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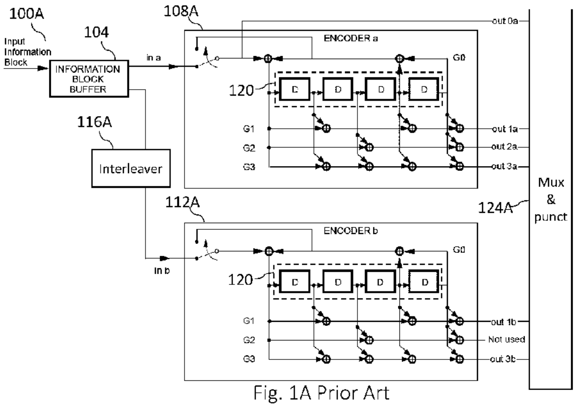

Fig. 1A Prior Art

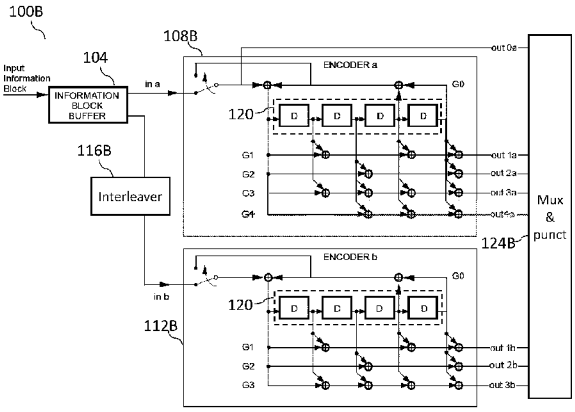

Fig. 1B

AA	état de la technique :
100A, 100B	Bloc d'informations d'entrée
104	Tampon de bloc d'informations
116A, 116B	Entrelaceur
BB	CODEUR

(57) Abstract: A turbo encoder intended for use in earth stations communicating through data networks where Successive Interference Cancellation (S IC) multiple access to Low Earth Orbit (LEO) satellites is employed. The disclosed turbo encoder constitutes an enhancement to code rate 1/ 8 of a known in the art code rate 1 / 6 turbo encoder that comprises two recursive convolutional encoders, an encoder a and an encoder b. The enhancement is achieved by adding two recursive convolutional encoder forward connection vectors to the code rate 1 / 6 turbo encoder as follows : adding forward connection vector G4 10111 to either encoder a or encoder b; and adding forward connection vector G2 10101 to encoder b.

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SYSTEM AND METHOD FOR FORWARD ERROR CORRECTION IN SATELLITE DATA NETWORKS

FIELD OF THE INVENTION

The present invention relates generally to Forward Error Correction (FEC) techniques, and more particularly to FEC techniques for use in satellite data networks comprising Successive Interference Cancellation (SIC) multiple access.

BACKGROUND OF THE INVENTION

There is an increasing demand to provide data services, in particular Internet access, for isolated, possibly mobile, end points over the globe. LEO satellite networks have become a cost-effective solution for this demand due to various limitations and drawbacks of alternative solutions such as Geostationary Equatorial Orbit (GEO) satellites-based networks. Turbo code FEC defined by the Consultative Committee for Space Data Systems (CCSDS) is commonly used in LEO satellite data networks so as to cope with low Signal-to-Noise Ratio (SNR) conditions. However, CCSDS turbo code schemes are not sufficiently powerful for loaded network, in particular when Successive Interference Cancellation (SIC) multiple access technique is employed. Hence, there is a clear need in the art for a more powerful FEC schemes than the currently available in LEO satellite data networks.

SUMMARY OF THE INVENTION

Accordingly, it is a principal object of the present invention to provide an enhanced parallel concatenated recursive convolution based turbo encoder scheme, to be used in earth stations communicating through a data network where Successive Interference Cancellation (SIC) multiple access to Low Earth Orbit (LEO) satellites is employed.

The disclosed turbo encoder constitutes an enhancement to code rate 1/8 of the known in the art code rate 1/6 turbo encoder provided in the CCSDS TM SYNCHRONIZATION AND CHANNEL CODING RECOMMENDED STANDARD, which comprises two recursive convolutional encoders, an encoder a and an encoder b. Encoder a receives the data to be encoded directly, while encoder b receives the data through an interleaver. Encoder a is configured to encode the input data using a feedback shift register having forward connection vectors G1 = 11011, G2 = 10101 and G3 = 11111. Encoder b is configured to encode the data it received from the interleaver using a feedback shift register having forward connection vectors G1 = 11011 and G3 = 11111.

the enhancement to code rate 1/8 is achieved by adding two forward connection vectors to the code rate 1/6 turbo encoder as follows:

adding forward connection vector G4 = 10111 to either encoder a or encoder b; and

adding forward connection vector G2 = 10101 to encoder b.

In typical embodiments, the aforementioned interleaver is quadratic permutation polynomial ("QPP") based, wherein the permutation is from a set i in (0,N-1) to a set j in (0,N-1), governed by the function j = modulo(f1*i+f2*i^2,N), wherein f1 is the odd number 713 and f2 is the even number 420.

In embodiments of the present invention, also a method of dynamic code rate control in a data network as described above is provided, comprising the steps of:

constantly monitoring the Bit Error Rate (BER) of the data received at at least one satellite; and

upon detecting that the BER goes below a predetermined threshold, instructing at least part of the earth stations in the network to increase their turbo encoders code rate, e.g. from 1/8 to 1/6, while preserving their transmission symbol rate, so as to alleviate the access contention associated with the SIC at the satellite.

In one embodiment, the aforementioned method further comprises the step of instructing said at least part of the earth stations to apply a predetermined delay to the data massages they transmit so as to avoid momentarily increased throughput in the network due to the increased code rate and the resulted shortening of the bursts transmitted from the earth stations.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood from the following detailed description of the embodiments thereof, taken together with the drawing in which:

Fig. 1A shows a Prior Art example of a block diagram that schematically illustrates a turbo code encoder intended for earth stations communicating through satellite data networks;

Fig. 1B shows a block diagram that schematically illustrates a turbo code encoder intended for earth stations communicating through satellite data networks, in accordance with an embodiment of the present invention;

Fig. 2 shows a flowchart that schematically illustrates a method of dynamically adjusting the FEC code rate in satellite data networks, in accordance with an embodiment of the present invention; and

Fig. 3 shows a block diagram that schematically illustrates an earth station transmitter, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Embodiments of the present invention provide an enhanced parallel concatenated turbo encoder scheme for earth stations in LEO satellite data networks that employ SIC multiple access. The enhanced encoding is necessity to cope with peak traffic conditions, which induce too low SIR at the satellite demodulator input. It should be noted that the following description has focused on specific details that are essential for understanding certain features of the disclosed techniques. Conventional elements, aspects and configurations that are not needed for this understanding have been omitted from the figures described below for the sake of simplicity, e.g. satellite-based network architecture and satellite internal stages like demodulator and network management function, but will be apparent to persons of ordinary skill in the art.

Referring to Fig. 1A Prior Art, there is shown a code rate 1/6 encoder 100A defined by the CCSDS standard "TM SYNCHRONIZATION AND CHANNEL CODING". The encoder comprises a data buffer 104 that feeds two recursive convolutional encoders: an encoder a, referenced as 108A, directly, and an encoder b, referenced as 112A, through an interleaver block 116A that is separating therebetween, and is also specified by the CCSDS standard. The recursive convolution in each encoder is achieved by a feedback shift register 120, which is connected to backward connection vector G0 and to forward connection vectors G1, G2 and G3. The connection vectors are structured as follows:

In both encoders G0 = 10011.

In encoder a: G1 = 11011, G2 = 10101, G3 = 11111.

In encoder b: G1 = 11011, G2 is not used, G3 = 11111.

Buffer 104 output, as well as the forward connection vector outputs, are connected to a multiplexing and puncturing block 124A, which is also specified in the CCSDS standard.

Fig. 1B illustrates the disclosed code rate 1/8 turbo encoder, 100B, which is achieved by modifying the code rate 1/6 encoder, shown in Fig. 1A, as follows:

Encoder a, referenced now as 108B, contains an added forward connection vector G4 = 10111, and

in encoder b, referenced as 112B, forward connection vector G2 = 10101 is now used.

In some embodiments, the above vector G4 10111 is added to encoder b 112B rather than to encoder a 108B.

Block 124B differs from block 124A by added support to the above new forward connection vectors G2 and G4. Different configurations of block 124B also allow the dynamic code rate control, which is described below with reference to Fig. 2.

Interleaver block 116B comprises a 252 bytes length quadratic permutation polynomial ("QPP") interleaver, based on permutation from a set i in (0,N-1) to a set j in (0,N-1), governed by the function j = modulo(f1*i+f2*i^2,N), wherein f1 is the odd number 713 and f2 is the even number 420.

Referring now to Fig. 2, there is shown a flowchart 200 that schematically illustrates a method of dynamic code rate control, achieved by dynamically adjusting the FEC code rate in satellite data networks comprising SIC multiple access, in accordance with an embodiment of the present invention.

The method begins with a setting step 204, in which a satellite onboard network management function (not shown in the figures) commands the network earth stations to set their transmission code rate to the new low rate 1/8. Next, in a decision step 208, the management function checks if the SIR at the satellite demodulator is sufficiently high. This is done by constantly monitoring the Bit Error Rate (BER) of the data received at the satellite. If the BER goes bellow a predetermined threshold BERmin, optionally minus a safety margin ΔBER, the method proceeds to step 212.

In step 212 the management function instructs earth stations that can transmit strongly enough to the satellite to increase their transmission code rate, e.g. to 1/6. The earth stations increase their code rate without decreasing the transmitted symbol rate, so as to alleviate the access contention associated with the SIC at the satellite demodulator, which is achieved due to the shorter transmitted bursts. Simultaneously with step 212, in step 216 the management function also causes an appropriate predetermined delay of the data bursts, either in the satellite or in the earth stations, so as to avoid momentarily increased throughput in the network due to the increased code rate and the resulted shortening of the bursts transmitted from the earth stations. Flowchart 200 returns now to decision step 208.

If the condition of step 208 is not met, the management function checks, in a decision step 220, if the BER at the satellite demodulator exceeds the BERmin threshold. If the threshold is not exceeded, the flowchart returns to step 208 and the method process proceeds as explained so far. If the threshold is exceeded, the flowchart proceeds to step 224, in which the management function instructs those earth stations that increased their transmission code rate to fall back to a lower code rate. Simultaneously with step 224, in step 228 the management function also cancels the delay that was introduced in step 216. Flowchart 200 now returns to decision step 208 and proceeds as explained above.

Flowchart 200 is an example flowchart, which was chosen purely for the sake of conceptual clarity. In alternative embodiments, any other suitable flowchart can also be used for illustrating the disclosed method. Method steps that are not mandatory for understanding the disclosed techniques were omitted from Fig. 2 for the sake of simplicity.

Referring now to Fig. 3, there is shown a block diagram 300 that schematically illustrates the transmit part of an earth station, in accordance with a preferred embodiment. Following is a description of the main transmit part blocks.

Block 304 represents a 16 byte cyclic redundancy check (CRC16) to be calculated over the transmit data bytes (not including the CRC itself). The CRC16 polynomial is x^16+x^12+x^5+1, and the CRC is the remainder of the division of the data bytes by the polynomial. Block 308 represents the turbo encoder depicted in Fig. 1B. Block 312 represents the aforementioned interleaver 116B, which is actually contained in block 308 though depicted separately in Fig. 3. Block 316 that follows represents inclusion of known symbols (pilots) such that to each 80 coded bits a batch of 8 bits of value ‘0’ is added. The batch is inserted in the middle such that there are 40 coded bits, 8 pilots and additional 40 coded bits. Block 320 represents a QPSK modulator, which maps each input nibble such that the 1st bit pair is mapped to the real axis and the 2nd pair is mapped to the imaginary axis, and on each axis binary 1 is mapped to -1 and binary 0 is mapped to +1.

In block 324, signal spreading is employed as part of the satellite multiple access scheme, which also contains the aforementioned SIC mechanism at the satellite transponder receiver. The spreading is performed in the following two steps: In the 1st step, each QPSK symbol is replicated 32 times. In the 2nd step a 3GPP Gold sequence multiplies the resulting stream of step 1. This sequence has very good orthogonality properties over a period much larger than the maximum duration of a spread frame. Block 324 also applies random cyclic shifts of the spreading sequence within the transmitted bursts so as to achieve low cross-correlation between the bursts transmitted from the various earth stations in the data network, even in case of synchronized burst transmissions.

Referring to the preamble insertion block 328, the transmitter chooses randomly one of four options for the combination preamble + sequence initialization option. One of 4 possible preambles are inserted. The initialization seeds for Xn for the different 4 options are:

Option	Seed
0	0x310000
1	0x310001
2	0x310002
3	0x310003

The choice of the preamble creates a separation of about 13db between different preambles. Due to link budget limitations and power control, such separation is expected to be enough for preventing false detection of the i-th preamble when matched by a correlator to the j-th one (i≠j).

For pulse shaping, performed in block 332, a root raised cosine with roll-off 0.2 is used. The root raised cosine shapes the signal at x2 sampling rate while using a 25 taps filter.

Waveform summary:

- Data Length – 250 bytes
- CRC – 2 bytes

- FEC – Turbo code rate 1/8. Total coded bits: 16160.
- Modulation – QPSK
- Spreading – 32. Total number of payload chips: 258560.
- Preamble – 40x128 = 5120 chips.
- Pilots – 1/10
- Total number of chips: 289536.
- Chip Rate: 3.84Mchips/sec.
- Bit Rate: 26.525 kbps.
- Duration: 75.4 milliseconds.

The above blocks are implemented, in typical embodiments, using commonly used component types such as ASICs and FPGAs. It will thus be appreciated that the embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and sub-combinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art.

CLAIMS

1. A turbo encoder intended for use in earth stations communicating through a data network where successive interference cancellation (SIC) multiple access to one or more Low Earth Orbit (LEO) satellites is employed, the turbo encoder being an enhancement to code rate 1/8 of a code rate 1/6 turbo encoder, said code rate 1/6 turbo encoder comprising a recursive convolutional encoder a configured to encode data using a feedback shift register having forward connection vectors G1 = 11011, G2 = 10101 and G3 = 11111, and a recursive convolutional encoder b, configured to receive the data through an interleaver and to encode the data it receives from the interleaver using a feedback shift register having forward connection vectors G1 = 11011 and G3 = 11111, wherein the enhancement to code rate 1/8 is achieved by adding two forward connection vectors to the code rate 1/6 turbo encoder as follows:

   adding forward connection vector G4 = 10111 to either encoder a or encoder b; and

   adding forward connection vector G2 = 10101 to encoder b.

2. The turbo encoder of claim 1, wherein the interleaver is quadratic permutation polynomial (“QPP”) based, wherein the permutation is from a set i in (0,N-1) to a set j in (0,N-1), governed by the function j = modulo(f1*i+f2*i^2,N), wherein f1 is the odd number 713 and f2 is the even number 420.

3. A method of dynamic code rate control in a data network as of claim 1, comprising the steps of:

   constantly monitoring the Bit Error Rate (BER) of the data received at at least one satellite; and

   upon detecting that the BER goes below a predetermined threshold, instructing at least part of the earth stations in the network to increase their turbo encoders code rate, e.g. from 1/8 to 1/6, while preserving their transmission symbol rate, so as to alleviate the access contention associated with the SIC at the satellite.

4. The method of claim 3, further comprising the step of instructing said at least part of the earth stations to apply a predetermined delay to the data bursts they transmit so as to avoid momentarily increased throughput in the network due to the increased code rate and the resulted shortening of the bursts transmitted from the earth stations.

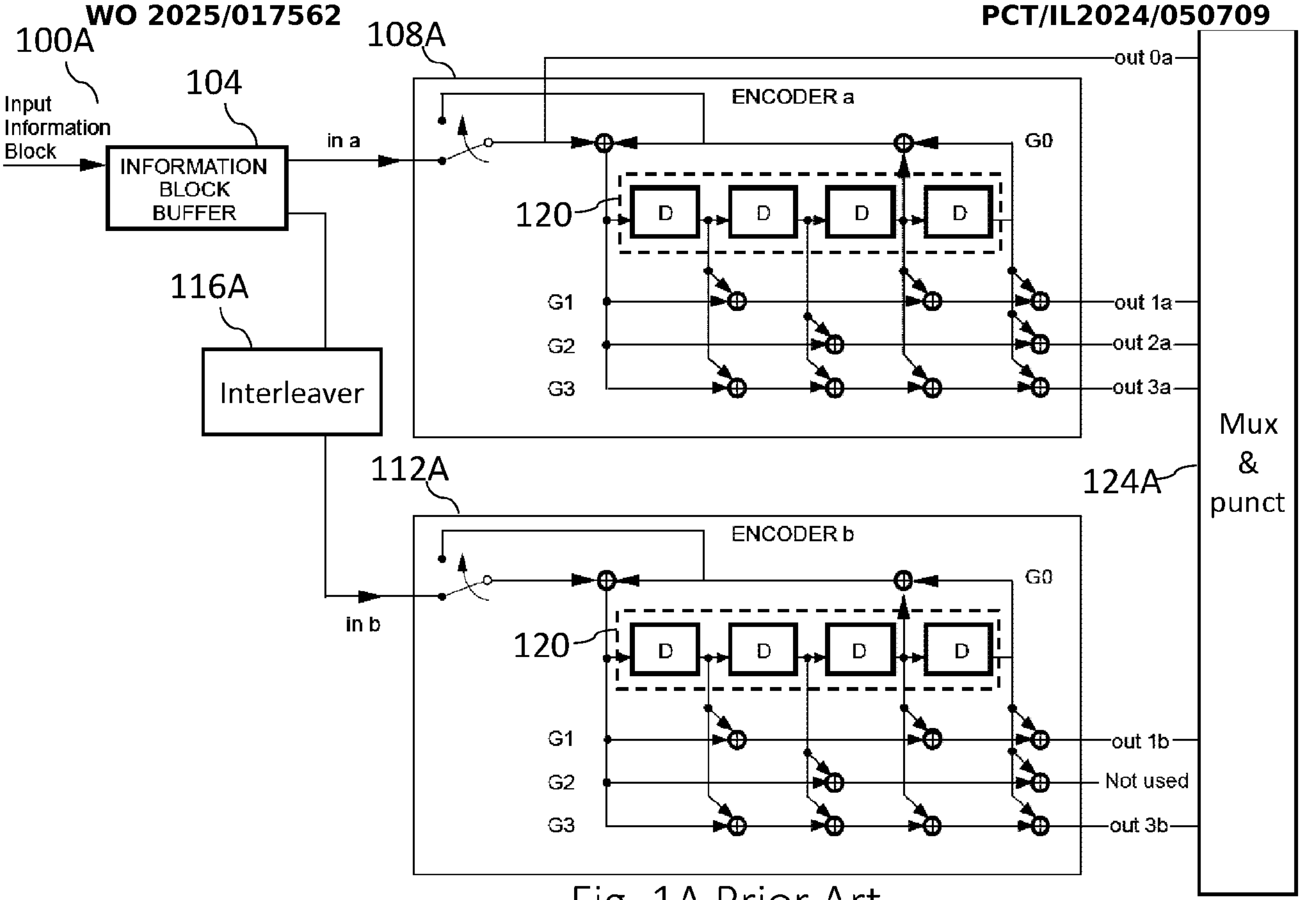

Fig. 1A Prior Art

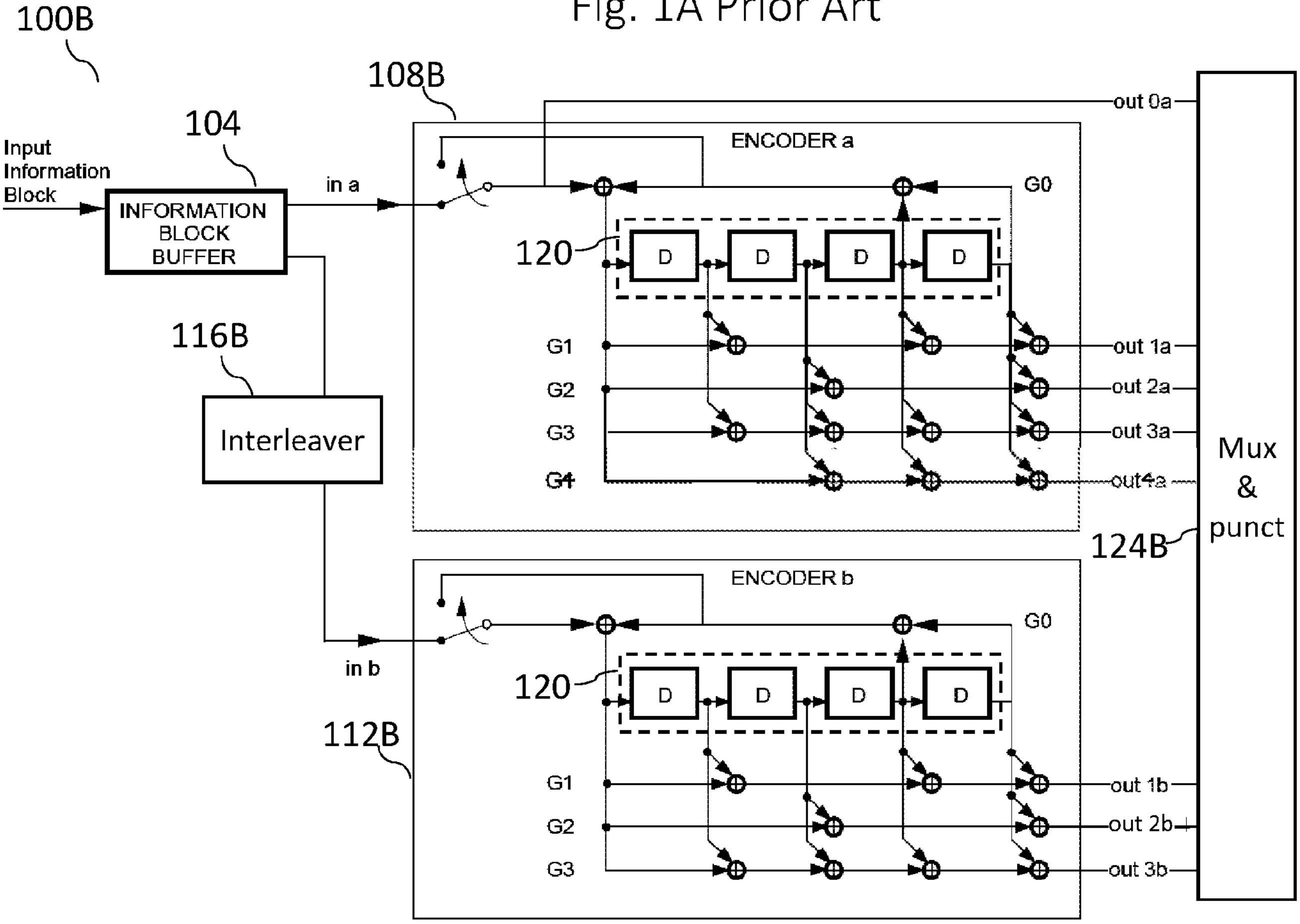

Fig. 1B

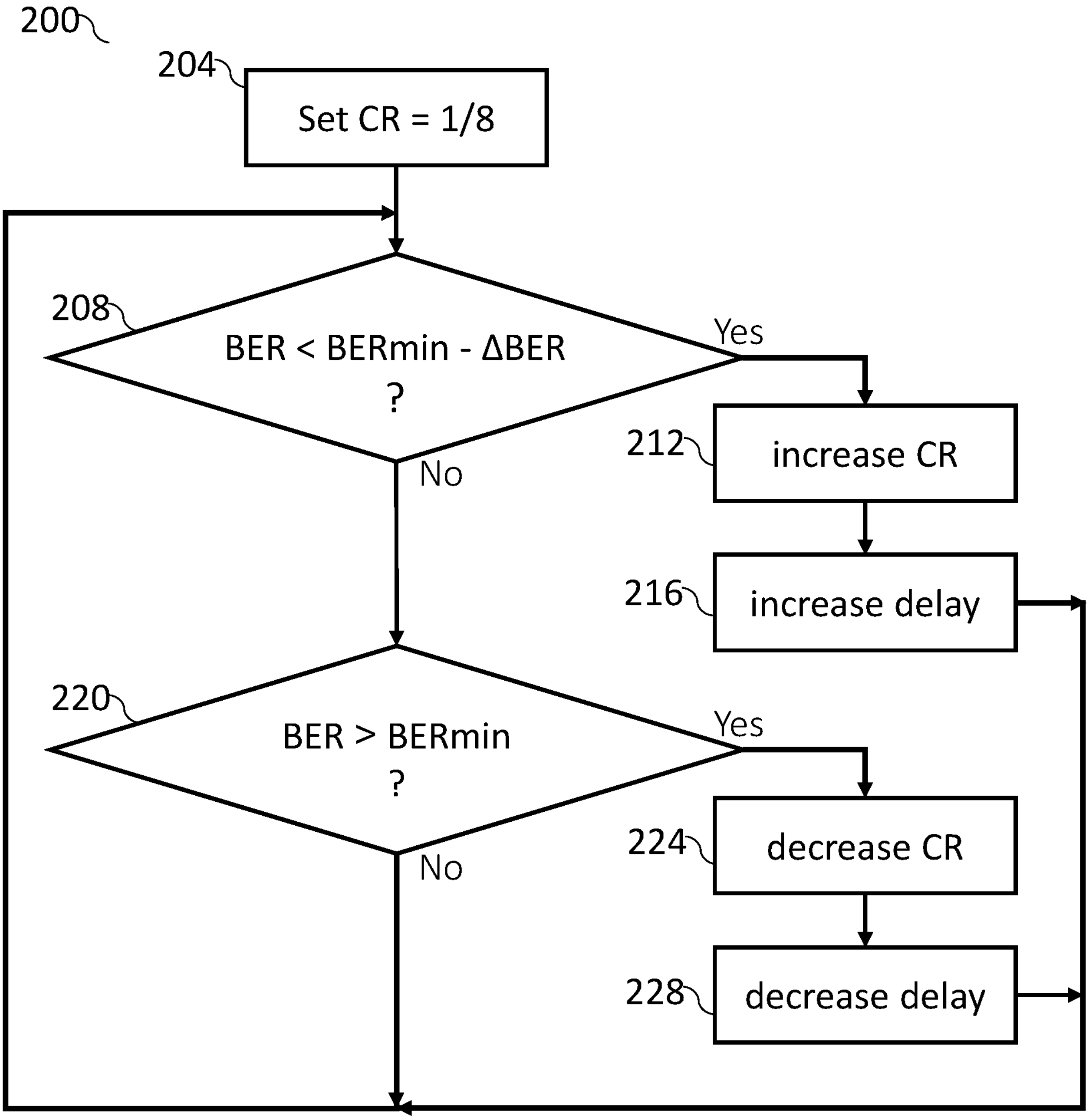
200
204
Set CR = 1/8
208
BER < BERmin - ΔBER
?
Yes
No
212
increase CR
216
increase delay
220
BER > BERmin
?
Yes
No
224
decrease CR
228
decrease delay

Fig. 2

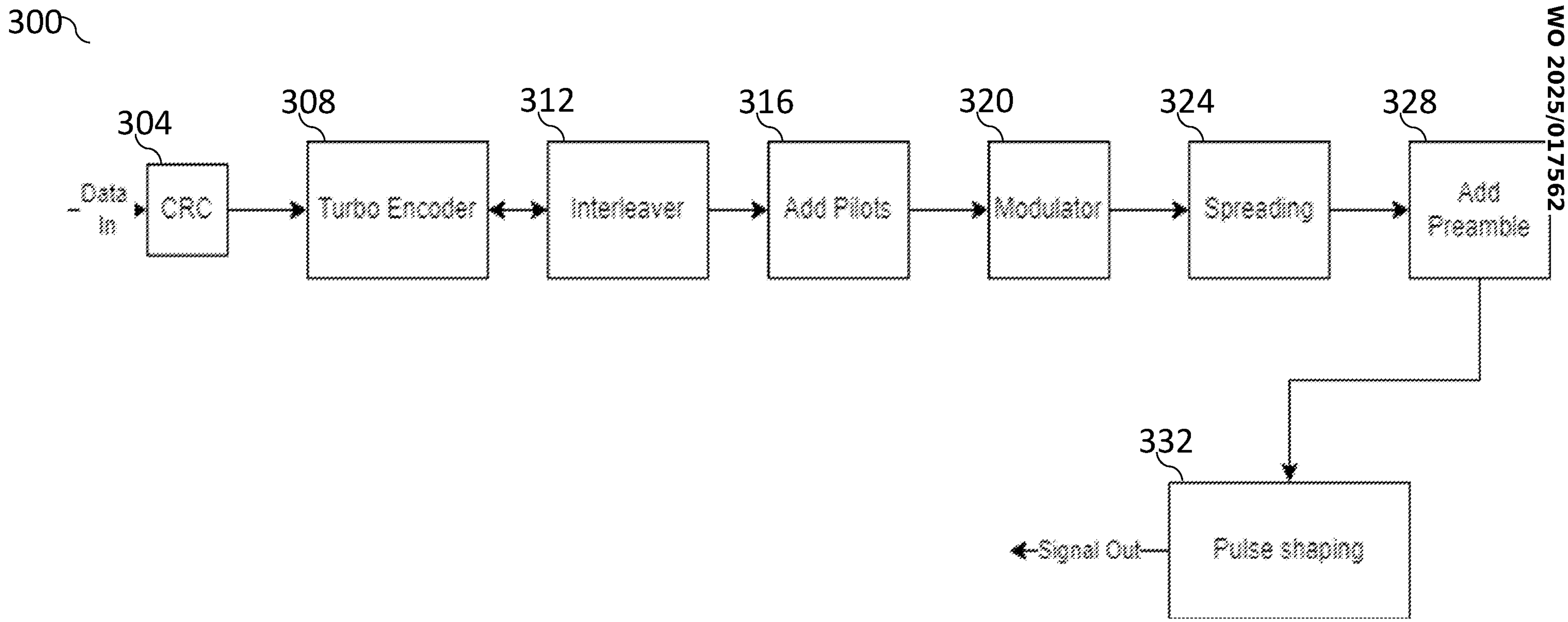
300
304
308
312
316
320
324
328
332
Data In
CRC
Turbo Encoder
Interleaver
Add Pilots
Modulator
Spreading
Add Preamble
Pulse shaping
Signal Out

Fig. 3