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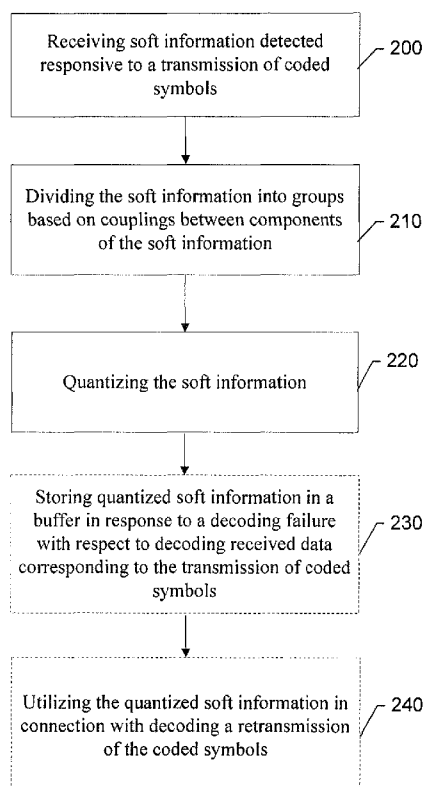
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(54) Title: METHOD AND APPARATUS FOR PROVIDING QUANTIZATION AND CODING OF GROUPINGS OF SOFT INFORMATION



(57) Abstract: An apparatus for providing quantization and coding of groupings of soft information may include at least one processor and at least one memory including computer program code. The at least one memory and the computer program code may be configured, with the processor, to cause the apparatus to perform at least receiving soft information detected responsive to a transmission of coded symbols, dividing the soft information into groups based on couplings between components of the soft information, and quantizing the soft information. A corresponding method and computer program product are also provided.

FIG. 7.



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METHOD AND APPARATUS FOR PROVIDING QUANTIZATION AND CODING OF GROUPINGS OF SOFT INFORMATION

TECHNOLOGICAL FIELD

Embodiments of the present invention relate generally to communication technology and, more particularly, relate to an apparatus, method and a computer program product for providing quantization and coding of groupings of soft information.

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BACKGROUND

The modern communications era has brought about a tremendous expansion of wireline and wireless networks. Computer networks, television networks, and telephony networks are experiencing an unprecedented technological expansion, fueled by consumer demand. Wireless and mobile networking technologies have addressed related consumer demands, while providing more flexibility and immediacy of information transfer.

Current and future networking technologies continue to facilitate ease of information transfer and convenience to users. In order to provide easier or faster information transfer and convenience, telecommunication industry service providers are developing improvements to existing networks. For example, the evolved universal mobile telecommunications system (UMTS) terrestrial radio access networks (UTRAN and E-UTRAN), WiMAX (worldwide interoperability for microwave access), HSPA (high speed packet access), WLAN (wireless local area network) and the GERAN (GSM (global system for mobile communications)/EDGE (enhanced data rates for GSM evolution) radio access network) system are currently being developed. The E-UTRAN, which is also known as Long Term Evolution (LTE) or 3.9G, is aimed at upgrading prior technologies by improving efficiency, lowering costs, improving services, making use of new spectrum opportunities, and providing better integration with other open standards. These and many other communication networks, employ base stations or access points that are connected to a network in order to wirelessly communicate with wireless communication

devices that may be distributed throughout a coverage area of a given base station or access point.

The wireless communication networks described above, and others like them, are generally aimed at providing wireless communication to mobile users. Some of the improvements made in connection with some or all of the above networks are aimed at providing ever higher data rates to end users using potentially hostile propagation channels. In order to achieve these aims, some of the systems feature mechanisms that adapt the data rate to the current channel conditions so that, for example, the data rate can be lowered if a signal is weaker than expected.

One example of this type of data rate adaptation has been implemented in connection with the hybrid automatic repeat request (HARQ) error control method. However, given that network resources are limited or have associated costs, it may be desirable to improve or otherwise modify existing solutions to provide performance gains in consideration of the costs in terms of network resources.

BRIEF SUMMARY OF EXEMPLARY EMBODIMENTS

A method and apparatus are therefore provided that may enable the provision of improved network performance in terms of balancing cost considerations with performance criteria. In this regard, for example, some embodiments of the present invention may provide for a mechanism by which couplings between soft information recovered from a received signal may be used along with quantization in order to provide recovery of transmitted bits with good accuracy while using relatively less memory resources.

In one exemplary embodiment, a method of providing quantization and coding of groupings of soft information is provided. The method may include receiving soft information detected responsive to a transmission of coded symbols, dividing the soft information into groups based on couplings between components of the soft information, and quantizing the soft information.

In another exemplary embodiment, a computer program product for providing quantization and coding of groupings of soft information is provided. The computer program product may include at least one computer-readable storage medium having computer-executable program code instructions stored therein. The computer-executable program code instructions may include program code instructions for receiving soft information detected responsive to a transmission of coded symbols, dividing the soft information into groups based on couplings between components of the soft information, and quantizing the soft information.

In another exemplary embodiment, an apparatus for providing quantization and coding of groupings of soft information is provided. The apparatus may include at least one processor and at least one memory including computer program code. The at least one memory and the computer program code may be configured, with the processor, to cause the apparatus to perform at least receiving soft information detected responsive to a transmission of coded symbols, dividing the soft information into groups based on couplings between components of the soft information, and quantizing the soft information.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 illustrates one example of a communication system according to an exemplary embodiment of the present invention;

FIG. 2 illustrates a schematic block diagram of an apparatus for providing quantization and coding of groupings of soft information according to an exemplary embodiment of the present invention;

FIG. 3 illustrates a schematic block diagram of a system in which an example embodiment of the present invention may be employed;

FIG. 4 illustrates a schematic block diagram of a quantization function for providing quantization and coding of groupings of soft information according to an exemplary embodiment of the present invention;

FIG. 5 illustrates a schematic block diagram of a quantization function for providing quantization and coding of groupings of soft information according to an alternative exemplary embodiment of the present invention;

FIG. 6 illustrates a scatter plot of log likelihood ratios (LLRs) derived from an example modulation showing coupling between LLRs in accordance with an exemplary embodiment of the present invention;

FIG. 7 illustrates a flowchart of a method of providing quantization and coding of groupings of soft information in accordance with an exemplary embodiment of the present invention;

FIG. 8 illustrates a more detailed flowchart of an alternative method of providing quantization and coding of groupings of soft information in accordance with an exemplary embodiment of the present invention; and

FIG. 9 illustrates a more detailed flowchart of another alternative method of providing quantization and coding of groupings of soft information in accordance with an exemplary embodiment of the present invention.

DETAILED DESCRIPTION

Some embodiments of the present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all
5 embodiments of the invention are shown. Indeed, various embodiments of the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like reference numerals refer to like elements throughout. As used herein, the terms “data,” “content,” “information” and
10 similar terms may be used interchangeably to refer to data capable of being transmitted, received and/or stored in accordance with embodiments of the present invention. Moreover, the term “exemplary”, as used herein, is not provided to convey any qualitative assessment, but instead merely to convey an illustration of an example. Thus, use of any such terms should not be taken to limit the spirit and scope of embodiments of the
15 present invention.

Additionally, as used herein, the term ‘circuitry’ refers to (a) hardware-only circuit implementations (e.g., implementations in analog circuitry and/or digital circuitry); (b) combinations of circuits and computer program product(s) comprising software and/or
20 firmware instructions stored on one or more computer readable memories that work together to cause an apparatus to perform one or more functions described herein; and (c) circuits, such as, for example, a microprocessor(s) or a portion of a microprocessor(s), that require software or firmware for operation even if the software or firmware is not physically present. This definition of ‘circuitry’ applies to all uses of this term herein, including in any claims. As a further example, as used herein, the term ‘circuitry’ also
25 includes an implementation comprising one or more processors and/or portion(s) thereof and accompanying software and/or firmware. As another example, the term ‘circuitry’ as used herein also includes, for example, a baseband integrated circuit or applications processor integrated circuit for a mobile phone or a similar integrated circuit in a server, a cellular network device, other network device, and/or other computing device.

30 Some embodiments of the present invention may provide a mechanism by which improvements may be experienced in relation to efficient resource utilization in a communication network. In a communication network employing a data rate adaptation system such as, for example, a Hybrid Automatic Repeat reQuest (HARQ) system, some embodiments of the present invention may provide for grouping soft information and
35 quantization of data prior to storage of the quantized data in a storage buffer (e.g., a HARQ buffer) to enable usage of a smaller buffer to achieve good quality data decoding

performance. In this regard, in a typical communication system, bits of information that are to be transmitted may initially be encoded by an encoder prior to mapping of the encoded bits into symbols for transmission. The symbols may then be transmitted and received by a receiver that recovers "soft information", i.e. probabilistic information about the data. The soft information may be generated based on the received symbols that may have been modified by the addition of noise in the transmission channel used to transmit the symbols. The soft information, in general, may include an indication of each received value and the corresponding uncertainty associated with each respective value. In some examples, "soft bits", also called LLRs, may be used to present the soft information. Soft bits may include the detected bit value and an indication of the uncertainty associated with the detected bit value. However, soft bits are merely one example of a mechanism by which soft information may be conveyed.

In some current systems, received soft information is stored in a HARQ buffer for combining with any retransmissions in the event of a decoding failure. The HARQ buffers typically used are relatively large as there may be a significant amount of memory required to store the soft information. Moreover, the soft information is typically stored in the HARQ buffer using some form of scalar soft bit quantization and compression that entails coding individual soft bits without exploitation of any potential coupling between the soft bits. As such, the size of the HARQ buffer typically increases as the maximum data rate of the system increases. Thus, for high data rate systems that are envisioned for future networks, potentially large and high cost HARQ buffers or other memory devices may be required.

Some embodiments of the present invention provide a mechanism for performing lossy compression jointly involving groups of soft information that take advantage of couplings between components of the soft information (e.g., couplings between soft bits). In some cases, embodiments of the present invention may provide for grouping of soft information based on couplings between components of the soft information in connection with quantization prior to storing the soft information in a buffer for combining to any further transmissions. However, since the couplings between components of the soft information (or groupings of soft information) may be utilized, the soft information may be jointly coded such that, for example, soft bits belonging to a single symbol of a higher-order modulation may be grouped together prior to employing vector quantization and coding with respect to the coupled or grouped soft information. By utilizing couplings between soft bits, a reduction in the amount of storage space associated with the HARQ buffer may be realized.

FIG. 1 illustrates a generic system diagram in which a device such as a mobile terminal 10, which may benefit from embodiments of the present invention, is shown in an

exemplary communication environment. In this regard, the mobile terminal 10 may be configured to provide quantization and coding of groupings of soft information in accordance with an exemplary embodiment. As shown in FIG. 1, an embodiment of a system in accordance with an example embodiment of the present invention may include

5 a first communication device (e.g., mobile terminal 10) and a second communication device 20 capable of communication with each other. In an exemplary embodiment, the mobile terminal 10 and the second communication device 20 may be in communication with each other via a network 30. In some cases, embodiments of the present invention may further include one or more network devices with which the mobile terminal 10

10 and/or the second communication device 20 may communicate to provide, request and/or receive information. The network devices may include, for example, one or more servers, base stations, access points, gateways, communication controllers or other computers configured to perform various functions. In some cases, embodiments of the present invention may also or alternatively be practiced on one or more of the network devices.

15 It should be noted that although FIG. 1 shows a communication environment that may support client/server application execution, in some embodiments, the mobile terminal 10 and/or the second communication device 20 may employ embodiments of the present invention without any network communication, but instead via a direct communication link between the mobile terminal 10 and the second communication

20 device 20. As such, for example, applications executed locally at the mobile terminal 10 and served to the second communication device 20 via a direct wired or wireless link may also benefit from embodiments of the present invention. However, it should be noted that communication techniques such as those described herein can be used not only in embedded devices, but in desktops and servers as well.

25 The network 30, if employed, may include a collection of various different nodes, devices or functions that may be in communication with each other via corresponding wired and/or wireless interfaces. As such, the illustration of FIG. 1 should be understood to be an example of a broad view of certain elements of the system and not an all inclusive or detailed view of the system or the network 30. One or more communication

30 terminals such as the mobile terminal 10 and the second communication device 20 may be in communication with each other via the network 30 or via device to device (D2D) communication and each may include an antenna or antennas for transmitting signals to and for receiving signals from a base site, which could be, for example a base station that is a part of one or more cellular or mobile networks or an access point that may be

35 coupled to a data network, such as a local area network (LAN), a metropolitan area network (MAN), and/or a wide area network (WAN), such as the Internet. In turn, other devices such as processing elements (e.g., personal computers, server computers or the

like) may be coupled to the mobile terminal 10 and/or the second communication device 20 via the network 30. By directly or indirectly connecting the mobile terminal 10 and/or the second communication device 20 and other devices to the network 30 or to each other, the mobile terminal 10 and/or the second communication device 20 may be
5 enabled to communicate with the other devices or each other, for example, according to numerous communication protocols including Hypertext Transfer Protocol (HTTP) and/or the like, to thereby carry out various communication or other functions of the mobile terminal 10 and the second communication device 20, respectively.

Furthermore, although not specifically shown in FIG. 1, the mobile terminal 10 and
10 the second communication device 20 may communicate in accordance with, for example, radio frequency (RF), Bluetooth (BT), Infrared (IR) or any of a number of different wireline or wireless communication techniques, including LAN, wireless LAN (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), WiFi, ultra-wide band (UWB), Wibree techniques and/or the like. As such, the mobile terminal 10 and the second
15 communication device 20 may be enabled to communicate with the network 30 and each other by any of numerous different access mechanisms. For example, mobile access mechanisms such as wideband code division multiple access (W-CDMA), CDMA2000, global system for mobile communications (GSM), LTE, general packet radio service (GPRS) and/or the like may be supported as well as wireless access mechanisms such
20 as WLAN, WiMAX, and/or the like and fixed access mechanisms such as digital subscriber line (DSL), cable modems, Ethernet and/or the like.

In example embodiments, the first communication device (e.g., the mobile terminal 10) may be a mobile communication device such as, for example, a personal digital assistant (PDA), wireless telephone, mobile computing device, camera, video
25 recorder, audio/video player, positioning device (e.g., global positioning system (GPS)), game device, television device, radio device, or various other like devices or combinations thereof. The second communication device 20 may also be a mobile device such as those listed above or other mobile or embedded devices, but could also be a fixed communication device in some instances. As such, the mobile terminal 10,
30 network device and/or the second communication device 20 may include, for example, processing circuitry that may include a processor and memory for storing instructions that are executable by the processor in order to cause the mobile terminal 10, network device and/or the second communication device 20, respectively, to perform corresponding operations that are defined by the instructions. In some cases, the processor of the
35 mobile terminal 10, network device and/or the second communication device 20 may be embodied as, include, or otherwise control processing hardware such as one or more

application specific integrated circuits (ASICs) that are configured to provide a corresponding specific functionality.

In an exemplary embodiment, the mobile terminal 10 may be configured to include or otherwise employ an apparatus according to an exemplary embodiment of the present invention. FIG. 2 illustrates a schematic block diagram of an apparatus for providing quantization and coding of groupings of soft information according to an exemplary embodiment of the present invention. An exemplary embodiment of the invention will now be described with reference to FIG. 2, in which certain elements of an apparatus 50 for providing quantization and coding of groupings of soft information are displayed. The apparatus 50 of FIG. 2 may be employed, for example, on a communication device (e.g., the mobile terminal 10) or a variety of other devices, such as, for example, any of the network or other devices listed above. However, it should be noted that the components, devices or elements described below may not be mandatory and thus some may be omitted in certain embodiments. Additionally, some embodiments may include further components, devices or elements beyond those shown and described herein.

Referring now to FIG. 2, the apparatus 50 may include or otherwise be in communication with a processor 70, a user interface 72, a communication interface 74 and a memory device 76. The memory device 76 may include, for example, one or more volatile and/or non-volatile memories. In other words, for example, the memory device 76 may be an electronic storage device comprising gates configured to store data (e.g., bits) that may be retrievable by a machine (e.g., a computing device). The memory device 76 may be configured to store information, data, applications, instructions or the like for enabling the apparatus to carry out various functions in accordance with exemplary embodiments of the present invention. For example, the memory device 76 could be configured to buffer input data for processing by the processor 70. Additionally or alternatively, the memory device 76 could be configured to store instructions for execution by the processor 70.

The processor 70 may be embodied in a number of different ways. For example, the processor 70 may be embodied as one or more of various processing means such as a coprocessor, a microprocessor, a controller, a digital signal processor (DSP), a processing element with or without an accompanying DSP, or various other processing devices including integrated circuits such as, for example, an ASIC (application specific integrated circuit), an FPGA (field programmable gate array), a hardware accelerator, a special-purpose computer chip, or the like. In an exemplary embodiment, the processor 70 may be configured to execute instructions stored in the memory device 76 or otherwise accessible to the processor 70. Alternatively or additionally, the processor 70

may be configured to execute hard coded functionality. As such, whether configured by hardware or software methods, or by a combination thereof, the processor 70 may represent an entity (e.g., physically embodied in circuitry) capable of performing operations according to embodiments of the present invention while configured

5 accordingly. Thus, for example, when the processor 70 is embodied as an ASIC, FPGA or the like, the processor 70 may be specifically configured hardware for conducting the operations described herein. Alternatively, as another example, when the processor 70 is embodied as an executor of software instructions, the instructions may specifically

10 configure the processor 70 to perform the algorithms and/or operations described herein when the instructions are executed. However, in some cases, the processor 70 may be a processor of a specific device (e.g., a mobile terminal or network device) adapted for employing embodiments of the present invention by further configuration of the processor 70 by instructions for performing the algorithms and/or operations described herein. The processor 70 may include, among other things, a clock, an arithmetic logic unit (ALU) and

15 logic gates configured to support operation of the processor 70.

Meanwhile, the communication interface 74 may be any means such as a device or circuitry embodied in either hardware, software, or a combination of hardware and software that is configured to receive and/or transmit data from/to a network and/or any other device or module in communication with the apparatus. In this regard, the

20 communication interface 74 may include, for example, an antenna (or multiple antennas) and supporting hardware and/or software for enabling communications with a wireless communication network. In some environments, the communication interface 74 may alternatively or also support wired communication. As such, for example, the communication interface 74 may include a communication modem and/or other

25 hardware/software for supporting communication via cable, digital subscriber line (DSL), universal serial bus (USB) or other mechanisms.

The user interface 72 may be in communication with the processor 70 to receive an indication of a user input at the user interface 72 and/or to provide an audible, visual, mechanical or other output to the user. As such, the user interface 72 may include, for

30 example, a keyboard, a mouse, a joystick, a display, a touch screen, soft keys, a microphone, a speaker, or other input/output mechanisms. In an exemplary embodiment in which the apparatus is embodied as a server or some other network devices, the user interface 72 may be limited, or eliminated. However, in an embodiment in which the apparatus is embodied as a communication device (e.g., the mobile terminal 10), the user

35 interface 72 may include, among other devices or elements, any or all of a speaker, a microphone, a display, and a keyboard or the like. In this regard, for example, the processor 70 may comprise user interface circuitry configured to control at least some

functions of one or more elements of the user interface, such as, for example, a speaker, ringer, microphone, display, and/or the like. The processor 70 and/or user interface circuitry comprising the processor 70 may be configured to control one or more functions of one or more elements of the user interface through computer program instructions

5 (e.g., software and/or firmware) stored on a memory accessible to the processor 70 (e.g., memory device 76, and/or the like).

In an exemplary embodiment, the processor 70 may be embodied as, include or otherwise control an information grouper 80, a quantizer 82 and an information collector 84. The information grouper 80, the quantizer 82 and the information collector 84 may
10 each be any means such as a device or circuitry operating in accordance with software or otherwise embodied in hardware or a combination of hardware and software (e.g., processor 70 operating under software control, the processor 70 embodied as an ASIC or FPGA specifically configured to perform the operations described herein, or a combination thereof) thereby configuring the device or circuitry to perform the
15 corresponding functions of the information grouper 80, the quantizer 82 and the information collector 84, respectively, as described herein. Thus, in examples in which software is employed, a device or circuitry (e.g., the processor 70 in one example) executing the software forms the structure associated with such means.

The information grouper 80 may be configured to group data based on any of a
20 number of criteria that may take into account couplings between components of soft information received by the information grouper 80. In this regard, for example, the information grouper 80 may be configured to collect symbols and generate groupings based on the symbols used. However, the basis for generation of the groupings may be arbitrarily chosen depending upon design choice for a given implementation. As such, for
25 example, grouping may be accomplished in some cases on the basis of time, frequency or bits associated with a single symbol. In an exemplary embodiment, the information grouper 80 may perform grouping in a predefined manner (e.g., based on any of the criteria described above) prior to the quantization (e.g., vector or scalar quantization) employed by the quantizer 82 as shown in the examples of FIGS. 4 and 5. As such, for
30 example, a scalar quantizer may be employed and thereafter, the encoder 83 may be configured to bind (via grouping) quantized soft information together by compression or encoding. Some examples are described in greater detail below in connection with the descriptions of FIGS. 3-5.

The quantizer 82 may be configured to perform quantization of soft information
35 received at the quantizer 82. In an exemplary embodiment, the quantizer 82 may be configured to perform vector quantization on data received from the information grouper 80. In other words, in some cases, the quantizer 82 may be configured to perform vector

quantization on groups of information received in which the groups have been generated based on couplings between components of soft information. In an alternative embodiment, scalar quantization may be employed by the quantizer 82 and then the quantized information may be bound together via grouping during coding and/or
5 compression after the information collector 82 by the encoder 83. Some examples are described in greater detail below in connection with the descriptions of FIGS. 3-5.

The information collector 84 may be configured to collect quantized data received from the quantizer 82 and combine the quantized data into one output for storage in connection with use for providing decoding in instances of decoding failure or, in some
10 cases, for encoding. In this regard, due to the quantized data being divided into groups by the information grouper 80, the output of the quantizer 82 may include a plurality of quantized outputs corresponding to the groups. In an exemplary embodiment, an optional encoder 83 may be configured to bind quantized soft information from the groups together by compression and/or encoding. As such, in some cases, the encoder 83 may
15 be configured to perform encoding in order to compress the grouped data after the information collector 84 has collected the quantized data from the various groups.

FIG. 3 illustrates an example system in which an embodiment of the present invention may be employed. In this regard, FIG. 3 illustrates an exemplary communication system employing multiple-input multiple-output (MIMO) channels and/or
20 higher-order modulation alphabets. As shown in FIG. 3, in an exemplary embodiment, information bits that are to be transmitted $\mathbf{i}$ are encoded by an encoder 100 into encoded bits $\mathbf{b}$ and then mapped onto symbols $\mathbf{x}$ by a bit-to-symbol mapper 102. The encoder 100 may be any suitable encoder known in the art that is capable of encoding data according to a particular coding scheme. As such, the encoder 100 may be any means
25 or device including hardware, software or a combination of hardware and software that is configured to perform encoding. The bit-to-symbol mapper 102 may be any means or device including hardware, software or a combination of hardware and software that is configured to map encoded bits onto symbols for transmission. In an exemplary embodiment, the bit-to-symbol mapper 102 may employ 16/64-QAM (quadrature
30 amplitude modulation). In some cases, the bit-to-symbol mapping performed by the bit-to-symbol mapper 102 may be accomplished using Gray coding resulting in a non-linear mapping between bits and symbols and thus creating strong couplings between bits belonging to a single symbol.

In an exemplary embodiment, after the encoded bits $\mathbf{b}$ are mapped onto the
35 symbols $\mathbf{x}$ by a bit-to-symbol mapper 102, the symbols are transmitted through a channel (e.g., represented by the channel matrix $\mathbf{H}$), and additive white Gaussian noise

(AWGN) $\mathbf{n}$ is added during transmission. At the receiver (e.g., the mobile terminal 10), the observed data $\mathbf{y}$ may be used passed through a detector 104 in order to extract the soft information $\mathbf{s}$. The detector 104 may be any means or device including hardware, software or a combination of hardware and software that is configured to extract soft information from input data. As such, in some cases, the detector 104 may be configured to utilize knowledge of the symbols used in transmission to determine the soft information that was encoded mapped to symbols and transmitted to the receiver. In an exemplary embodiment, the soft information $\mathbf{s}$, may be quantized by a quantization function Q . The quantization function Q may be embodied by portions of the apparatus 50 (e.g., the information grouper 80 and the quantizer 82) according to an exemplary embodiment.

By utilizing the apparatus 50 to provide the functionality of the quantization function Q of FIG. 3, the HARQ buffer 106 may be smaller in size than a typical HARQ buffer that would be required if conventional quantization were employed for the quantization function Q . The HARQ buffer 106 may be a storage device (e.g., the memory device 76, a portion of the memory device 76, or another memory accessible to the processor 70) configured to store quantized soft information $\tilde{\mathbf{s}}$ from one or more transmissions received by the receiver for comparison and/or coordinated usage with later transmissions of data corresponding to the data stored in order to enable decoding of the transmitted data at a decoder 108. In an exemplary embodiment, the quantized soft information $\tilde{\mathbf{s}}$ stored in the HARQ buffer 106 may be stored for later use in response to a decoding failure with respect to the data being decoded and read again in the case of a later retransmission of the data. The decoder 108 may be any means or device including hardware, software or a combination of hardware and software that is configured to decode soft-bits or other soft information to generate recovered data $\hat{\mathbf{i}}$ corresponding to the information bits that were to be transmitted $\mathbf{i}$.

In some cases, the decoder 108 may be able to directly decode the soft information $\mathbf{s}$ received. However, in other instances, such as where decoding errors occur due to poor channel conditions, the decoder 108 may utilize the quantized soft information $\tilde{\mathbf{s}}$ stored in the HARQ buffer 106 along with data corresponding to the soft information $\mathbf{s}$ received during a subsequent transmission of the information bits that were to be transmitted $\mathbf{i}$ in order to decode the data received to determine the recovered data $\hat{\mathbf{i}}$.

In an exemplary embodiment, the soft information is represented using a LLR (log likelihood ratio) for every bit in $\mathbf{b}$. However, other representations of the soft information are also possible. In accordance with exemplary embodiments, the design of the quantization function Q may be tailored to reducing the amount of memory (e.g., the

HARQ buffer 106) for a given distortion level of the soft information. As such, for example, the quantization function Q may be embodied as the information grouper 80, the quantizer 82 and the information collector 84 as shown in either FIG. 4 or FIG. 5.

An exemplary embodiment will now be described in connection with FIG. 4, which illustrates an alternative embodiment in which vector quantization is employed with respect to soft information that is grouped by the information grouper 80 prior to quantization by the quantizer 82. Thus, in this embodiment, the quantizer 82 is configured to perform vector quantization instead of scalar quantization with a vector quantization device 122. As shown in FIG. 4, in an exemplary embodiment, the soft information is split into groups by the information grouper 80 and the quantization performed by the vector quantization device 122 is performed jointly in each of the groups. The splitting of the soft information into groups may provide for any couplings between soft information inside each group to be exploited to reduce the distortion for a given memory requirement. Thus, for example, if it is assumed that the size of each group is L , the quantization may be performed by partitioning the L -dimensional space into regions, each having an associated reconstruction value.

As shown in FIG. 4, after the soft bits have been quantized via the vector quantization device 122 in their respective groups, the information collector 84 may collect the group-based quantized data into the quantized soft information $\tilde{s}$ that may thereafter be encoded via the encoder 83 in some examples and/or communicated to the HARQ buffer 106 for storage until being used by the decoder 108 in response to a decode failure.

FIG. 5 illustrates an alternative example embodiment in which scalar quantization may be employed in connection with grouping of components of the soft information according to an exemplary embodiment. As such, in this example, the quantizer 82 may be embodied as a scalar quantization device 120. As shown in FIG. 5, the information grouper 80 may receive the soft information s , and break it into groups which may include soft bits s_1 to s_N . The scalar quantization device 120 then perform scalar quantization on the soft bits to produce quantized respective soft data $\tilde{s}_1$ to $\tilde{s}_N$. When only a single, common scalar quantizer is used, the scalar quantization device 120 may otherwise be similar to the traditional way of handling the soft information in that the soft bits are traditionally handled individually and in a single, common manner. However, handling the soft bits individually may encounter problems in that any variations in the certainty of the bits (e.g., resulting from Gray coding) may not be reflected in the quantizer and therefore lead to losses.

To improve upon the traditional scheme, an exemplary embodiment may employ the information grouper 80 as described above. Additionally, in order to combine the quantized data into a single output, the information collector 84 may be employed along with, in some cases, the encoder 83 to provide coding in consideration of groupings
 5 provided and to bind groups of data together by compression. Thus, for example, the quantized soft data $\tilde{s}_1$ to $\tilde{s}_N$ corresponding to the groups provided by the information grouper 80 may be compressed and coded after quantization in order to reduce the amount of memory space used to store the quantized soft information $\tilde{s}$.

FIG. 6 shows an example distribution of two LLRs associated with a single 4-PAM
 10 (pulse amplitude modulation) Gray coded symbol in a Rayleigh fading channel in order to illustrate how vector quantization over the soft bits belonging to a particular symbol may be beneficial for Gray coded higher-order modulation. As shown in FIG. 6, for this L=2 example, there is a distinct coupling between s_1 and s_2 while using scalar quantization may have only produced a simple rectangular partitioning of the space. Thus, exploiting
 15 the couplings between the soft bits allows a reduction in the storage requirement.

When designing the partitioning of the L-dimensional space of a vector quantizer (VQ), similar distortion measures can be used as is the case for designing a scalar quantizer (SQ). For example, minimum mean-squared error or minimum mutual information loss may be employed. The actual design of the vector quantizer (VQ) may
 20 be performed in any of various ways, e.g. by minimizing the distortion function based on the probability density function and the decision boundaries of the variables being quantized or based on training of the vector quantizer (VQ) over a training set. In addition, the output of any quantizer (e.g., either a scalar quantizer as shown in FIG. 5 or a vector quantizer as shown in FIG. 4) may be coded using lossless or lossy compression
 25 after quantization is performed to reduce any residual redundancy present not captured by the quantizer. In other words, for example, any couplings not included in the groupings of a vector quantizer (VQ), may be utilized after quantization as shown in FIG. 4 by the use of e.g., entropy coding.

Accordingly, an exemplary embodiment of the present invention may provide for
 30 improved efficiency with respect to system performance for a given memory size for storing prior transmissions from which soft information has been derived. This may also mean that the same level of performance can be achieved with a smaller memory (e.g., HARQ buffer). In an exemplary embodiment, the information grouper 80 configured to group data based on criteria that may take into account couplings between components
 35 of soft information received by the information grouper 80 may be utilized in connection with quantization. Thus, in an exemplary embodiment, the information grouper 80 is

configured to break soft information apart prior to employing vector quantization using the quantizer 82. The result is that less memory space may need to be used to store data received in situations where channel conditions dictate that it is advisable to store data received for combining with new data to be received for improved decoding accuracy. As an alternative, a scalar quantization may be performed by the quantizer 82 and an output of the quantizer 82 may be coded by the encoder 83 to achieve a similar reduction in the amount of memory space used in a memory device such as a HARQ buffer.

Thus, according to an exemplary embodiment, an apparatus for providing quantization and coding of groupings of soft information is provided. By exploiting couplings present in the soft information, an exemplary embodiment of the present invention may facilitate a reduction in the data rate required to maintain a given distortion level of the soft information, which is desirable in, for example, wireless communication systems utilizing HARQ principles. The couplings present in the soft information are exploited by grouping the soft information according to the couplings and separate vector quantization within each of the groups is then performed. If desired, the output of the vector quantization process may further be encoded using for example entropy coding to capture any residual couplings present in the output.

FIGS. 7-9 are flowcharts of a system, method and program product according to exemplary embodiments of the invention. It will be understood that each block or step of the flowcharts, and combinations of blocks in the flowcharts, may be implemented by various means, such as hardware, firmware, processor, circuitry and/or other device associated with execution of software including one or more computer program instructions. For example, one or more of the procedures described above may be embodied by computer program instructions. In this regard, the computer program instructions which embody the procedures described above may be stored by a memory device of an apparatus employing an embodiment of the present invention and executed by a processor in the apparatus. As will be appreciated, any such computer program instructions may be loaded onto a computer or other programmable apparatus (e.g., hardware) to produce a machine, such that the resulting computer or other programmable apparatus embody means for implementing the functions specified in the flowchart block(s) or step(s). These computer program instructions may also be stored in a computer-readable memory that may direct a computer or other programmable apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture the execution of which implements the function specified in the flowchart block(s) or step(s). The computer program instructions may also be loaded onto a computer or other programmable apparatus to cause a series of operational steps to be performed on the computer or other

programmable apparatus to produce a computer-implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block(s) or step(s).

Accordingly, blocks or steps of the flowcharts support combinations of means for performing the specified functions, combinations of steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that one or more blocks or steps of the flowchart, and combinations of blocks or steps in the flowcharts, can be implemented by special purpose hardware-based computer systems which perform the specified functions or steps, or combinations of special purpose hardware and computer instructions.

In this regard, one embodiment of a method for providing quantization and coding of groupings of soft information according to an exemplary embodiment, as shown in FIG. 7 includes receiving soft information detected responsive to a transmission of coded symbols at operation 200. The method further includes dividing the soft information into groups based on couplings between components of the soft information at operation 210 and quantizing the soft information at operation 220.

In some embodiments, the method may include additional optional operations shown in dashed lines in FIG. 7. As such, for example, the method may further include storing quantized soft information in a buffer in response to a decoding failure with respect to decoding received data corresponding to the transmission of coded symbols at operation 230 and, in some cases also, utilizing the quantized soft information in connection with decoding a retransmission of the coded symbols at operation 240.

In some embodiments, certain ones of the operations above may be modified or further amplified as described below. In this regard, for example, dividing the soft information into groups may include jointly coding soft bits belonging to a single symbol. In some cases, receiving the soft information may include receiving log likelihood ratios (LLRs) for bits of the coded symbols.

In particular, operations 210 and 220 could be performed in any order in different alternative embodiments. Examples of two alternative embodiments are shown in FIGS. 8 and 9. In this regard, as shown in FIG. 8 (which corresponds to an example embodiment employing only the information grouper 80 and quantizer 82 of FIG. 5), the method may include receiving soft information detected responsive to a transmission of coded symbols at operation 200. The method further includes dividing the soft information into groups at operation 210' and quantizing the soft information using a scalar quantizer at operation 220'. The method may also include an optional operation of binding components based on the couplings during compression and coding after the quantizing at operation 222.

Meanwhile, as shown in FIG. 9 (which corresponds to an example embodiment employing only the information grouper 80 and quantizer 82 of FIG. 4), the method may include receiving soft information detected responsive to a transmission of coded symbols at operation 200. The method further includes dividing the soft information into groups at
5 operation 210" prior to quantizing the soft information using a vector quantizer at operation 220". In some cases, the method may further include an optional operation of encoding the quantized soft information at operation 224. Operations 230 and/or 240 may then be completed as described above. In some cases, operations 222 and 224 could be performed in each of the methods of FIGS. 8 and 9.

10 In an exemplary embodiment, an apparatus for performing the method of FIGS. 7-9 above may comprise a processor (e.g., the processor 70) configured to perform some or each of the operations (200-240) described above. The processor may, for example, be configured to perform the operations (200-240) by performing hardware implemented logical functions, executing stored instructions, or executing algorithms for performing
15 each of the operations. Alternatively, the apparatus may comprise means for performing each of the operations described above. In this regard, according to an example embodiment, examples of means for performing operations 200-240 may comprise, for example, the processor 70, respective ones of the information grouper 80, the quantizer 82, the information collector 84, and/or a device or circuit for executing instructions or
20 executing an algorithm for processing information as described above.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific
25 embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the associated drawings describe exemplary embodiments in the context of certain exemplary combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by
30 alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

WHAT IS CLAIMED IS:

1. An apparatus comprising at least one processor and at least one memory including computer program code, the at least one memory and the computer program
5 code configured to, with the processor, cause the apparatus to at least perform:
receiving soft information detected responsive to a transmission of coded
symbols;
dividing the soft information into groups based on couplings between components
of the soft information; and
10 quantizing the soft information.
2. The apparatus of claim 1, wherein the program code causes the apparatus
to divide the soft information into groups prior to quantizing the soft information using a
vector quantizer.
15
3. The apparatus of claim 1, wherein the program code causes the apparatus
to bind components based on the couplings during compression and coding after
quantizing the soft information using a scalar quantizer.
- 20 4. The apparatus of claim 1, wherein the program code causes the apparatus
to bind components based on the couplings during compression and coding after
quantizing the soft information using a vector quantizer.
5. The apparatus of claim 1, wherein the program code further causes the
25 apparatus to store quantized soft information in a buffer in response to a decoding failure
with respect to decoding received data corresponding to the transmission of coded
symbols.
6. The apparatus of claim 5, wherein the program code further causes the
30 apparatus to utilize the quantized soft information in connection with decoding a
retransmission of the coded symbols.
7. The apparatus of claim 1, wherein the program code causes the apparatus
to divide the soft information into groups by jointly coding soft bits belonging to a single
35 symbol.

8. The apparatus of claim 1, wherein the program code causes the apparatus to receive the soft information comprising log likelihood ratios (LLRs) for bits of the coded symbols.

5 9. A method comprising:
receiving soft information detected responsive to a transmission of coded symbols;
dividing the soft information into groups based on couplings between components of the soft information; and
10 quantizing the soft information.

10. The method of claim 9, wherein dividing the soft information into groups is performed prior to quantizing the soft information and quantizing the soft information is performed using a vector quantizer.

15 11. The method of claim 9, wherein dividing the soft information includes binding components based on the couplings during compression and coding after quantizing the soft information, wherein quantizing the soft information comprises quantizing using a scalar quantizer.

20 12. The method of claim 9, wherein dividing the soft information includes binding components based on the couplings during compression and coding after quantizing the soft information, wherein quantizing the soft information comprises quantizing using a vector quantizer.

25 13. The method of claim 9, further comprising storing quantized soft information in a buffer in response to a decoding failure with respect to decoding received data corresponding to the transmission of coded symbols.

30 14. The method of claim 13, further comprising utilizing the quantized soft information in connection with decoding a retransmission of the coded symbols.

35 15. The method of claim 9, wherein dividing the soft information into groups comprises dividing the soft information into groups by jointly coding soft bits belonging to a single symbol.

16. The method of claim 9, wherein receiving the soft information comprises receiving log likelihood ratios (LLRs) for bits of the coded symbols.

17. A computer program product comprising at least one computer-readable storage medium having computer-executable program code portions stored therein, the computer-executable program code portions comprising:

program code instructions for receiving soft information detected responsive to a transmission of coded symbols;

program code instructions for dividing the soft information into groups based on couplings between components of the soft information; and

program code instructions for quantizing the soft information.

18. The computer program product of claim 17, wherein program code instructions for dividing the soft information into groups include instructions for dividing the soft information into groups prior to quantizing the soft information using a vector quantizer.

19. The computer program product of claim 17, wherein program code instructions for dividing the soft information include instructions for binding components based on the couplings during compression and coding after quantizing the soft information, and wherein quantizing the soft information comprises quantizing using a scalar quantizer.

20. The computer program product of claim 17, wherein program code instructions for dividing the soft information include instructions for binding components based on the couplings during compression and coding after quantizing the soft information, and wherein quantizing the soft information comprises quantizing using a vector quantizer.

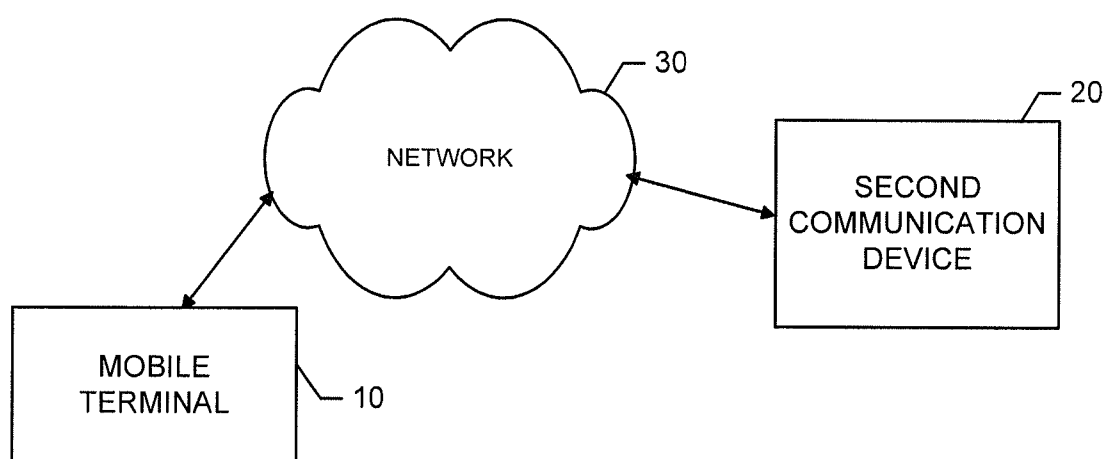
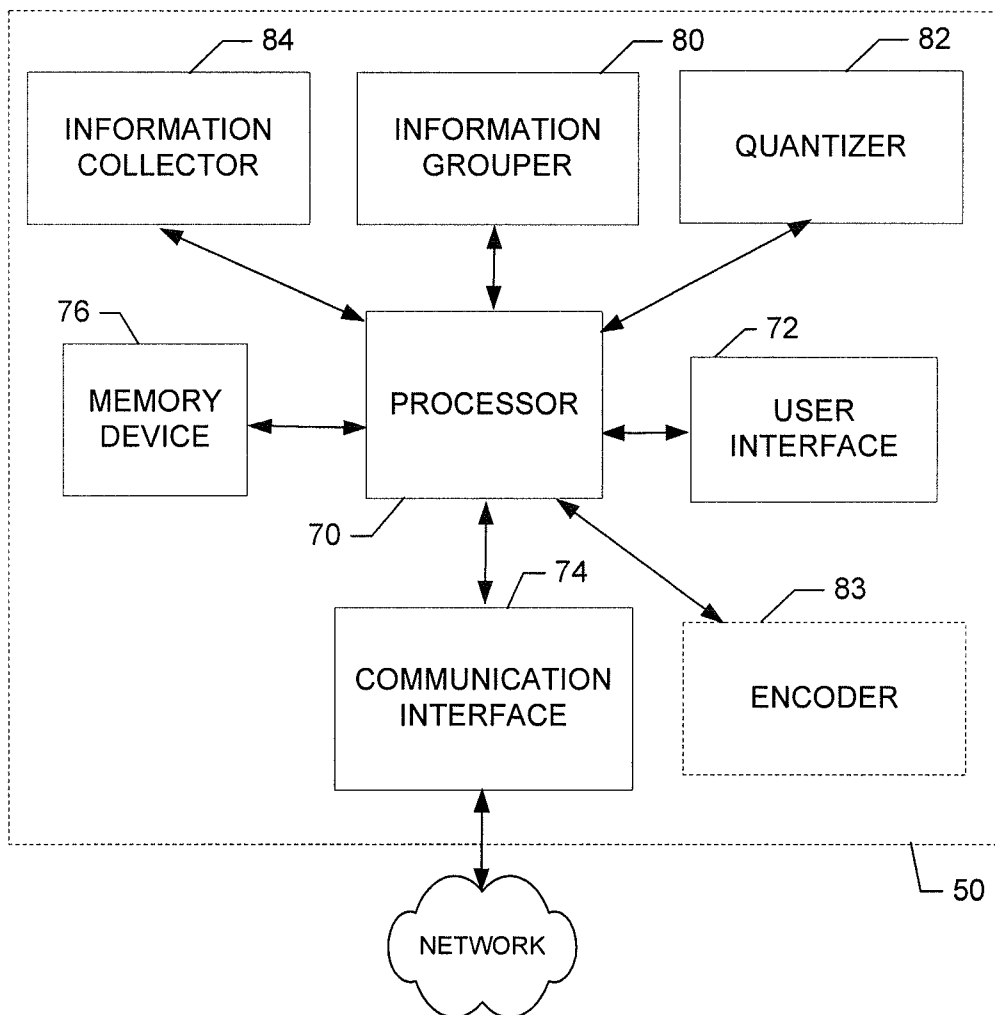
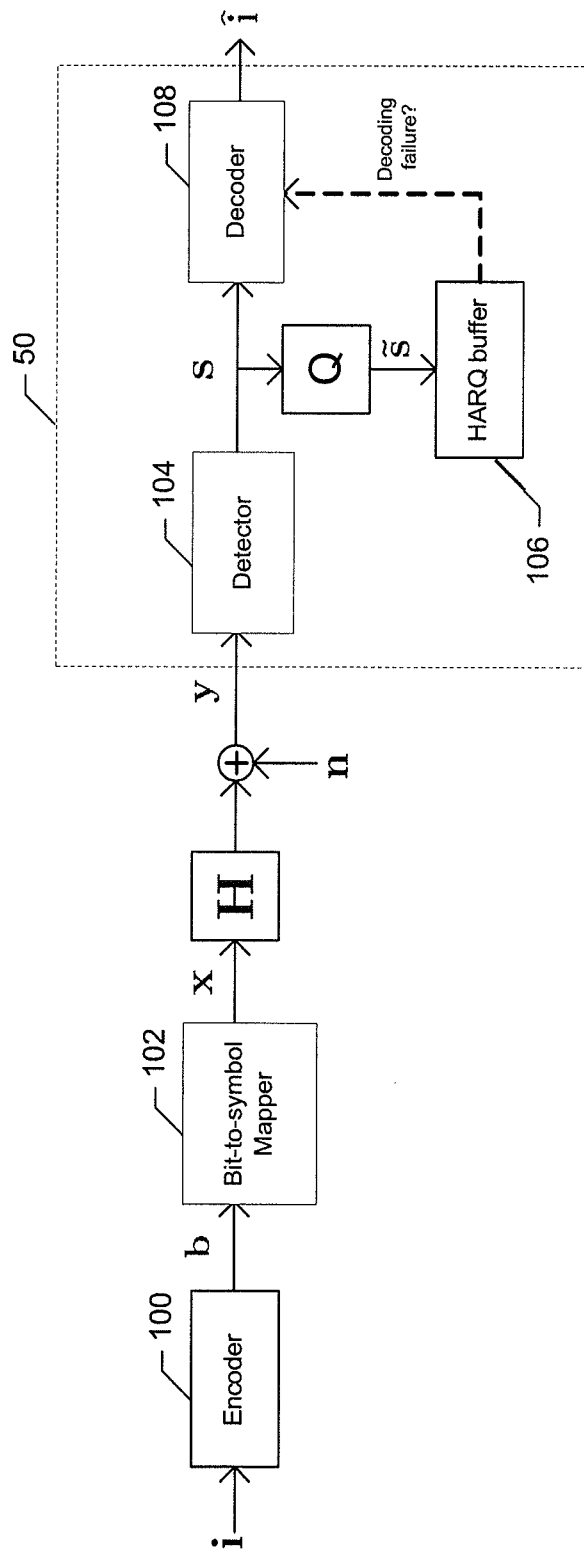
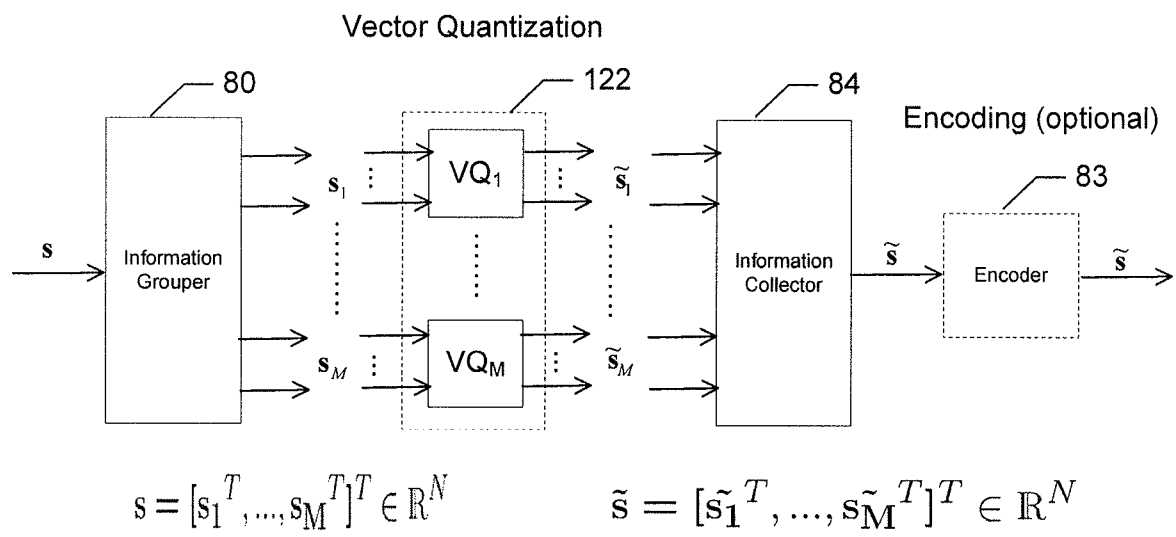
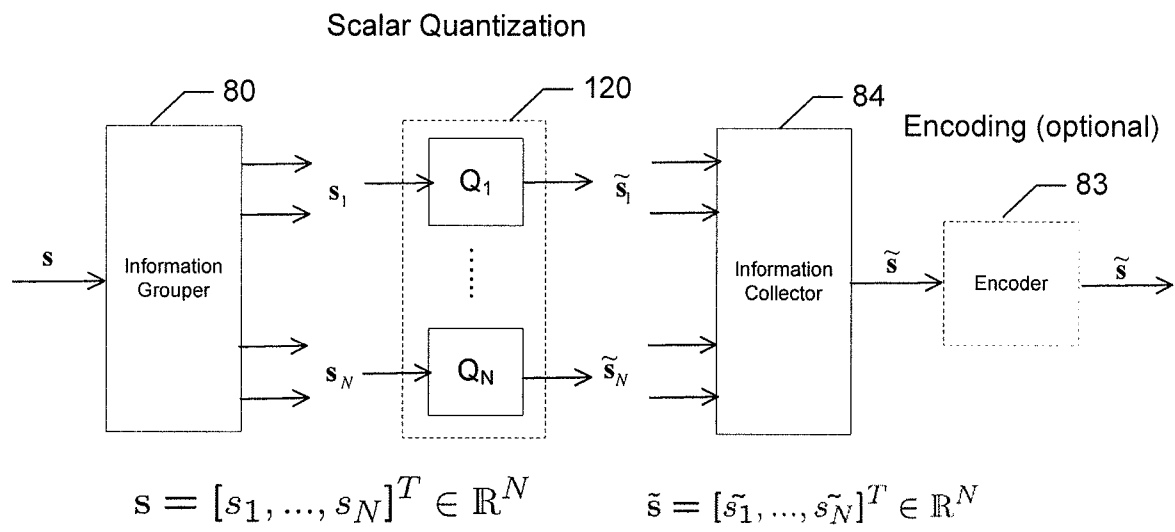


FIG. 1.

**FIG. 2.**

FIG. 3.

**FIG. 4.**

**FIG. 5.**

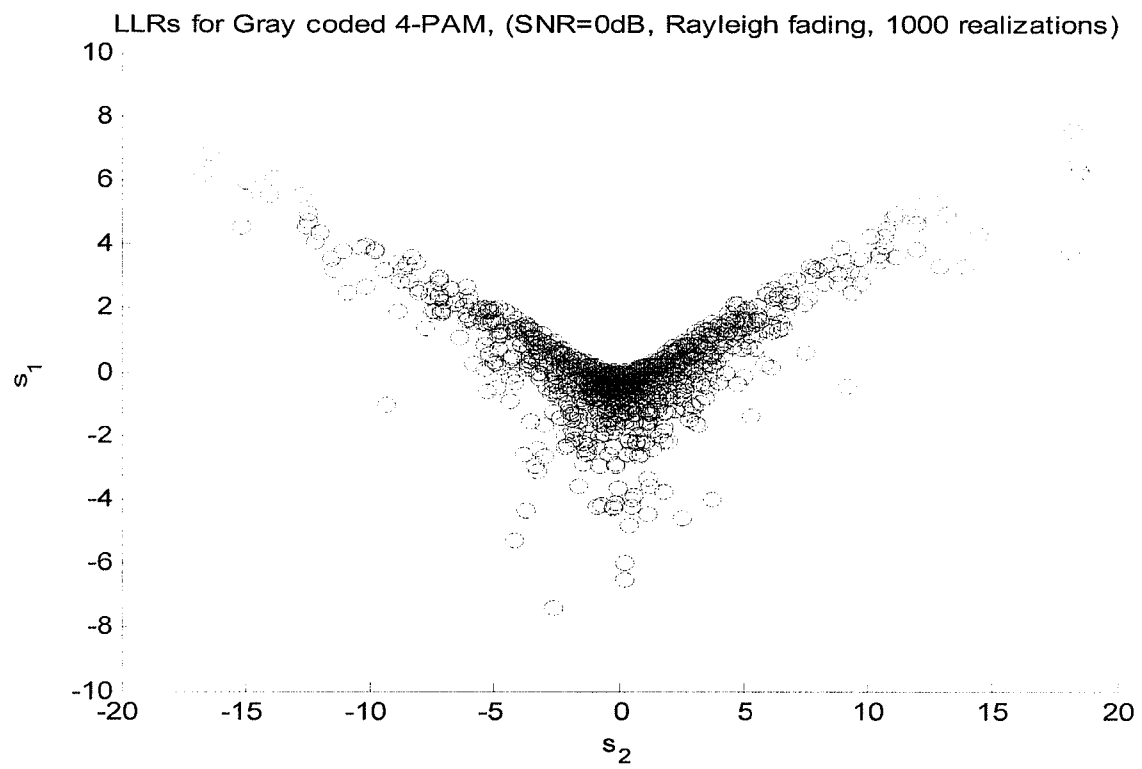


FIG. 6.

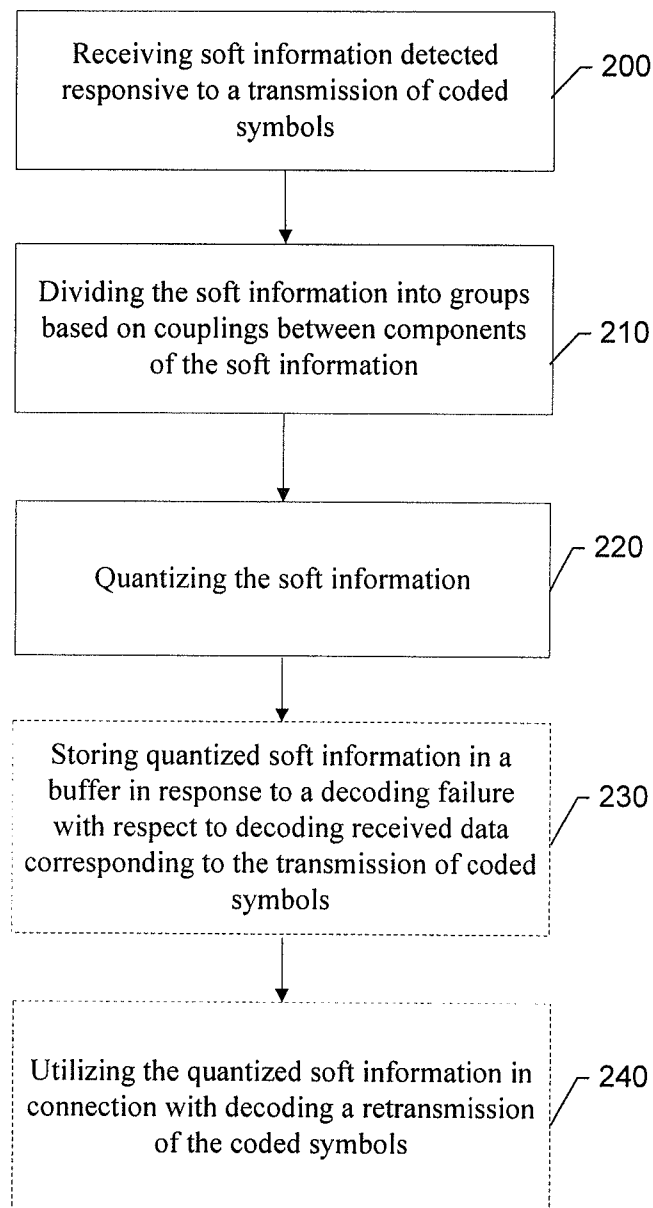
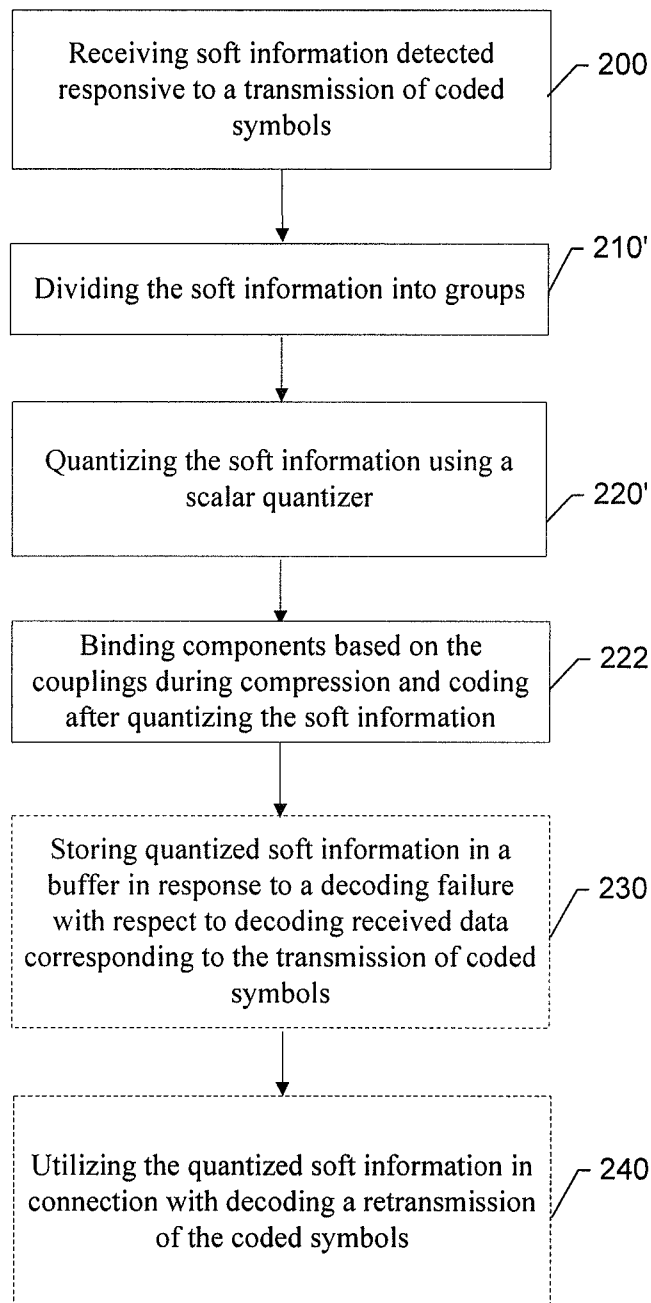
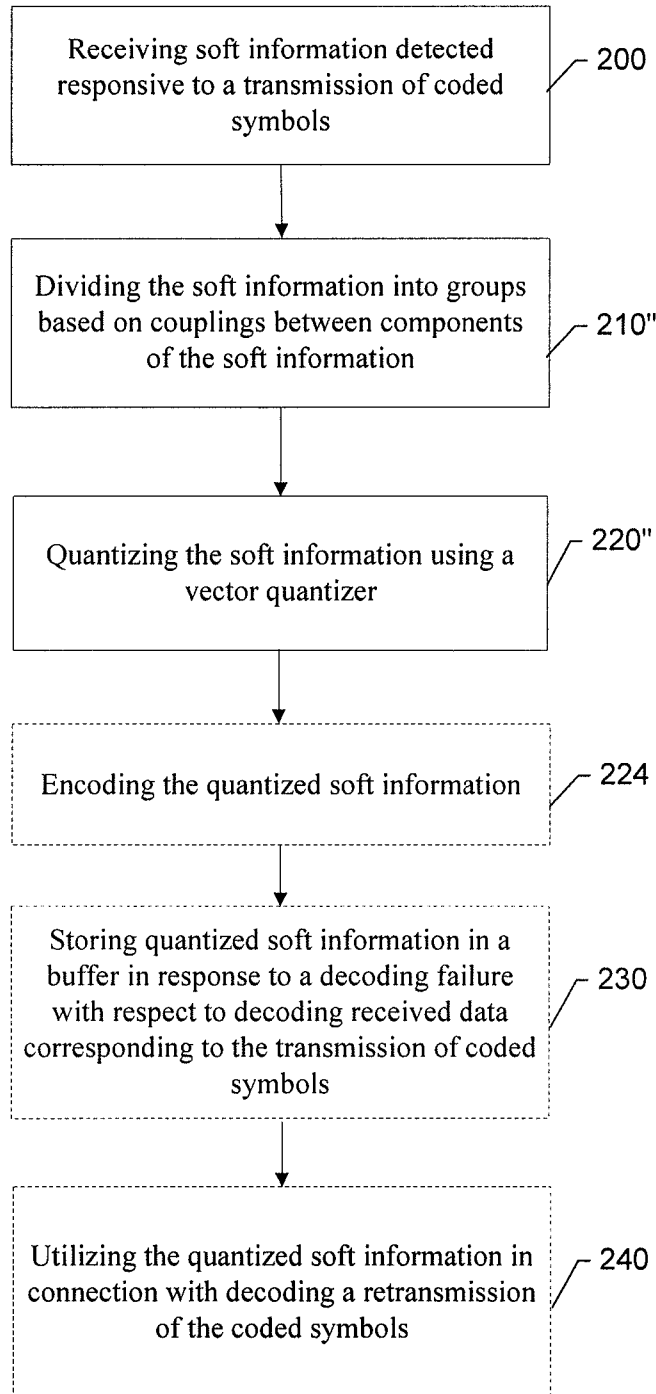


FIG. 7.

**FIG. 8.**

**FIG. 9.**

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/052527

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04L1/18

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)
H04L

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/138530 A1 (HUANG WENSHENG [US] ET AL) 23 June 2005 (2005-06-23) abstract; figures 3-7 paragraph [0040] - paragraph [0052] paragraph [0059] - paragraph [0060] paragraph [0064] - paragraph [0067] claims 15-18	1-20
X	US 2005/044473 A1 (HUANG WENSHENG [US] ET AL) 24 February 2005 (2005-02-24) abstract; figures 3-7 paragraph [0034] - paragraph [0048] paragraph [0056] - paragraph [0057] paragraph [0061] - paragraph [0064] claims 15-18 ----- -/--	1-20

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

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

11 March 2010

Date of mailing of the international search report

17/03/2010

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Authorized officer

Haas, Hans

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2009/052527

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1 564 908 A1 (ERICSSON TELEFON AB L M [SE]) 17 August 2005 (2005-08-17) abstract; figures 9-12 paragraph [0023] paragraph [0034] paragraph [0069] - paragraph [0076] -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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