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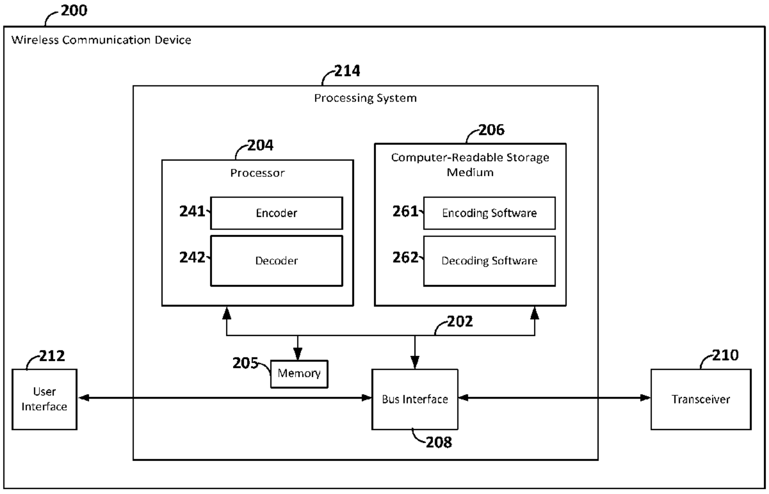

FIG. 2

(57) **Abstract**: Polar codes may be generated with a variable block length utilizing puncturing. Some puncturing algorithms consider punctured bits as unknown bits, and set the LLR for those bits to zero; while other puncturing algorithms consider punctured bits as known bits, and set the LLR for those bits to infinity. Each of these algorithms has been observed to provide benefits over the other under different circumstances, especially corresponding to different coding rates or different SNR. According to aspects of the present disclosure, both puncturing algorithms are performed and compared, and the algorithm resulting in the better performance is utilized for transmission.

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GENERATION OF POLAR CODES WITH A VARIABLE BLOCK LENGTH UTILIZING PUNCTURING

TECHNICAL FIELD

[1] The technology discussed below relates generally to information communication systems, and more particularly, to channel coding utilizing polar codes in communication systems.

BACKGROUND

[2] Block codes, or error correcting codes are frequently used to provide reliable transmission of digital messages over noisy channels. In a typical block code, an information message or sequence is split up into blocks, and an encoder at the transmitting device then mathematically adds redundancy to the information message. Exploitation of this redundancy in the encoded information message is the key to reliability of the message, enabling correction for any bit errors that may occur due to the noise. That is, a decoder at the receiving device can take advantage of the redundancy to reliably recover the information message even though bit errors may occur, in part, due to the addition of noise to the channel.

[3] Many examples of such error correcting block codes are known to those of ordinary skill in the art, including Hamming codes, Bose-Chaudhuri-Hocquenghem (BCH) codes, turbo codes, and low-density parity check (LDPC) codes, among others. Many existing wireless communication networks utilize such block codes, such as 3GPP LTE networks, which utilize turbo codes; and IEEE 802.11n Wi-Fi networks, which utilize LDPC codes. However, for future networks, a new category of block codes, called polar codes, presents a potential opportunity for reliable and efficient information transfer with improved performance relative to turbo codes and LDPC codes.

[4] While research into implementation of polar codes continues to rapidly advance its capabilities and potential, additional enhancements are desired, particularly for potential deployment of future wireless communication networks beyond LTE.

SUMMARY

[5] The following presents a simplified summary of one or more aspects of the present disclosure, in order to provide a basic understanding of such aspects. This summary is

not an extensive overview of all contemplated features of the disclosure, and is intended neither to identify key or critical elements of all aspects of the disclosure nor to delineate the scope of any or all aspects of the disclosure. Its sole purpose is to present some concepts of one or more aspects of the disclosure in a simplified form as a prelude to the more detailed description that is presented later.

[6] Various aspects of the disclosure provide for the generation of polar codes with a variable block length utilizing puncturing. Some puncturing algorithms consider punctured bits as unknown bits, and set the LLR for those bits to zero; while other puncturing algorithms consider punctured bits as known bits, and set the LLR for those bits to infinity. Each of these algorithms has been observed to provide benefits over the other under different circumstances, especially corresponding to different coding rates or different SNR. According to aspects of the present disclosure, both puncturing algorithms are performed and compared, and the algorithm resulting in the better performance is utilized for transmission.

[7] These and other aspects of the invention will become more fully understood upon a review of the detailed description, which follows. Other aspects, features, and embodiments of the present invention will become apparent to those of ordinary skill in the art, upon reviewing the following description of specific, exemplary embodiments of the present invention in conjunction with the accompanying figures. While features of the present invention may be discussed relative to certain embodiments and figures below, all embodiments of the present invention can include one or more of the advantageous features discussed herein. In other words, while one or more embodiments may be discussed as having certain advantageous features, one or more of such features may also be used in accordance with the various embodiments of the invention discussed herein. In similar fashion, while exemplary embodiments may be discussed below as device, system, or method embodiments it should be understood that such exemplary embodiments can be implemented in various devices, systems, and methods.

BRIEF DESCRIPTION OF THE DRAWINGS

[8] FIG. 1 is a schematic illustration if wireless communication utilizing block codes.

[9] FIG. 2 is a block diagram illustrating an example of a hardware implementation for a wireless communication device employing a processing system according to some embodiments.

[10] FIG. 3 is a flow chart illustrating an example of a process for generating a polar coded transmission according to some embodiments.

[11] FIG. 4 is a schematic illustration of the construction of a polar code considering punctured bits as unknown bits according to some embodiments.

[12] FIG. 5 is a schematic illustration of the construction of a polar code considering punctured bits as known bits according to some embodiments.

[13] FIG. 6 is a flow chart illustrating an example of a process for decoding a polar coded transmission according to some embodiments.

DETAILED DESCRIPTION

[14] The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

[15] FIG. 1 is a schematic illustration of wireless communication between a first wireless communication device 102 and a second wireless communication device 104. In the illustrated example, the first wireless communication device 102 transmits a digital message over a communication channel 106 (e.g., a wireless channel) to the second wireless communication device 104. One issue in such a scheme that must be addressed to provide for reliable communication of the digital message, is to take into account the noise that affects the communication channel 106.

[16] Block codes, or error correcting codes are frequently used to provide reliable transmission of digital messages over such noisy channels. In a typical block code, an information message or sequence is split up into blocks, each block having a length of K bits. An encoder 124 at the first (transmitting) wireless communication device 102 then mathematically adds redundancy to the information message, resulting in codewords having a length of N, where $N > K$. Here, the code rate R is the ratio between the message length and the block length: i.e., $R = K / N$. Exploitation of this redundancy in the encoded information message is the key to reliability of the message, enabling correction for any bit errors that may occur due to the noise. That is, a decoder 142 at the second (receiving) wireless communication device 104 can take advantage of the redundancy to reliably recover the information message even though bit errors may occur, in part, due to the addition of noise to the channel.

[17] Many examples of such error correcting block codes are known to those of ordinary skill in the art, including Hamming codes, Bose-Chaudhuri-Hocquenghem (BCH) codes, turbo codes, and low-density parity check (LDPC) codes, among others. Many existing wireless communication networks utilize such block codes, such as 3GPP LTE networks, which utilize turbo codes; and IEEE 802.11n Wi-Fi networks, which utilize LDPC codes. However, for future networks, a new category of block codes, called polar codes, presents a potential opportunity for reliable and efficient information transfer with improved performance relative to turbo codes and LDPC codes.

[18] Polar codes are linear block error correcting codes invented in 2007 by Erdal Arikan, and currently known to those skilled in the art. In general terms, channel polarization is generated with a recursive algorithm that defines polar codes. Polar codes are the first explicit codes that achieve the channel capacity of symmetric binary-input discrete memoryless channels. That is, polar codes achieve the channel capacity (the Shannon limit) or the theoretical upper bound on the amount of error-free information that can be transmitted on a discrete memoryless channel of a given bandwidth in the presence of noise.

[19] Polar codes may be considered as block codes (N, K). While it would be flexible for an encoder 124 to be able to select the number of information bits K, with polar codes, the codeword length N must be a power of 2 (e.g., 256, 512, 1024, etc.) because the original construction of a polarizing matrix is based on the Kronecker product of $\begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$. However, in a given communication system, it is generally not possible to guarantee that a resource can afford always to utilize this limited set of codeword lengths. To support the variable size of resources in a practical system, the block size of polar codes must be flexible to the resource size.

[20] Puncturing is widely used to obtain length-compatible polar codes having a codeword whose block length is not a power of 2. For example, to obtain a 1000-bit code word length, 24 bits may be punctured from a $2^{10} = 1024$-bit code word. According to various aspects of the present disclosure, puncturing may be utilized to obtain codewords of arbitrary length (e.g., lengths that are not necessarily a power of 2).

[21] When performing codeword puncturing, the selection of which bits to puncture (the puncturing pattern) is an important concern and can affect the efficiency of the algorithm. Even if it is possible, it is not desirable to perform an exhaustive search of all puncture patterns to find the optimal puncture pattern, due to the extensive computation complexity that would be required.

[22] It has been known in the art to employ random puncturing patterns, among other various puncture patterns. Among the known puncturing patterns, a uniform puncturing pattern provides good performance. One example of a uniform puncturing pattern is described in *Kai Niu et al.*, BEYOND TURBO CODES: RATE-COMPATIBLE PUNCTURED POLAR CODES, 2013 IEEE International Conference on Communications. Details of this algorithm are known to those of ordinary skill in the art and are not described in detail in the present disclosure. In the exemplary algorithm described below, a uniform puncturing pattern is described, although those skilled in the art will recognize that nonuniform (e.g., random) puncturing may be utilized within the scope of the present disclosure.

[23] Another aspect of a puncturing algorithm is how the decoder is to treat the punctured bits. In some examples of codeword puncturing, the punctured bits may be considered to be unknown bits. That is, the decoder may set the log-likelihood ratio (LLR) for the punctured bits to zero, indicating that the punctured bits are unknown. One example of a puncturing pattern where the punctured bits are considered unknown bits is described in *Dong-Min Shin et al.*, DESIGN OF LENGTH-COMPATIBLE POLAR CODES BASED ON THE REDUCTION OF POLARIZING MATRICES, IEEE Transactions on Communications, Vol. 61, No. 7, July 2013. Details of this algorithm are known to those of ordinary skill in the art and are not described in detail in the present disclosure.

[24] In other examples of codeword puncturing, the punctured bits may be considered to be known bits. That is, the decoder may set the LLR for the punctured bits to be very high (e.g., to infinity) indicating that the punctured bits have a known value of zero. The construction of polar codes using a puncturing scheme where the punctured bits are considered known bits was introduced by *Runxin Wang and Rongke Liu*, A NOVEL PUNCTURING SCHEME FOR POLAR CODES, IEEE Communications Letters, Vol. 18, No. 12, December 2014. Details of this algorithm are known to those of ordinary skill in the art and are not described in detail in the present disclosure.

[25] According to aspects of the present disclosure, it has been observed that, when the punctured bits are considered unknown bits, a puncturing algorithm generally provides

better performance than known-bit puncturing when utilizing lower coding rates (e.g., when the coding rate R is less than ½). On the other hand, considering the punctured bits as known bits generally provides better performance than unknown-bit puncturing when utilizing high coding rates (e.g., when the coding rate R is higher than ½). Furthermore, the performance of the encoder may additionally depend on other factors or parameters, such as the signal to noise ratio (SNR) region experienced on the communication channel.

[26] According to an aspect of the present disclosure, a puncturing algorithm may select between such known-bit puncturing and unknown-bit puncturing in order to achieve the best performance in any conditions, independent of the coding rate or SNR region being experienced.

[27] FIG. 2 is a block diagram illustrating an example of a hardware implementation for a wireless communication device 200 employing a processing system 214. In accordance with various aspects of the disclosure, an element, or any portion of an element, or any combination of elements may be implemented with a processing system 214 that includes one or more processors 204. For example, the wireless communication device 200 may be a user equipment (UE), a base station, or any other suitable apparatus or means for wireless communication. Examples of processors 204 include microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. That is, the processor 204, as utilized in a wireless communication device 200, may be used to implement any one or more of the processes described below and illustrated in FIGs. 3–6.

[28] In this example, the processing system 214 may be implemented with a bus architecture, represented generally by the bus 202. The bus 202 may include any number of interconnecting buses and bridges depending on the specific application of the processing system 214 and the overall design constraints. The bus 202 links together various circuits including one or more processors (represented generally by the processor 204), a memory 205, and computer-readable media (represented generally by the computer-readable medium 206). The bus 202 may also link various other circuits such as timing sources, peripherals, voltage regulators, and power management circuits, which are well known in the art, and therefore, will not be described any further. A bus

interface 208 provides an interface between the bus 202 and a transceiver 210. The transceiver 210 provides a means for communicating with various other apparatus over a transmission medium. Depending upon the nature of the apparatus, a user interface 212 (e.g., keypad, display, speaker, microphone, joystick) may also be provided.

[29] The processor 204 may include an encoder 241, which may in some examples operate in coordination with encoding software 261 stored in the computer-readable storage medium 206. Further, the processor 204 may include a decoder 242, which may in some examples operate in coordination with decoding software 262 stored in the computer-readable medium 206.

[30] The processor 204 is responsible for managing the bus 202 and general processing, including the execution of software stored on the computer-readable medium 206. The software, when executed by the processor 204, causes the processing system 214 to perform the various functions described below for any particular apparatus. The computer-readable medium 206 may also be used for storing data that is manipulated by the processor 204 when executing software.

[31] One or more processors 204 in the processing system may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software modules, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. The software may reside on a computer-readable medium 206. The computer-readable medium 206 may be a non-transitory computer-readable medium. A non-transitory computer-readable medium includes, by way of example, a magnetic storage device (e.g., hard disk, floppy disk, magnetic strip), an optical disk (e.g., a compact disc (CD) or a digital versatile disc (DVD)), a smart card, a flash memory device (e.g., a card, a stick, or a key drive), a random access memory (RAM), a read only memory (ROM), a programmable ROM (PROM), an erasable PROM (EPROM), an electrically erasable PROM (EEPROM), a register, a removable disk, and any other suitable medium for storing software and/or instructions that may be accessed and read by a computer. The computer-readable medium may also include, by way of example, a carrier wave, a transmission line, and any other suitable medium for transmitting software and/or instructions that may be accessed and read by a computer. The computer-readable medium 206 may reside in the processing system 214, external to the processing system 214, or distributed across multiple entities including the processing system 214. The computer-readable medium 206 may be embodied in a computer program product. By way of example, a computer program product may include a computer-readable medium in packaging materials. Those skilled in the art will recognize how best to implement the described functionality presented throughout this disclosure depending on the particular application and the overall design constraints imposed on the overall system.

[32] FIG. 3 is a flow chart illustrating an exemplary process 300 for generating a polar coded transmission according to some aspects of the present disclosure. In some examples, the process 300 may be implemented by a wireless communication device 102, 104, or 200 as described above and illustrated in FIGs. 1 and 2. In some examples, the process 300 may be implemented by any suitable means for carrying out the described functions.

[33] At block 302, the wireless communication device 202 may provide a predetermined (e.g., uniform or quasi-uniform) initial puncturing pattern P_u. For example:

$$P_u = (1 \quad 1 \quad 1 \quad \cdots \quad 1 \quad 0 \quad 0 \quad \cdots \quad 0)_N$$

[34] As seen here, the puncture pattern P_u is represented by a vector with all elements having a value of 1 except for the last N–M elements, which have a value of 0. Here, N is the codeword length, and M is the desired block length after puncturing. If a value in this vector is zero, then information bits at that position will be punctured. If the value is 1, then information bits at that position will be kept. Thus, the initial puncturing pattern P_u functions as a mask, zeroing the last N–M elements of a codeword to which it is applied.

[35] The generator matrix (e.g., a polarizing matrix) G_N for generating a polar code with a block length of N can be expressed as:

$$G_N = B_N F^{\otimes n}$$

[36] Here, B_N is the bit-reversal permutation matrix for successive cancellation (SC) decoding (functioning in some ways similar to the interleaver function used by a turbo coder in LTE networks), and $F^{\otimes n}$ is the n^{th} Kronecker power of F. The basic matrix F is $\begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$. The matrix $F^{\otimes n}$ is generated by raising the basic 2x2 matrix F by the n^{th} Kronecker power. This matrix is a lower triangular matrix, in that all the entries above the main diagonal are zero. Because the bit-reversal permutation just changes the index of the rows, the matrix of $F^{\otimes n}$ may be analyzed instead. The matrix of $F^{\otimes n}$ can be expressed as:

$$F^{\otimes n} = \begin{bmatrix} 1 & 0 & 0 & & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & \cdots & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & & 0 & 0 & 0 & 0 \\ & \vdots & & \ddots & & \vdots & & \\ 1 & 0 & 0 & & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & \cdots & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & & 1 & 1 & 1 & 1 \end{bmatrix}$$

[37] Suppose the desired block length is M. To obtain length-compatible codes, the last $N-M$ columns of the matrix $F^{\otimes n}$ may be removed. As it can be seen above, in the last column, all the values are zero, except for only the last row, which includes a 1. Thus, if the last column is removed, then the last row may be removed as well. If the last column and the last row are removed, then the value of the punctured bit will be zero. This applies to each removed column: when removed, the corresponding bottom row is also removed. This implies that the last $N-M$ rows are removed at the same time. Because the puncture starts from the last column of the matrix to left one by one, the value of the punctured bits will be known with values of zeros as long as the last $N-M$ information bits are set as frozen bits with values of zeros. That is, frozen bits are bits that are fixed as 0 or 1 because the channel for those bits is bad. The value of the frozen bits may generally be known at both the transmitting device and the receiving device. It is noted that this puncture pattern is similar to a uniform puncture pattern after doing bit-reversal permutation B_N.

[38] Thus, at block 304, the wireless communication device 200 may calculate a final puncturing pattern P by utilizing bit-reversal permutation. At block 306, the wireless communication device 200 may perform unknown-bit puncturing and generate a first LLR sum. Referring now to FIG. 4, the construction of a polar code with punctured bits as unknown bits is schematically illustrated. As described above, the N-bit information sequence is punctured utilizing the initial puncturing pattern P_u, such that the last $N-M$ bits have values of 0. The wireless communication device 200 may set an initial LLR of each punctured bit as zero, such that the punctured bits are considered unknown. Bit-reversal permutation is then performed by applying the bit-reversal permutation matrix B_N described above to the N bits (including K information bits and $N-K$ frozen bits), resulting in the last $N-M$ bits of the information sequence being distributed throughout the permuted sequence, as illustrated with the dashed lines in FIG. 4. That is, with bit-reversal permutation, the location of the punctured bits will be uniformly distributed across the codeword.

[39] At this point, density evolution (DE) or Gaussian approximation may be performed to obtain the bit error probability for each bit. Density evolution has been known to be used for the construction of polar codes, and is generally known to those skilled in the art, and therefore the details thereof are not described herein. It has also been known in the art to use a lower complexity version of density evolution utilizing Gaussian approximation of densities, for the construction of polar codes. Gaussian approximation is also known to those skilled in the art.

[40] Once the bit error probability is obtained for each bit, the wireless communication device 200 may determine whether each channel is good or bad. For example, the wireless communication device 200 may sort the channels from highest to lowest, according to the final LLR of the codeword bits. After sorting, the best K channels (e.g., good channels) may be determined for the information bits, leaving the remaining $N–K$ bad channels for frozen bits. Here, the value of the channel may be set as zero for the frozen bits. Finally, the first LLR sum may be calculated by determining the sum of the final LLRs for all of the information bits.

[41] At block 308, the wireless communication device 200 may perform known-bit puncturing and generate a second LLR sum. Referring now to FIG. 5, the construction of a polar code with punctured bits as known bits is schematically illustrated. As described above, the N-bit information sequence is punctured utilizing the initial puncturing pattern P_u, such that the last $N–M$ bits have values of 0. The wireless communication device 200 may set an initial LLR of each punctured bit as infinity, such that the punctured bits are considered known. Bit-reversal permutation is then performed, resulting in the last $N–M$ bits of the information sequence being distributed throughout the permuted sequence, as illustrated with the dashed lines in FIG. 4. At this point, density evolution (DE) or Gaussian approximation may be performed to obtain the bit error probability for each bit.

[42] Once the bit error probability is obtained for each bit, the wireless communication device may sort the channels from highest to lowest, according to the final LLR of the codeword bits. After sorting, the best K channels (e.g., good channels), here, excluding the channels corresponding to $N–M$ frozen bits, may be determined for the information bits, leaving $N–K$ bad channels for frozen bits. Finally, the second LLR sum may be calculated by determining the sum of the final LLRs for all of the information bits.

[43] Returning now to FIG. 3, at block 310, the wireless communication device 200 may compare the first LLR sum with the second LLR sum, and may select the puncturing algorithm corresponding to the larger sum.

[44] At block 312, the wireless communication device 200 may generate the codeword (i.e., the polar code) utilizing the final puncture pattern P, treating the punctured bits as known bits or unknown bits in accordance with which algorithm resulted in the larger LLR sum, as described above. At block 314, the wireless communication device may transmit the encoded information over the communication channel.

[45] Referring now to FIG. 6, a process 600 is illustrated for decoding a polar coded transmission according to some aspects of the disclosure. In some examples, the process 600 may be implemented by a wireless communication device 102, 104, or 200 as described above and illustrated in FIGs. 1 and 2. In some examples, the process 600 may be implemented by any suitable means for carrying out the described functions.

[46] At block 602, the wireless communication device 602 may determine whether punctured bits in a received codeword are to be treated as known bits or unknown bits. In various aspects of the disclosure, this determination may be explicit or implicit. For example, an explicit transmission may be made from the transmitting device to the receiving device, informing the decoder in the receiving device of which puncturing method is used. Any suitable transmission may be utilized for the explicit indication, e.g., being as simple as a single bit, with one value indicating that the punctured bits are to be treated as known bits, an another value indicating that the punctured bits are to be treated as unknown bits.

[47] In another example, the treatment of the punctured bits may be determined according to a predefined relationship with one or more other coding parameters. That is, in channel coding, information such as the coding rate, the size of the information message, and the size of the codewords may be transmitted to the receiver. According to an aspect of the present disclosure, this information may provide means for the receiver to deduce the puncturing used from the other parameters. As one particular example, the puncturing method may be determined according to the coding rate. That is, in this example, if the coding rate R is greater than a threshold (e.g., ½), then the decoder can take this to mean that known bit puncturing is used; and if the coding rate R is not greater than the threshold, then the decoder can take this to mean that unknown bit puncturing is used.

[48] At block 604, the wireless communication device 200 may set the initial LLR of the punctured bits as infinity or zero, according to which puncturing method is used, as determined at block 602. At block 606, the wireless communication device 200 may perform successive cancellation (SC) decoding, known to those of ordinary skill in the art, of a received codeword to determine the encoded information sequence. Here, an SC decoder calculates the LLR of each coded bit in a recursive manner and obtains the information sequence.

[49] Within the present disclosure, the word "exemplary" is used to mean "serving as an example, instance, or illustration." Any implementation or aspect described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects of the disclosure. Likewise, the term "aspects" does not require that all aspects of the disclosure include the discussed feature, advantage or mode of operation. The term "coupled" is used herein to refer to the direct or indirect coupling between two objects. For example, if object A physically touches object B, and object B touches object C, then objects A and C may still be considered coupled to one another—even if they do not directly physically touch each other. For instance, a first object may be coupled to a second object even though the first object is never directly physically in contact with the second object. The terms "circuit" and "circuitry" are used broadly, and intended to include both hardware implementations of electrical devices and conductors that, when connected and configured, enable the performance of the functions described in the present disclosure, without limitation as to the type of electronic circuits, as well as software implementations of information and instructions that, when executed by a processor, enable the performance of the functions described in the present disclosure.

[50] One or more of the components, steps, features and/or functions illustrated in FIGs. 1–6 may be rearranged and/or combined into a single component, step, feature or function or embodied in several components, steps, or functions. Additional elements, components, steps, and/or functions may also be added without departing from novel features disclosed herein. The apparatus, devices, and/or components illustrated in FIGs. 1–2 may be configured to perform one or more of the methods, features, or steps described herein. The novel algorithms described herein may also be efficiently implemented in software and/or embedded in hardware.

[51] It is to be understood that the specific order or hierarchy of steps in the methods disclosed is an illustration of exemplary processes. Based upon design preferences, it is

understood that the specific order or hierarchy of steps in the methods may be rearranged. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented unless specifically recited therein.

[52] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but are to be accorded the full scope consistent with the language of the claims, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." Unless specifically stated otherwise, the term "some" refers to one or more. A phrase referring to "at least one of" a list of items refers to any combination of those items, including single members. As an example, "at least one of: a, b, or c" is intended to cover: a; b; c; a and b; a and c; b and c; and a, b and c. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112(f) unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited using the phrase "step for."

CLAIMS

WHAT IS CLAIMED IS:

1. A method of constructing a polar code based on an information block, comprising:

providing a predetermined initial puncturing pattern;

calculating a final puncturing pattern by bit-reversal permutation of the initial puncturing pattern;

puncturing the information block utilizing the final puncturing pattern and generating a first LLR sum by considering the punctured bits as unknown bits;

puncturing the information block utilizing the final puncturing pattern and generating a second LLR sum by considering the punctured bits as known bits;

selecting between considering the punctured bits as unknown or known bits according to the greater LLR sum between the first LLR sum and the second LLR sum;

generating the polar code utilizing the selected puncturing; and

transmitting the polar code.

2. The method of claim 1, wherein the initial puncturing pattern comprises a uniform puncturing pattern.

3. The method of claim 1,

wherein the considering the punctured bits as unknown bits comprises setting an initial log likelihood ratio (LLR) for each punctured bit as infinity; and

wherein the generating the first LLR sum comprises:

performing density evolution or Gaussian approximation to obtain a bit error probability for each bit;

sorting channels according to a final LLR of each of the codeword bits;

selecting K best channels in accordance with the final LLR of each of the codeword bits, excluding channels corresponding to the punctured bits; and

calculating the sum of the final LLRs for all the information bits.

4. The method of claim 1,

wherein the considering the punctured bits as known bits comprises setting an initial log likelihood ratio (LLR) for each punctured bit as zero; and

wherein the generating the second LLR sum comprises:

performing density evolution or Gaussian approximation to obtain a bit error probability for each bit;

sorting channels according to a final LLR of each of the codeword bits;

selecting K best channels in accordance with the final LLR of each of the codeword bits; and

calculating the sum of the final LLRs for all the information bits.

5. The method of claim 1, further comprising transmitting an explicit indication of the selected puncturing along with the transmitted polar code.

6. A method of decoding a polar code, comprising:

receiving a polar coded information transmission;

determining whether punctured bits in the polar coded information transmission are considered known bits or unknown bits;

setting an initial log likelihood ratio (LLR) as zero if the punctured bits are considered unknown bits, or as infinity if the punctured bits are considered known bits; and

performing successive cancellation decoding of the received polar coded information transmission.

7. The method of claim 6, wherein the determining whether the punctured bits are considered known bits or unknown bits comprises:

receiving an explicit indication of the selected puncturing.

8. The method of claim 6, wherein the determining whether the punctured bits are considered known bits or unknown bits comprises:

receiving one or more parameters corresponding to channel coding of the polar code; and

deriving whether the punctured bits are considered known bits or unknown bits in accordance with the one or more parameters.

9. The method of claim 8, wherein the one or more parameters comprise a coding rate, and wherein the deriving whether the punctured bits are considered known bits or unknown bits comprises determining that the punctured bits are considered known bits if the coding rate is greater than a coding rate threshold, and determining that the punctured bits are considered unknown bits if the coding rate is not greater than the coding rate threshold.

10. The method of claim 9, wherein the coding rate threshold is ½.

11. An apparatus configured for constructing a polar code based on an information block, the apparatus comprising:

a processor;
a memory communicatively coupled to the processor; and
a transceiver communicatively coupled to the processor,
wherein the processor is configured to:

provide a predetermined initial puncturing pattern;

calculate a final puncturing pattern by bit-reversal permutation of the initial puncturing pattern;

puncture the information block utilizing the final puncturing pattern and generating a first LLR sum by considering the punctured bits as unknown bits;

puncture the information block utilizing the final puncturing pattern and generating a second LLR sum by considering the punctured bits as known bits;

select between considering the punctured bits as unknown or known bits according to the greater LLR sum between the first LLR sum and the second LLR sum;

generate the polar code utilizing the selected puncturing; and

transmit the polar code.

12. An apparatus configured for decoding a polar code, comprising:

a processor;
a memory communicatively coupled to the processor; and
a transceiver communicatively coupled to the processor,
wherein the processor is configured to:

receive a polar coded information transmission;

determine whether punctured bits in the polar coded information transmission are considered known bits or unknown bits;

set an initial log likelihood ratio (LLR) as zero if the punctured bits are considered unknown bits, or as infinity if the punctured bits are considered known bits; and

perform successive cancellation decoding of the received polar coded information transmission.

13. A non-transitory computer-readable medium storing computer-executable code, comprising instructions for causing a processor to:

provide a predetermined initial puncturing pattern;

calculate a final puncturing pattern by bit-reversal permutation of the initial puncturing pattern;

puncture the information block utilizing the final puncturing pattern and generating a first LLR sum by considering the punctured bits as unknown bits;

puncture the information block utilizing the final puncturing pattern and generating a second LLR sum by considering the punctured bits as known bits;

select between considering the punctured bits as unknown or known bits according to the greater LLR sum between the first LLR sum and the second LLR sum;

generate the polar code utilizing the selected puncturing; and

transmit the polar code.

14. A non-transitory computer-readable medium storing computer-executable code, comprising instructions for causing a processor to:

receive a polar coded information transmission;

determine whether punctured bits in the polar coded information transmission are considered known bits or unknown bits;

set an initial log likelihood ratio (LLR) as zero if the punctured bits are considered unknown bits, or as infinity if the punctured bits are considered known bits; and

perform successive cancellation decoding of the received polar coded information transmission.

15. An apparatus configured for constructing a polar code based on an information block, the apparatus comprising:

means for providing a predetermined initial puncturing pattern;

means for calculating a final puncturing pattern by bit-reversal permutation of the initial puncturing pattern;

means for puncturing the information block utilizing the final puncturing pattern and generating a first LLR sum by considering the punctured bits as unknown bits;

means for puncturing the information block utilizing the final puncturing pattern and generating a second LLR sum by considering the punctured bits as known bits;

means for selecting between considering the punctured bits as unknown or known bits according to the greater LLR sum between the first LLR sum and the second LLR sum;

means for generating the polar code utilizing the selected puncturing; and

means for transmitting the polar code.

16. An apparatus configured for decoding a polar code, comprising:

means for receiving a polar coded information transmission;

means for determining whether punctured bits in the polar coded information transmission are considered known bits or unknown bits;

means for setting an initial log likelihood ratio (LLR) as zero if the punctured bits are considered unknown bits, or as infinity if the punctured bits are considered known bits; and

means for performing successive cancellation decoding of the received polar coded information transmission.

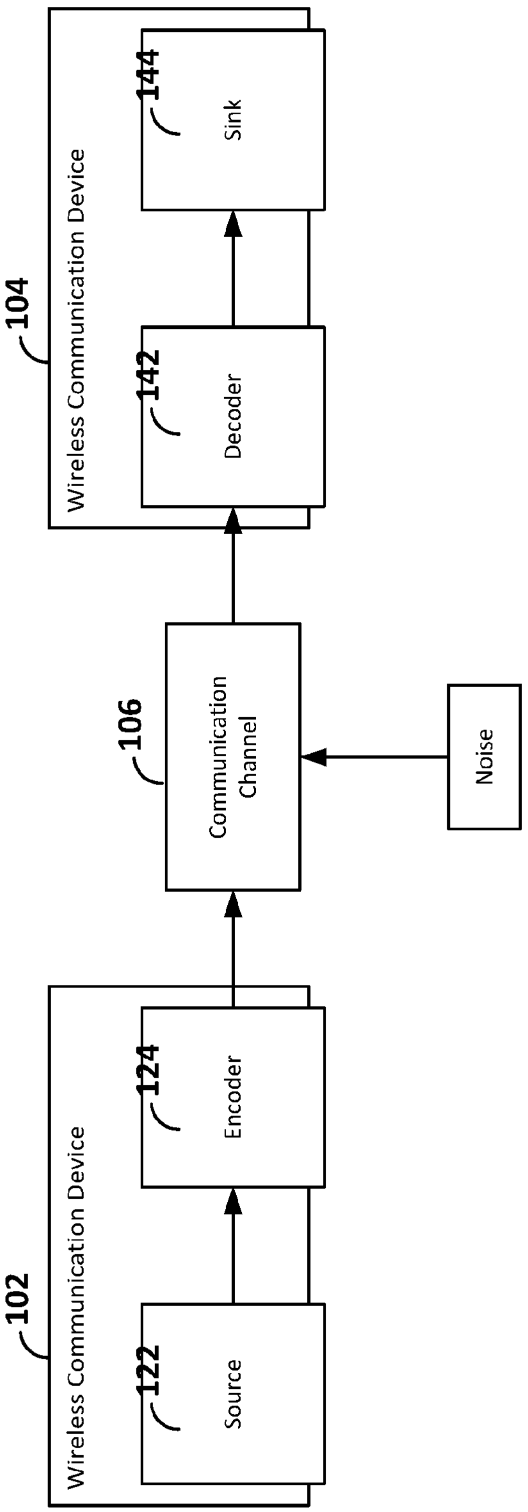
102
Wireless Communication Device
122
Source
124
Encoder
106
Communication Channel
Noise
104
Wireless Communication Device
142
Decoder
144
Sink

FIG. 1

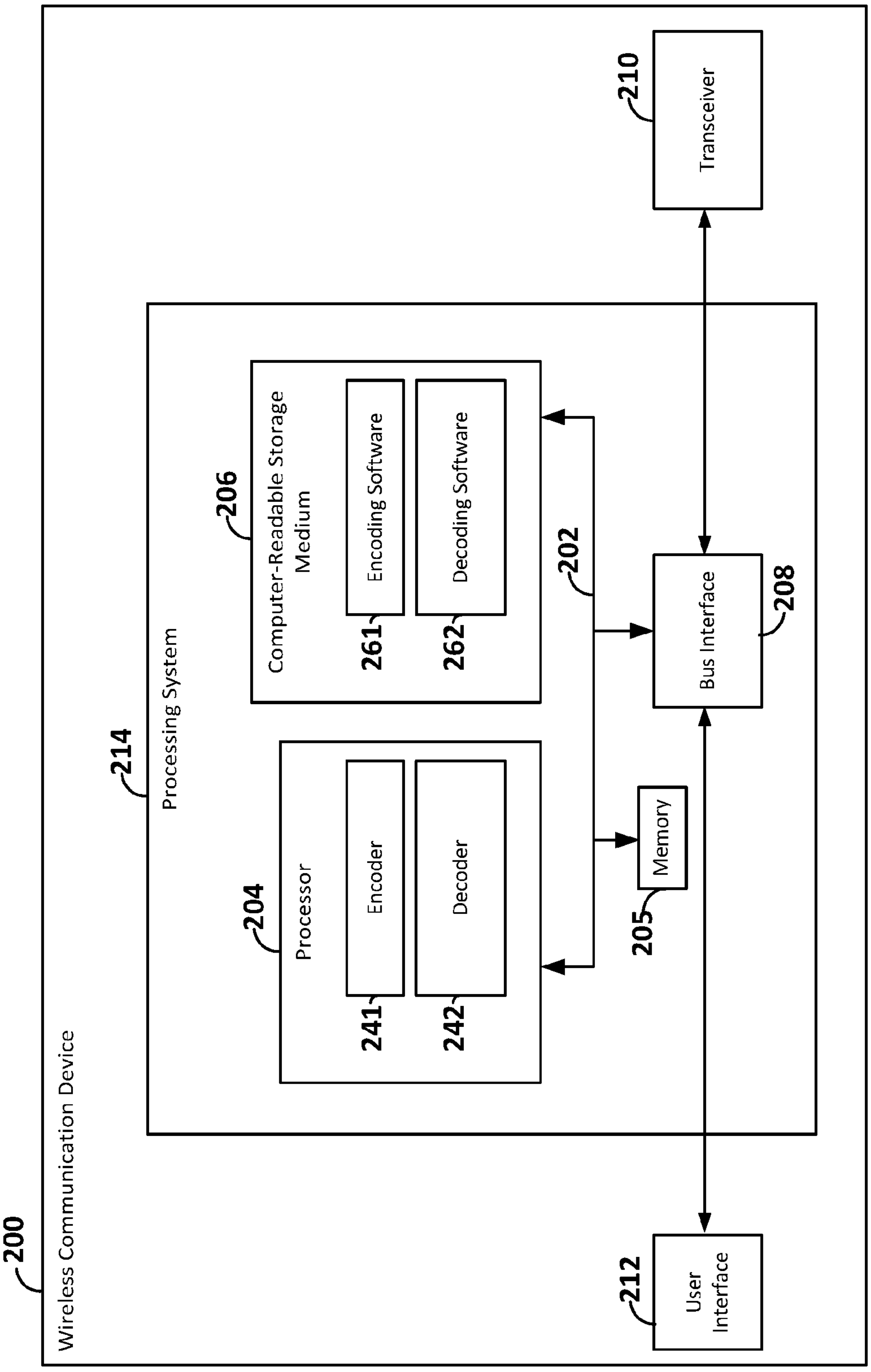
200
Wireless Communication Device
214
Processing System
204
Processor
Encoder
241
Decoder
242
206
Computer-Readable Storage Medium
Encoding Software
261
Decoding Software
262
202
205
Memory
208
Bus Interface
210
Transceiver
212
User Interface

FIG. 2

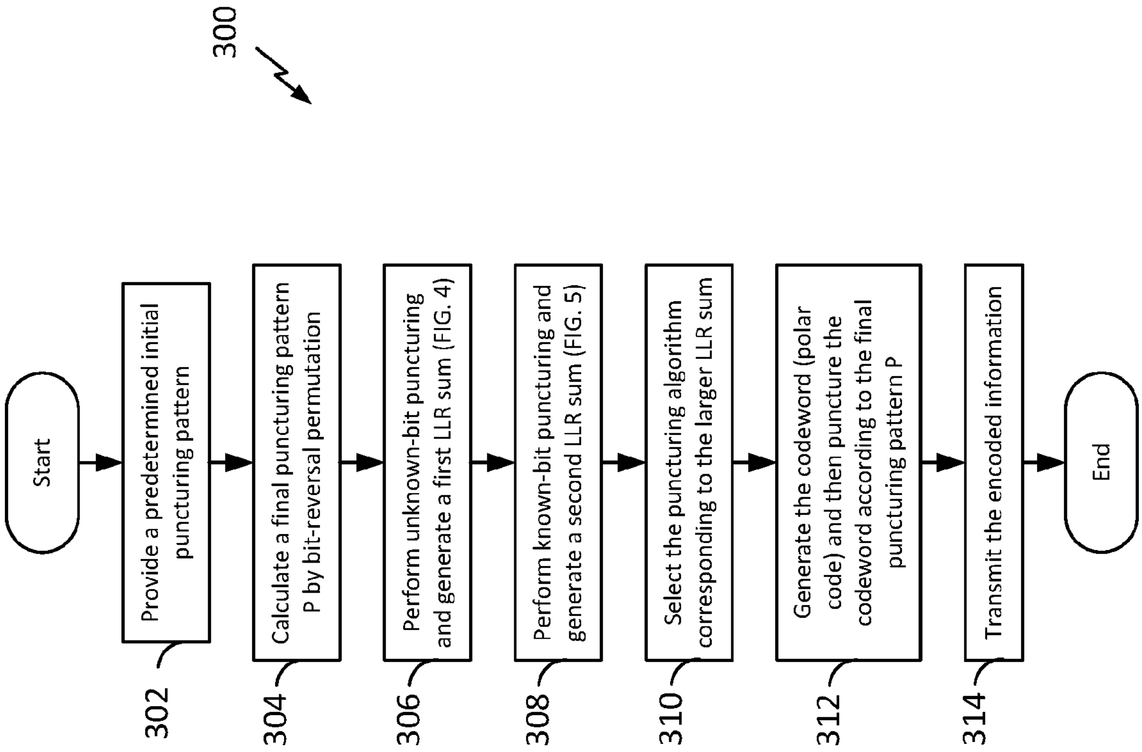
300
Start
Provide a predetermined initial puncturing pattern
302
Calculate a final puncturing pattern P by bit-reversal permutation
304
Perform unknown-bit puncturing and generate a first LLR sum (FIG. 4)
306
Perform known-bit puncturing and generate a second LLR sum (FIG. 5)
308
Select the puncturing algorithm corresponding to the larger LLR sum
310
Generate the codeword (polar code) and then puncture the codeword according to the final puncturing pattern P
312
Transmit the encoded information
314
End

FIG. 3

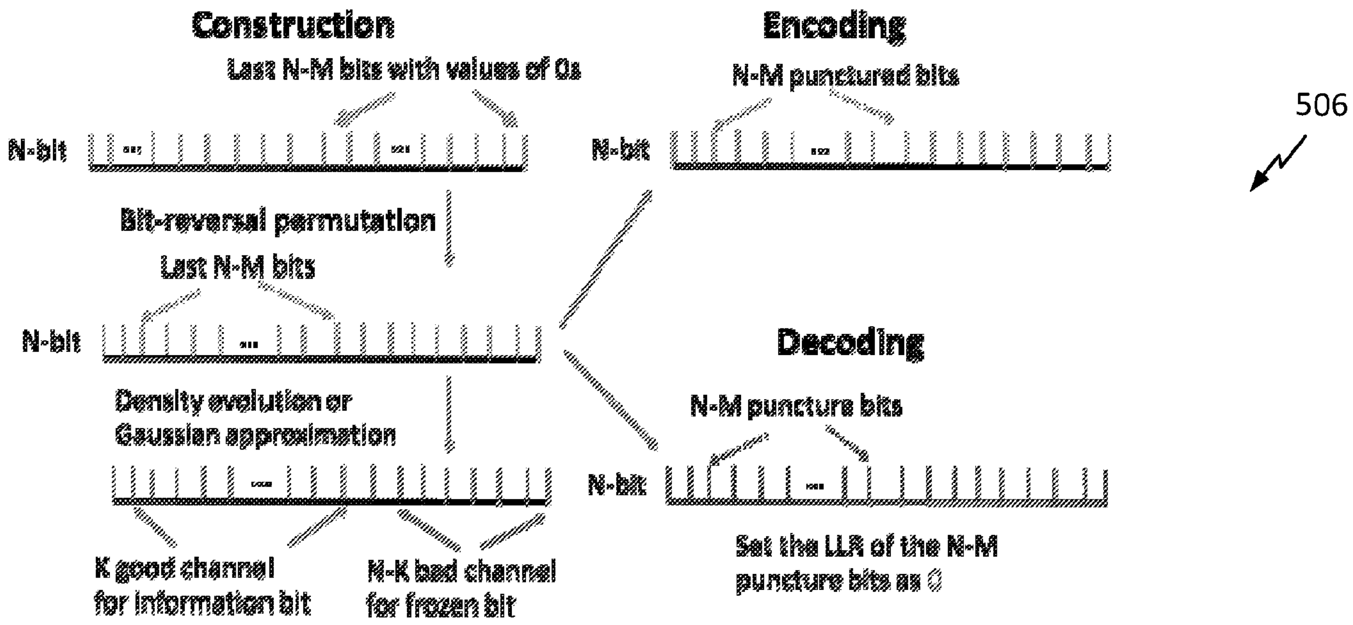

FIG. 4

Construction of Polar Code with
Punctured Bits as Unknown Bits

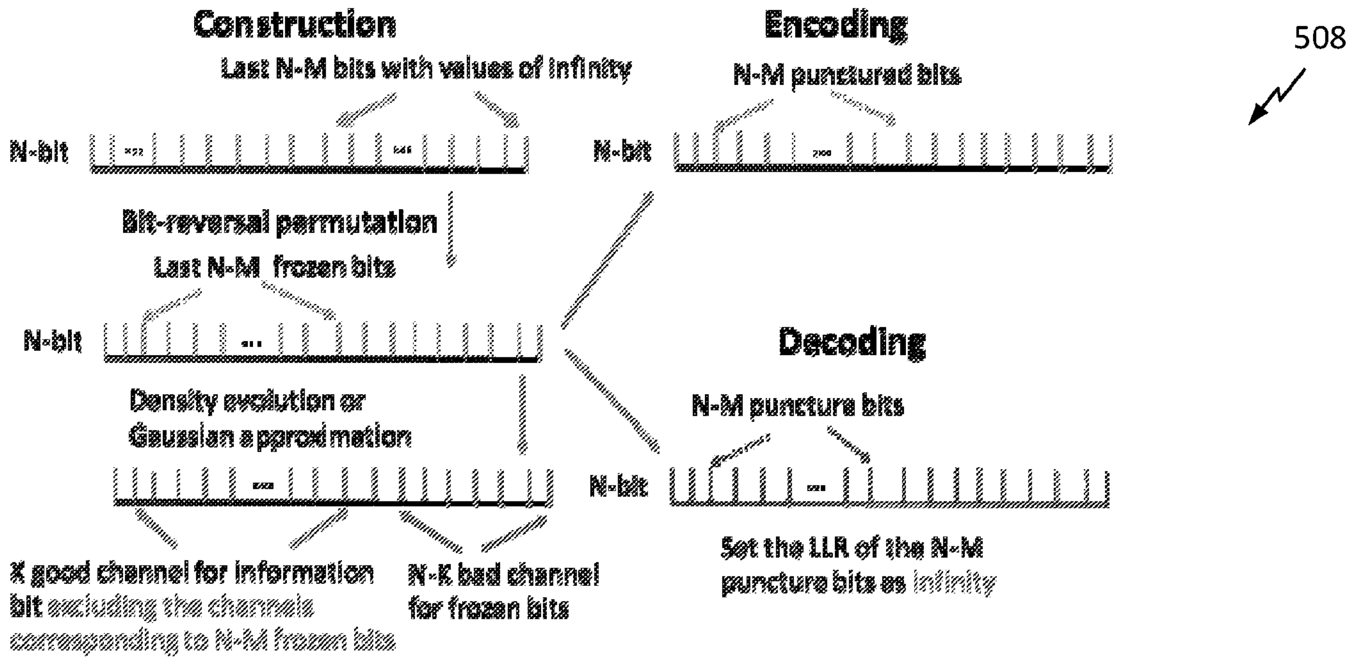

FIG. 5

Construction of Polar Code with Punctured Bits as Known Bits

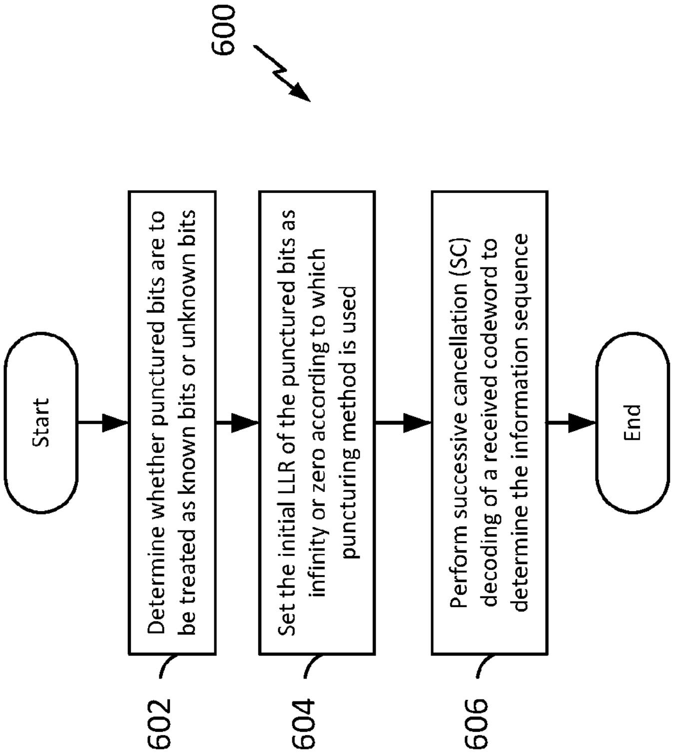
600
Start
Determine whether punctured bits are to be treated as known bits or unknown bits
602
Set the initial LLR of the punctured bits as infinity or zero according to which puncturing method is used
604
Perform successive cancellation (SC) decoding of a received codeword to determine the information sequence
606
End

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2016/071959

A. CLASSIFICATION OF SUBJECT MATTER

H04L 1/00(2006.01)i

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)

HO4L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USTXT;EPTXT;WOTXT;CNTXT;CNABS;VEN; IEEE: polar, puncture, LLR, log likelihood ratio, zero, infinity, known, unknown, bite, code

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 103023618 A (UNIV BEIJING POSTS & TELECOMM) 03 April 2013 (2013-04-03) the whole document	1-16
A	CN 103281166 A (UNIV BEIJING POSTS & TELECOMM) 04 September 2013 (2013-09-04) the whole document	1-16
A	CN 103414540 A (UNIV NANJING POSTS & TELECOMM) 27 November 2013 (2013-11-27) the whole document	1-16
A	CN 103778958 A (SAMSUNG ELECTRONICS CO LTD ET AL.) 07 May 2014 (2014-05-07) the whole document	1-16
A	US 2013343271 A1 (SAMSUNG ELECTRONICS CO LTD) 26 December 2013 (2013-12-26) the whole document	1-16

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:

"A"	document defining the general state of the art which is not considered to be of particular relevance	"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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search **22 September 2016**	Date of mailing of the international search report **10 October 2016**
Name and mailing address of the ISA/CN **STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA** **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	Authorized officer **SU,Qin**
Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)62089136**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2016/071959

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
CN 103023618 A	03 April 2013	CN 103023618 B	22 April 2015
CN 103281166 A	04 September 2013	CN 103281166 B	25 May 2016
CN 103414540 A	27 November 2013	None	
CN 103778958 A	07 May 2014	US 9239778 B2	19 January 2016
		EP 2722993 B1	10 June 2015
		KR 20140050152 A	29 April 2014
		EP 2722993 A1	23 April 2014
		US 2014108748 A1	17 April 2014
US 2013343271 A1	26 December 2013	WO 2013191435 A1	27 December 2013
		KR 20150023858 A	05 March 2015