

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
6 March 2008 (06.03.2008)

PCT

(10) International Publication Number
WO 2008/027613 A2

(51) International Patent Classification:
H04L 23/02 (2006.01)

(21) International Application Number:
PCT/US2007/065292

(22) International Filing Date: 27 March 2007 (27.03.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/841,446 30 August 2006 (30.08.2006) US
11/691,013 26 March 2007 (26.03.2007) US

(71) Applicant (for all designated States except US): **NAVINI NETWORKS, INC.** [US/US]; 2240 Campbell Creek Blvd., Suite 110, Richardson, TX 75082 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **HEDAYAT, Ahmadreza** [IR/US]; 1009 Bel Air Drive, Allen, TX 75013 (US). **JIN, Hang** [CA/US]; 3708 Stoneway Drive, Plano, TX 75025 (US).

(74) Agents: **CHEN, Howard** et al.; Kirkpatrick & Lockhart Preston Gates Ellis, LLP, 55 Second Street, Suite 1700, San Francisco, CA 94105 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- without international search report and to be republished upon receipt of that report

(54) Title: METHOD AND SYSTEM FOR IMPROVING THE PERFORMANCE OF A TRELLIS-BASED DECODER

(57) Abstract: The present invention discloses a method and system for improving the performance of a trellis-based decoder. The method comprises generating a first state with reduced uncertainty (SRU) and one or more second SRUs with one or more predetermined fields in a message; setting metrics of one or more states in the first SRU, which have an equal probability, to a first predetermined value; setting metrics of one or more states that are not in the first SRU to a second predetermined value, which corresponds to a minimum probability; and decoding the message while eliminating invalid candidate paths in a trellis by setting the metrics of the one or more states not belonging to the one or more second SRUs to a value corresponding to the second predetermined value.



WO 2008/027613 A2

METHOD AND SYSTEM FOR IMPROVING THE PERFORMANCE OF A TRELLIS-BASED DECODER

CROSS REFERENCE

[0001]The present application claims the benefit of U.S. Provisional Application Serial 60/841,446, which was filed on 8/30/2006 and U.S. Patent Application entitled "METHOD AND SYSTEM FOR IMPROVING THE PERFORMANCE OF A TRELLIS-BASED DECODER" filed March 26, 2007.

BACKGROUND

[0002]Trellis codes, such as convolutional codes, trellis coded modulation, bit-interleaved coded modulations, and space-time trellis codes have been widely used to improve the performance of a wireless communications system. One important issue of encoding messages using trellis codes is how to terminate a trellis. There are at least two common methods of terminating a trellis.

[0003]The first method is to force the encoder of a transmitting wireless station to enter a known starting state and then to a known terminating state, e.g. a zero state, after the last data bit is shifted in. This is commonly referred to as a zero-padding (ZP) method. This method brings the trellis into a known terminating state by feeding the encoder with a series of zeros after all data bits are shifted into the encoder. The number of zeros is equal to the size of the memory. Feeding the encoder with a series of zeros resets the state back to zero.

[0004]The trellis code decoder of a receiving wireless station decodes a receiving message using the information about the starting and terminating states of the trellis. Knowing the starting and terminating states of a trellis simplifies the design of the decoder of a receiving wireless station. However,

the padding of zeros at the end of trellis codes results in additional overhead. This problem is especially significant when the message is of small size.

[0005] Another method to terminate a trellis is called tail-biting (TB). In TB, the encoder of a transmitting wireless station is forced to terminate the encoding of a message at a state that is the same as the starting state. Since the TB method does not pad a trellis-encoded message with extra zeros, it does not result in extra overhead. Because the TB method starts and terminates a trellis in the same state, which is unknown to the decoder, decoding the tail-biting trellis with a trellis-based decoder is computationally expensive.

[0006] A trellis-based decoder employing the Viterbi algorithm (VA) is a maximum likelihood (ML) decoder if the starting and terminating states of the message encoded with trellis codes are known.

[0007] Because the starting and terminating states in a tail-biting method are the same, the ML decoder runs the Viterbi algorithm in each state and selects the code sequence representing the message with the highest probability. The brute force decoding method runs the Viterbi algorithm as many times as the number of states is; therefore, it demands a lot of computational resources. To reduce the computational complexity of the ML decoder for tail-biting trellis codes, several sub-optimal trellis-based decoders have been developed.

[0008] As such, what is desired is a method and system for further improving the performance of sub-optimal trellis-based tail-biting decoders

SUMMARY

[0009] The present invention discloses a method and system for improving the performance of a trellis-based decoder. The method comprises generating a first

state with reduced uncertainty (SRU) associated with a predetermined field and one or more second SRUs associated one-to-one with one or more predetermined fields in a message; setting metrics of one or more states in the first SRU, which have an equal probability, to a first predetermined value; setting metrics of one or more states that are not in the first SRU to a second predetermined value, which corresponds to a minimum probability; and decoding the message while eliminating invalid candidate paths in a trellis by setting the metrics of the one or more states not belonging to the one or more second SRUs to a value corresponding to the second predetermined value.

[0010] The construction and method of operation of the invention, however, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

[0011] The drawings accompanying and forming part of this specification are included to depict certain aspects of the invention. The invention may be better understood by reference to one or more of these drawings in combination with the description presented herein. It should be noted that the features illustrated in the drawings are not necessarily drawn to scale.

[0012] FIGs 1A, 1B, and 1C illustrate a message with one predetermined field.

[0013] FIG. 2 illustrates a message with multiple predetermined fields.

[0014] FIG. 3 illustrates a message with a predetermined field and appended with additional bits of a predetermined value at the end of the message.

[0015] FIG. 4 is a flow diagram that depicts a way to improve the performance of a Viterbi decoder by using the information about one predetermined field of a message.

[0016] FIG. 5 is a flow diagram that depicts a way to improve the performance of a Viterbi decoder by using the information about multiple predetermined fields of a message.

[0017] FIG. 6 is a flow diagram that depicts a way to improve the performance of a Viterbi decoder by using the information about one predetermined field of a message which is convolutionally encoded using a zero-padding method.

[0018] FIG. 7 is a block diagram of a system in accordance with the present invention.

DESCRIPTION

[0019] The following detailed description of the invention refers to the accompanying drawings. The description includes exemplary embodiments, not excluding other embodiments, and changes may be made to the embodiments described without departing from the spirit and scope of the invention. The following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims.

[0020] The present invention discloses a method and system for improving the performance of suboptimal trellis-based decoders employing the Viterbi algorithm by incorporating the information about the structure of the messages in the decoding process. The present invention is applicable to all types of trellis-based decoders for tail-biting trellis code.

[0021] The method disclosed in the present invention takes advantage of the knowledge about a predetermined field in a message. The information is used

either to improve the performance of a decoder or to reduce the complexity of the decoder. The decoder proposed in the present invention is programmable, i.e., the decoder can decode messages with different types of predetermined fields of various lengths and at various locations.

[0022] The method disclosed in the present invention exploits the information about the structure of a message to improve the performance of a trellis-based decoder. One such structure is the control message of communication standards, such as IEEE 802.16 (WiMax), which usually includes predetermined fields of known sizes. The bits in a predetermined field are usually set to a predetermined value (e.g. zero).

[0023] FIGs. 1A, 1B, and 1C illustrate a message with just one predetermined field. In FIG. 1A, a predetermined field 110 is located at the end of a message while in FIG. 1B a predetermined field 120 is in the middle of a message. At first glance, the messages in FIG. 1A and FIG. 1B seem to have different structures. However, if the fields in the message in FIG. 1B are rotated till the predetermined field 130 is at the end of the message, as shown in FIG. 1C, a person having skills in the art would recognize that the two messages have the same structure.

[0024] A control message may have multiple predetermined fields at several locations in a message. FIG. 2 illustrates a message with multiple predetermined fields 210 and 220. FIG. 3 illustrates a message having a predetermined field 310 and appended additional bits 320 of a predetermined value at the end of the message.

[0025] In a WiMax wireless communications system, the FCH is convolutionally encoded using tail-biting termination. The encoder has six memory cells, which means that there are 64 possible states. In other words, the

starting or terminating state has a probability of $1/64$ being in any of the 64 states.

[0026] By knowing that there is a 4-bit predetermined field in the FCH, the disclosed method reduces the number of possible states of a trellis-based decoder. Assuming that the reserved bits in the predetermined field are all set to zero, the number of states is reduced to 4. By setting the four reserved bits to zero, the numbers representing the starting and terminating states are multiples of 16. In other words, the starting and terminating states are one or two of the following states - {0,16,32,48}.

[0027] The term "the state with reduced uncertainty" (SRU) refers to a set of states that are associated with a predetermined field. The maximum likelihood path passes through one of these states by the end of the predetermined field.

[0028] Each SRU is associated with a time instance determined by the location of the predetermined state. The values of the states in an SRU are determined by the values of the bits in predetermined fields. Effectively, the information about each predetermined field reduces the number of states that the maximum likelihood path might pass through at the end of the predetermined field. As a result, the probability that the maximum likelihood path passes through one of the states in the SRU increases and thus the uncertainty is reduced.

[0029] The actual value of a predetermined bit is inconsequential as long as it is known a priori by the decoder. The non-zero predetermined bits change the SRU, but its size remains intact. The performance improvement or complexity reduction only depends on the size of the SRU.

[0030] A decoder can use the SRU in various ways. For example, a trellis-based decoder for tail-biting (TB) trellis codes performs the VA algorithm only in the

states of the SRU rather than all possible states. In the example described above, the VA algorithm only needs to repeat four times rather than 64 times.

[0031] The level of reduction in the complexity of a decoder depends on the number of bits in a predetermined field in a message and the number of memory cells (equivalent to the number of states) of the trellis code. As a result, the trellis-based decoder for TB trellis codes does not guarantee that it always reduces the complexity to the same degree. However, it is possible to take advantage of the SRU in sub-optimal trellis-based decoders for TB trellis codes.

[0032] A trellis-based decoder for convolutional codes is modeled and evaluated based on the level of its complexity and performance. The information about the SRU can be used to either reduce the complexity or improve the performance of a decoder. It is feasible to devise a decoder with a tradeoff between the performance and complexity.

[0033] A sub-optimal trellis-based decoder for TB trellis codes improves its performance by using the SRU to reduce the uncertainty in the initialization process. Depending on the number of states of trellis codes and the length of a message, most sub-optimal trellis-based decoders for TB trellis codes perform the VA algorithm more than once over the whole length of the message or part of the message in order to achieve a level of performance close to that of an optimal trellis-based decoder for TB trellis codes. For a short message that has a trellis code with a large number of states, the VA algorithm may be performed over the whole message twice or three times.

[0034] After a trellis-based decoder initializes the states based on the information about the SRU, its complexity is reduced. The decoder achieves similar performance as an optimal trellis-based decoder for TB trellis codes does, but it performs the VA algorithm with fewer iterations.

[0035] For the SRU of small size, the trellis-based decoder could run the VA algorithm once and then traces back (i.e. terminates the decoder) from the state that has the best metric at the end of the trellis. In this case, the complexity of the decoder is reduced by some degree and the level of performance is also improved to some degree.

[0036] FIG. 4 is a flow diagram that depicts a way to improve the performance of a trellis-based decoder by using the information about one predetermined field of a message in accordance with the method disclosed in the present invention.

[0037] The message structure is described in FIG. 1A and FIG. 1B. In step 410, the metric of a state in a trellis-based decoder is set depending on whether it is in the SRU. The states in the SRU are assigned with the same metric, i.e. zero. This is equivalent to making the probabilities of all the states in the SRU equal. Let the probabilities of the other states be set to the minimum or the largest negative number in logarithmic metric calculations.

[0038] In step 420, the location (time instance) of an encoded message sequence is selected. Because the message is terminated using a tail-biting method, the trellis representing the message is circular. In other words, the decoding algorithm such as the VA continues onto the beginning of the message after the end of the message is approached. Because of this property, the decoding process can start at any location in the encoded message sequence. This explains why FIG. 1A and FIG. 1B are deemed equivalent from a TB decoding perspective (see FIG. 1C).

[0039] In step 430, the decoding process starts from the selected location. The decoding process continues until the message is decoded and the terminating state of the decoder coincides with the starting state. Taking advantage of the

SRU, the decoding process can start from the field next to the right of the predetermined field.

[0040] FIG. 5 is a flow diagram that depicts a way to improve the performance of a trellis-based decoder by using the information about multiple predetermined fields of a message in accordance with the method disclosed in the present invention. The message structure is described in FIG. 2.

[0041] In step 510, multiple SRUs are generated. Each of the SRUs corresponds to one predetermined field. In step 520, one of the SRUs is selected as the primary SRU. Because the location and the size of each of the multiple predetermined fields are known to the trellis-based decoder, the trellis-based decoder can use this additional information to further improve the performance of the decoding process. One way to utilize the information about the structure of the message is to select a SRU with the smallest size.

[0042] Assume that there are two predetermined fields with predetermined bits K_1 and K_2 , and $K_2 > K_1$. Let SRU_1 represent a reduced set of states corresponding to the first predetermined field. Let SRU_2 represent a reduced set of states corresponding to the second predetermined field. Because SRU_2 is the smaller of the two, tail-biting decoding is performed based on SRU_2 .

[0043] The metric of a state in the trellis-based decoder is set depending on whether it is in SRU_2 . Each of the states in SRU_2 is assigned the same metric, i.e., zero. This is equivalent to making the probabilities of all the states in SRU_2 equal. Let the probabilities of the other states be set to the minimum or the largest negative number in logarithmic metric calculations.

[0044] Step 530 shows that at a predetermined time instance, the trellis-based decoder sets the metrics of the states that do not belong to SRU_1 in such a way that the probabilities of these states are the minimum. This is equivalent to

setting such states to the smallest number, or the largest negative number in logarithmic metric calculations. This action effectively prunes the trellis to eliminate the invalid candidate paths. This is because the maximum likelihood path must pass through one of the states that belong to SRU_1 at the predetermined time instance.

[0045] In step 540, the decoding process continues until the message is decoded and the terminating state of the decoder coincides with the starting state.

[0046] FIG. 6 is a flow diagram that depicts a way to improve the performance of a trellis-based decoder by using the information about one predetermined field of a message, which is convolutionally encoded using a zero-padding in accordance with the method disclosed in the present. The message is appended with bits of a predetermined value at the end of the message. The message structure is described in FIG. 3.

[0047] In step 610, a zero-padding method is applied to the message by inserting M zero bits at the end of the message. The size of the memory cells of the trellis code is M . In essence, the M zero tail bits create an SRU with a size of one, and the only element in the SRU is the all-zero state.

[0048] In step 620, the trellis-based decoder employs a conventional VA algorithm to decode the encoded message. In step 630, the trellis-based decoder sets the metric of a state to the smallest number or the largest negative number in logarithmic metric calculations, depending on whether it is in the SRU at a predetermined time instance. This action effectively prunes the trellis to eliminate the invalid paths. As a result, the performance of the trellis-based decoder is further improved.

[0049] In step 640, the decoding process continues until the message is decoded and the termination state of the trellis-based decoder coincides with the starting state.

[0050] FIG. 7 is a block diagram of a system in accordance with the present invention. The system is composed of a parser module 710, an SRU module 720, and a trellis-based decoder 730.

[0051] The parser module 710 identifies one or more predetermined fields in a message with a known value using the knowledge of the structure of the message. The means 720 generates one or more sets of states with reduced uncertainty (SRUs) based on the values of one or more predetermined fields.

[0052] The trellis-based decoder 730 initializes the states based on the information about the SRU of the smallest size and sets the metrics of the states in the SRU in such a way that the probabilities of the states are equal. The trellis-based decoder 730 selects a starting state, which could be any state in the encoded message sequence. Because the encoded message is terminated using a tail-biting method, the trellis representing the message is circular. The trellis-based decoder 730 prunes the trellis to eliminate the invalid paths while decoding the message by setting the metrics of the states that are not in the SRU in such a way that the probabilities of the states are the minimum.

[0053] The above illustration provides many different embodiments or embodiments for implementing different features of the invention. Specific embodiments of components and processes are described to help clarify the invention. These are, of course, merely embodiments and are not intended to limit the invention from that described in the claims.

[0054] Although the invention is illustrated and described herein as embodied in one or more specific examples, it is nevertheless not intended to be limited to

the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention, as set forth in the following claims.

WHAT IS CLAIMED IS:

1. A method for improving the performance of a trellis-based decoder, the method comprising:

generating first states with reduced uncertainty (SRU) and one or more second SRUs with one or more predetermined fields in a message;

setting metrics of one or more states in the first SRU, which have an equal probability, to a first predetermined value;

setting metrics of one or more states that are not in the first SRU to a second predetermined value, which corresponds to a minimum probability; and

decoding the message while eliminating invalid candidate paths in a trellis by setting the metrics of the one or more states not belonging to the one or more second SRUs to a value corresponding to the second predetermined value.

2. The method of claim 1, wherein the first SRU and the one or more second SRUs correspond to one or more predetermined fields respectively.
3. The method of claim 1, wherein generating the first SRU and the one or more second SRUs depends on the knowledge of the one or more predetermined fields with known values in the message.
4. The method of claim 3, wherein one or more predetermined fields with known values in the message comprising additional bits appended to the message by a zero-padding method.
5. The method of claim 4, wherein the known values of one or more predetermined fields are inconsequential as long as they are known prior by the decoder.

6. The method of claim 1, wherein the first predetermined value equals zero.
7. The method of claim 1, wherein the second predetermined value equals the largest negative number in logarithmic metric calculations.
8. A method for improving the performance of a trellis-based decoder, the method comprising:

generating a first states with reduced uncertainty (SRU) and one or more second SRUs with one or more predetermined fields in a message, which correspond to one or more predetermined fields respectively;

setting metrics of one or more states in the first SRU to a first predetermined value, which equals zero, so that the one or more states have equal probability;

setting metrics of one or more states that are not in the first SRU to a second predetermined value, which corresponds to a minimum probability; and

decoding the message while eliminating invalid candidate paths in a trellis by setting the metrics of the one or more states not belonging to the one or more second SRUs to a value corresponding to the second predetermined value.

9. The method of claim 8, wherein generating the first SRU and the one or more second SRUs depends on the knowledge of the one or more predetermined fields with known values in the message.
10. The method of claim 9, wherein the one or more predetermined fields with known values in the message comprise additional bits appended to the message by a zero-padding method.

11. The method of claim 10, wherein the known values of one or more predetermined fields are inconsequential as long as they are known prior by the decoder.

12. The method of claim 8, wherein the second predetermined value equals the largest negative number in logarithmic metric calculations.

13. A trellis based decoder, the system comprising:

a parser module identifying one or more predetermined fields in a message;

a states with reduced uncertainty (SRU) module generating a first states with reduced uncertainty (SRU) and one or more second SRUs; and

a decoder module decoding the message while eliminating invalid candidate paths in a trellis;

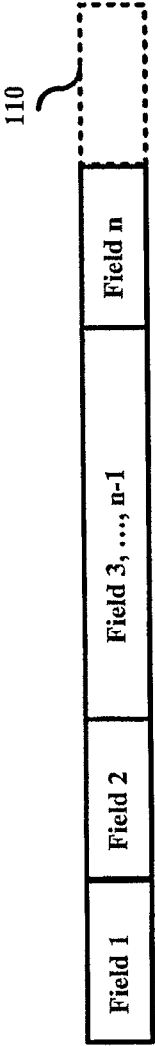
wherein the parser module identifies one or more predetermined fields with a known value using the knowledge of the structure of the message, and the SRU module generates the first SRU and the one or more second SRUs based on the values of the one or more predetermined fields.

14. The trellis-based decoder of claim 13, wherein the one or more predetermined fields in the message comprise additional bits appended to the message by a zero-padding method.

15. The trellis-based decoder of claim 13, wherein the first SRU and the one or more second SRUs correspond to one or more predetermined fields respectively.

16. The trellis-based decoder of claim 13, wherein the SRU module sets metrics of one or more states in the first SRU to a value equals to zero so that the one or more states have equal probability.

17. The trellis-based decoder of claim 13, wherein the SRU module sets metrics of one or more states that are not in the first SRU to a value corresponding to a minimum probability.
18. The trellis-based decoder of claim 13, wherein the decoder module decodes the message by eliminating invalid candidate paths in a trellis by setting the metrics of the one or more states not belonging to the one or more second SRUs to a value corresponding to a minimum probability.



100

FIG. 1A

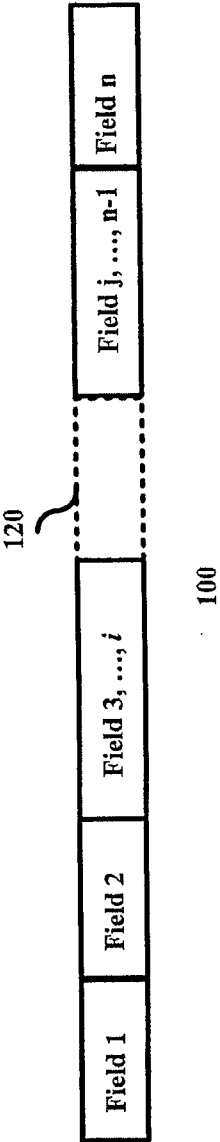


FIG. 1B

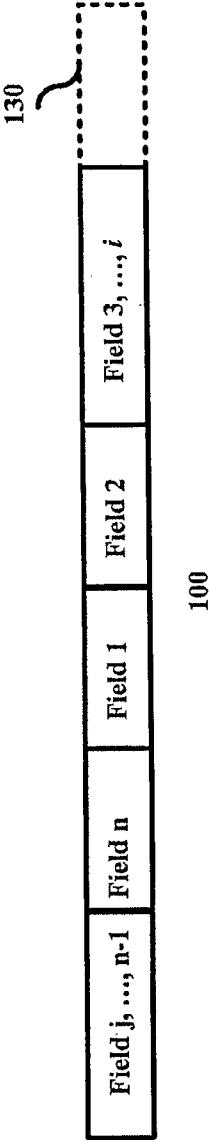


FIG. 1C

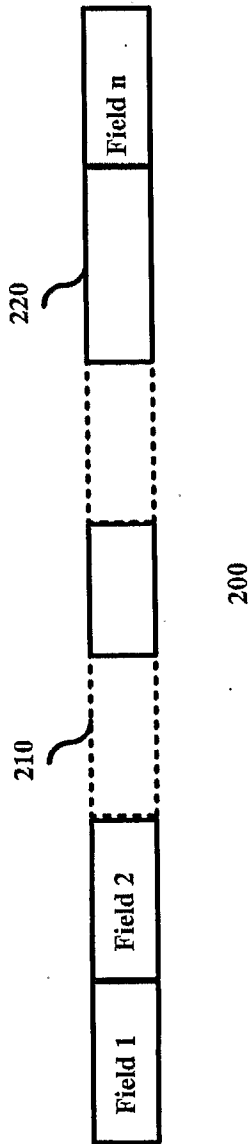


FIG. 2

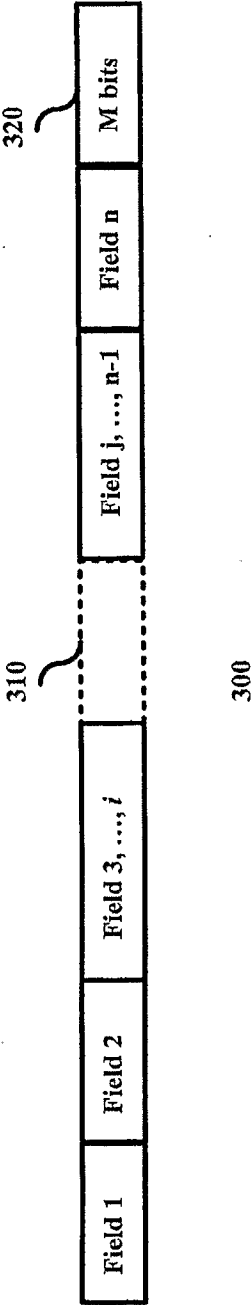


FIG. 3

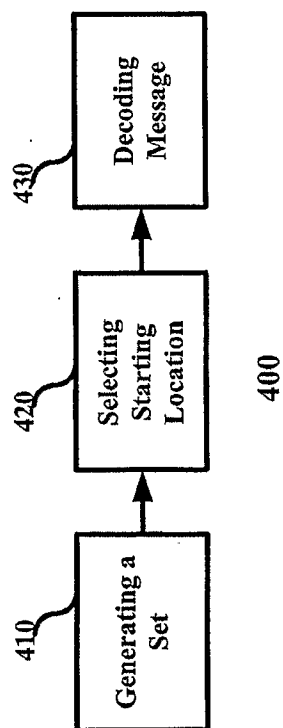


FIG. 4

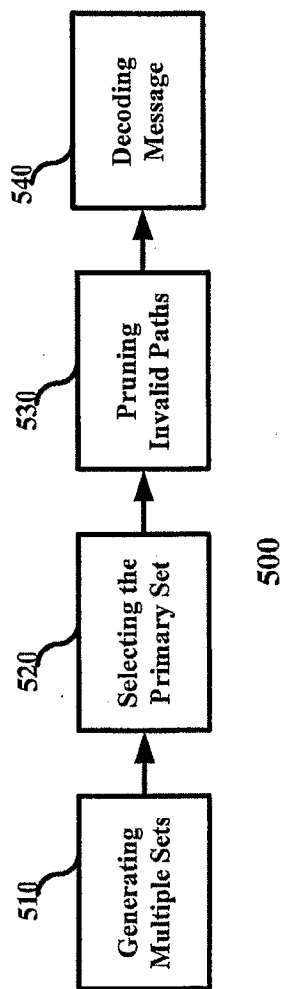
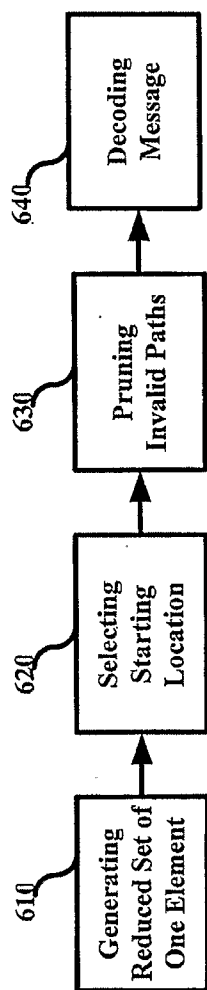


FIG. 5



600

FIG. 6

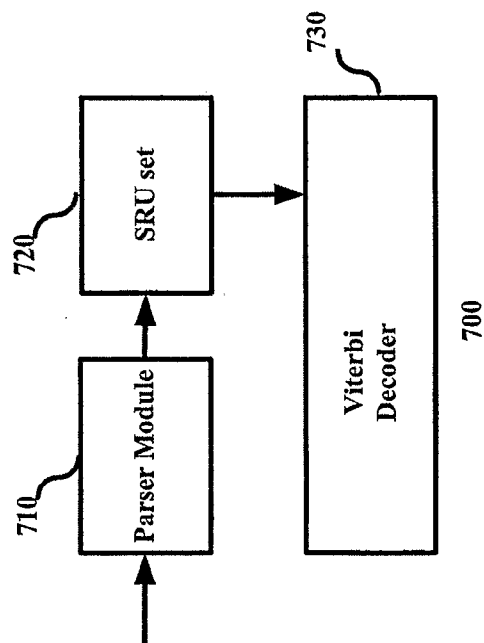


FIG. 7