets of code-words of a first constituent code, having maximum length, with code-words of a second constituent code, wherein each of the first constituent code and the second constituent code is associated with a different signal to noise ratio; and

including the code-word of said channel code in the frame header.

2. The method according to claim **1**, wherein said at least a code-word of said constituent codes is encapsulated into a code-word of said channel code.

3. The method according to claim **1**, wherein said at least a code-word of said channel code has length greater than remaining code-words of said channel code.

4. The method according to claim **1**, wherein a minimum distance of said constituent codes depends on signal to noise ratios, which are associated with user types and they are different from each said user type, and depends on a detection error rate.

5. The method according to claim **1**, wherein said minimum distance is computed for each said user type.

6. The method according to claim **1**, wherein a maximum code-word length of said channel code is obtained by the formula $N_i=\Sigma_{m=1}^{M}n_m$ where M is the maximum number of said code-words of said channel code corresponding to an highest said signal to noise ratio, m is an integer index varying from one to M and n_m is a length of said code-word of said constituent code at index m.

7. The method according to claim **1**, wherein said code-words of said channel code have variable length.

8. The method according to claim **1**, wherein said constituent codes are known linear codes.

9. The method according to claim **1**, wherein said at least a code-word of said channel code comprises a sequence of bits having values equal to zero to equalize the length of said at least a code-word.

10. The method according to claim **9**, wherein said code-words of said channel code have fixed length.

11. The method according to claim **1**, wherein said channel code is an UEP code.

12. The method according to claim **1**, wherein said channel codes are suitable to be used for a frame-header of a data packet of a communication system.

13. A system for generating channel codes, comprising:

at least an encoder configured to generate a channel code for a frame-header, wherein at least a code-word of said channel code is obtained by means of at least a concatenation of code-words of two constituent codes and said concatenation is performed on subsets of code-words of a first constituent code, having maximum length, with code-words of a second constituent code, wherein each of the first constituent code and the second constituent code is associated with a different signal to noise ratio.

14. The system according to claim **13**, wherein said encoder is suitable to be used in a communication system.

15. The system according to claim **14**, wherein said communication system comprises a plurality of user types having different signal to noise ratios.

16. The system according to claim **14**, wherein said communication system is an ACM ("Adaptive Coding and Modulation") communication system.

17. A method for generating a channel code for a frame header broadcast to users associated with different signal to noise ratios, the method comprising:

generating, with an encoder, a set of variable length code-words by concatenating a constituent code word from each of M codes, wherein a code-word for each mode i is obtained by concatenating code-words of constituent codes from M down to i; and

encapsulating, by the encoder, a code word of constituent codes into a code-word of the channel code, wherein the concatenation of the code words of the channel code is performed on subsets of code-words or a first constituent code with code-words of at least a second constituent code, wherein each of the first constituent code and the second constituent code is associated with a different signal to noise ratio.

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