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(54) **METHOD AND APPARATUS TO PERFORM ERASURE FORECASTING IN COMMUNICATION SYSTEMS**

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(57) **ABSTRACT**

Methods and apparatus to perform erasure forecasting in communication systems are disclosed. A disclosed example apparatus comprises a forward error correction (FEC) decoder to decode a first codeword and to provide a first error indication for the first codeword, an erasure forecaster to make an erasure decision for a second codeword based on the first error indication, and an erasure forecasting state table including a first field associated with first interleaved data and a second field associated with second interleaved data, the second codeword containing a first element from the first interleaved data and a second element from the second interleaved data.

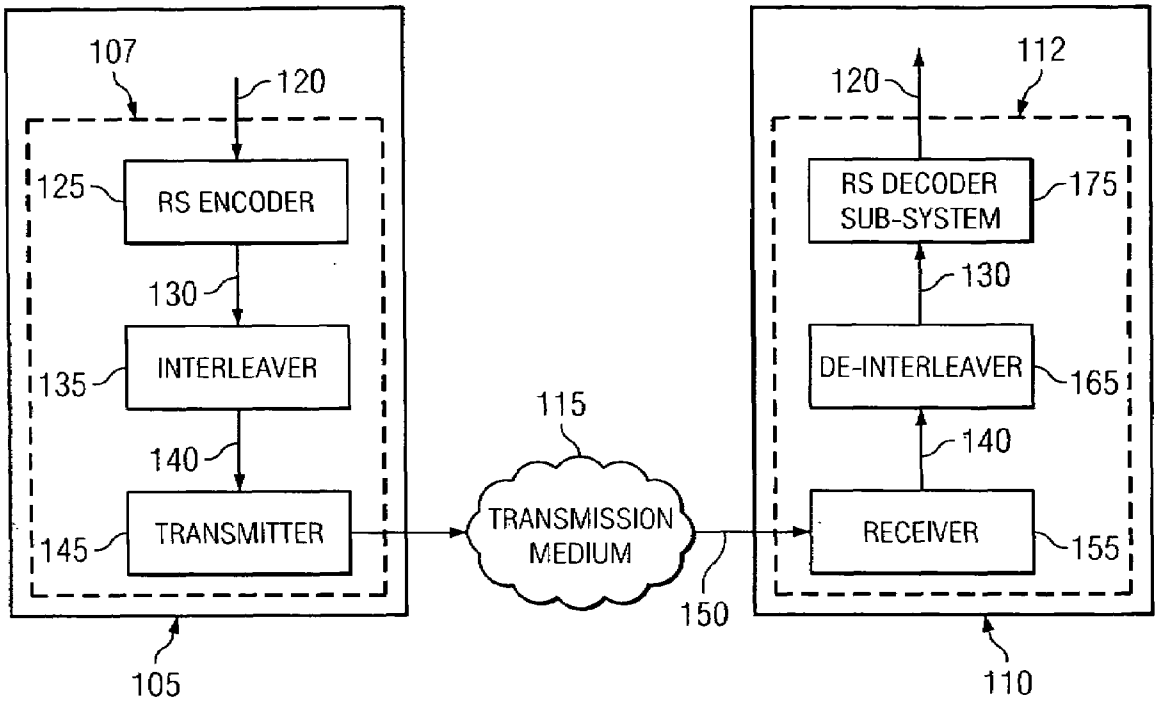


FIG. 1

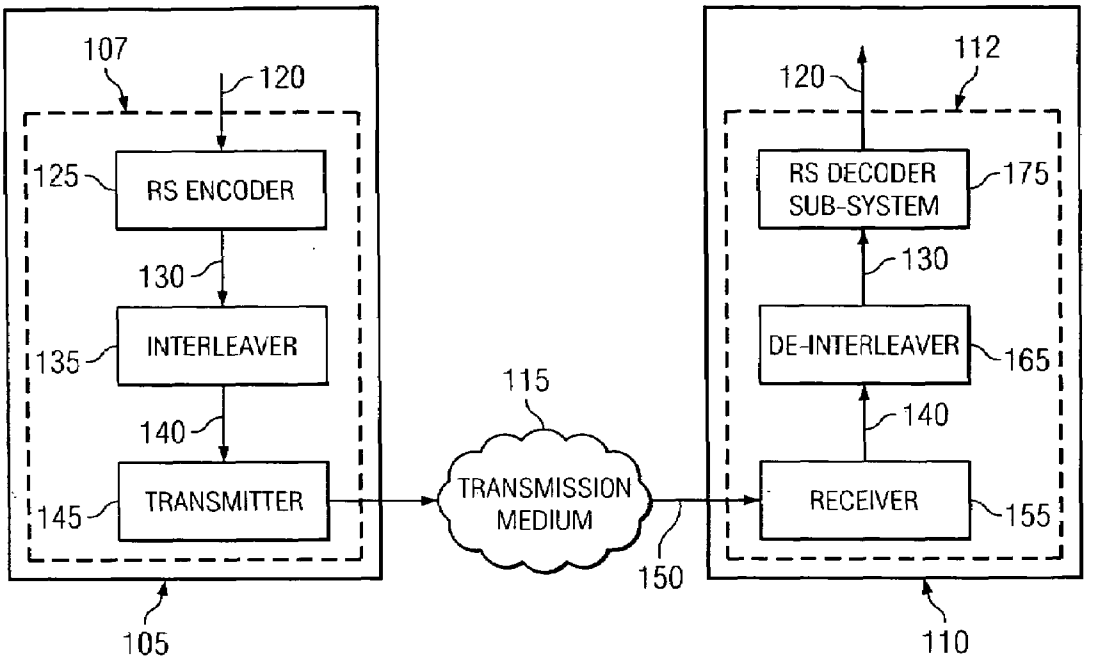

107
120
125
RS ENCODER
130
135
INTERLEAVER
140
145
TRANSMITTER
105
115
TRANSMISSION MEDIUM
150
112
120
RS DECODER SUB-SYSTEM
175
130
DE-INTERLEAVER
165
140
RECEIVER
155
110

FIG. 2

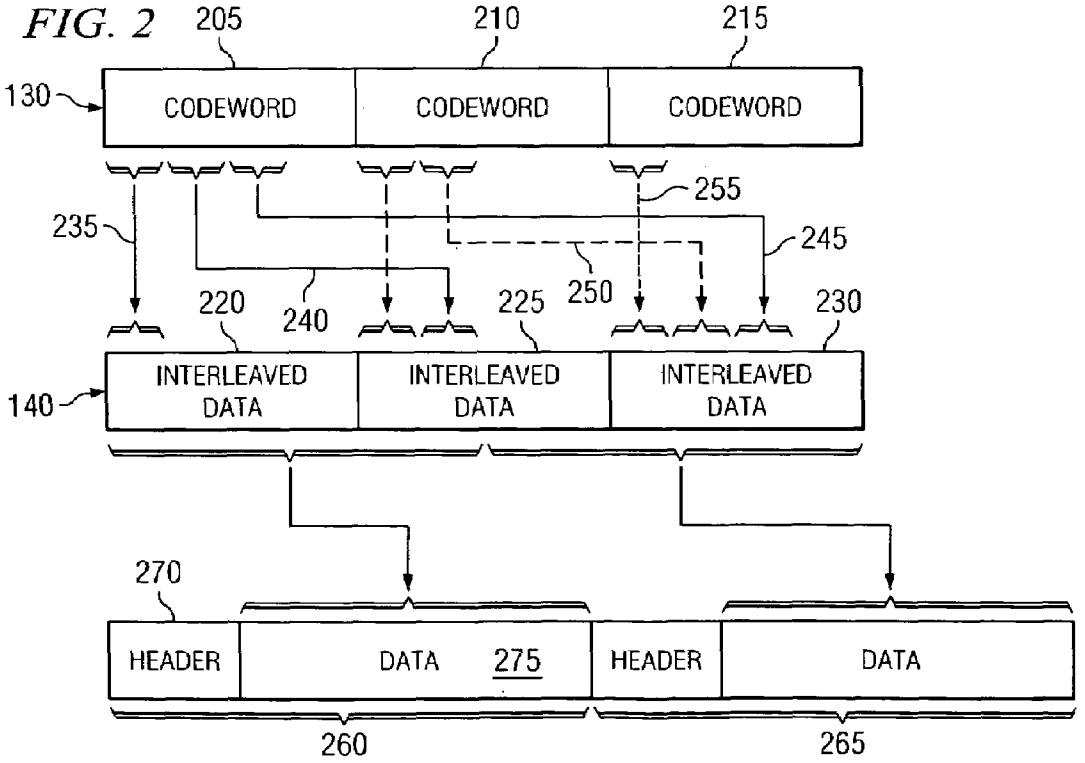

205
210
215
130
CODEWORD
CODEWORD
CODEWORD
255
235
245
220
240
225
250
230
140
INTERLEAVED DATA
INTERLEAVED DATA
INTERLEAVED DATA
270
HEADER
DATA
275
HEADER
DATA
260
265

FIG. 3

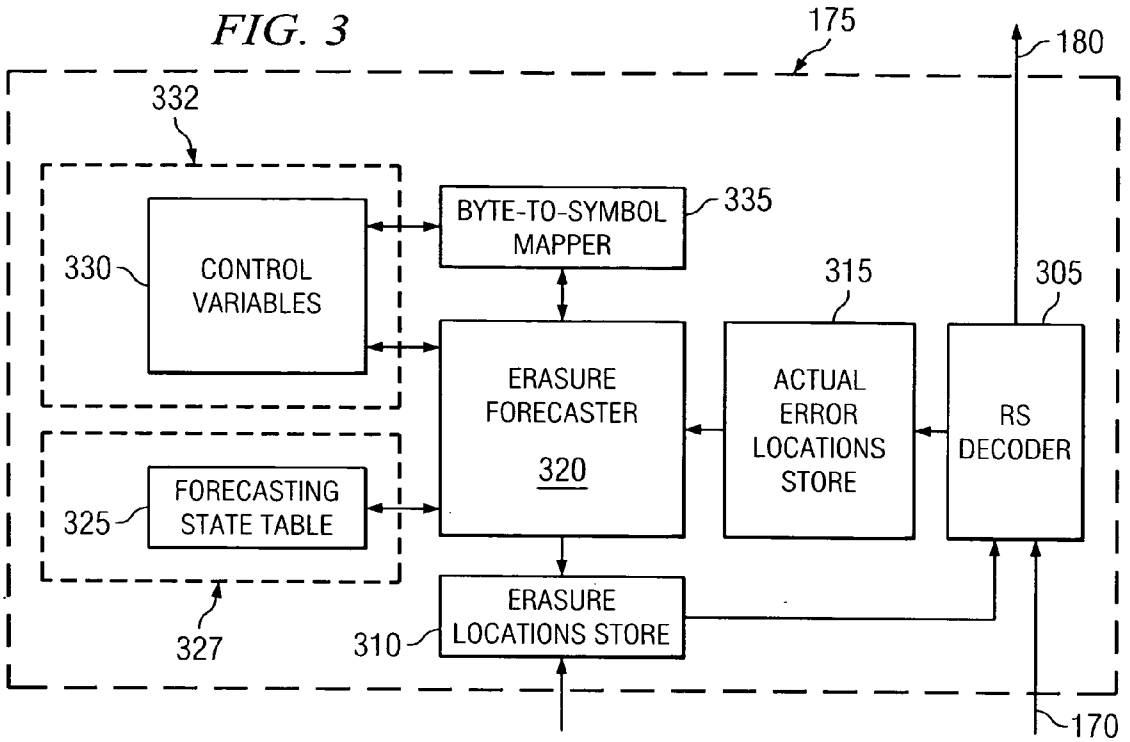


FIG. 4

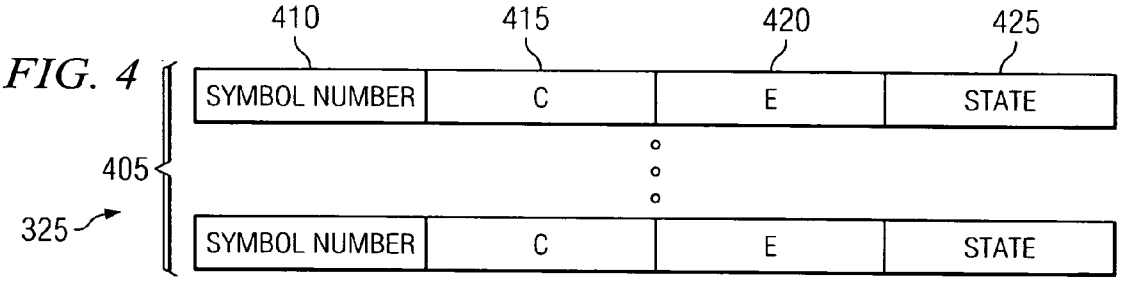
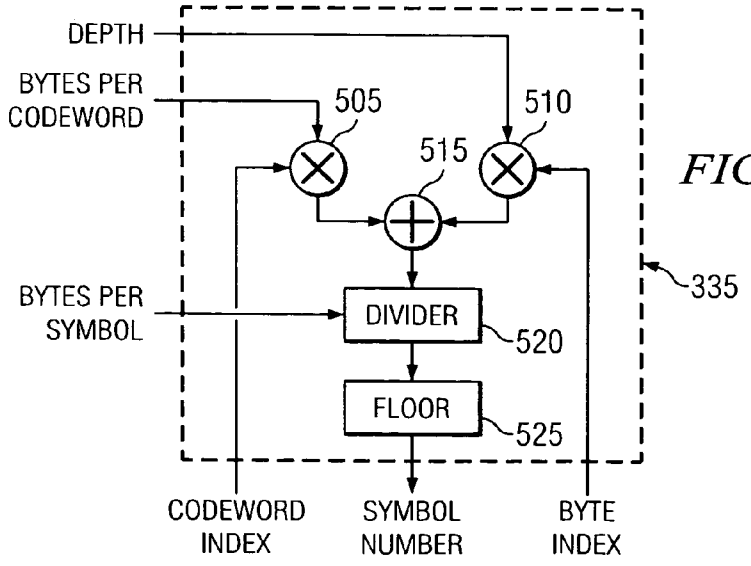


FIG. 5



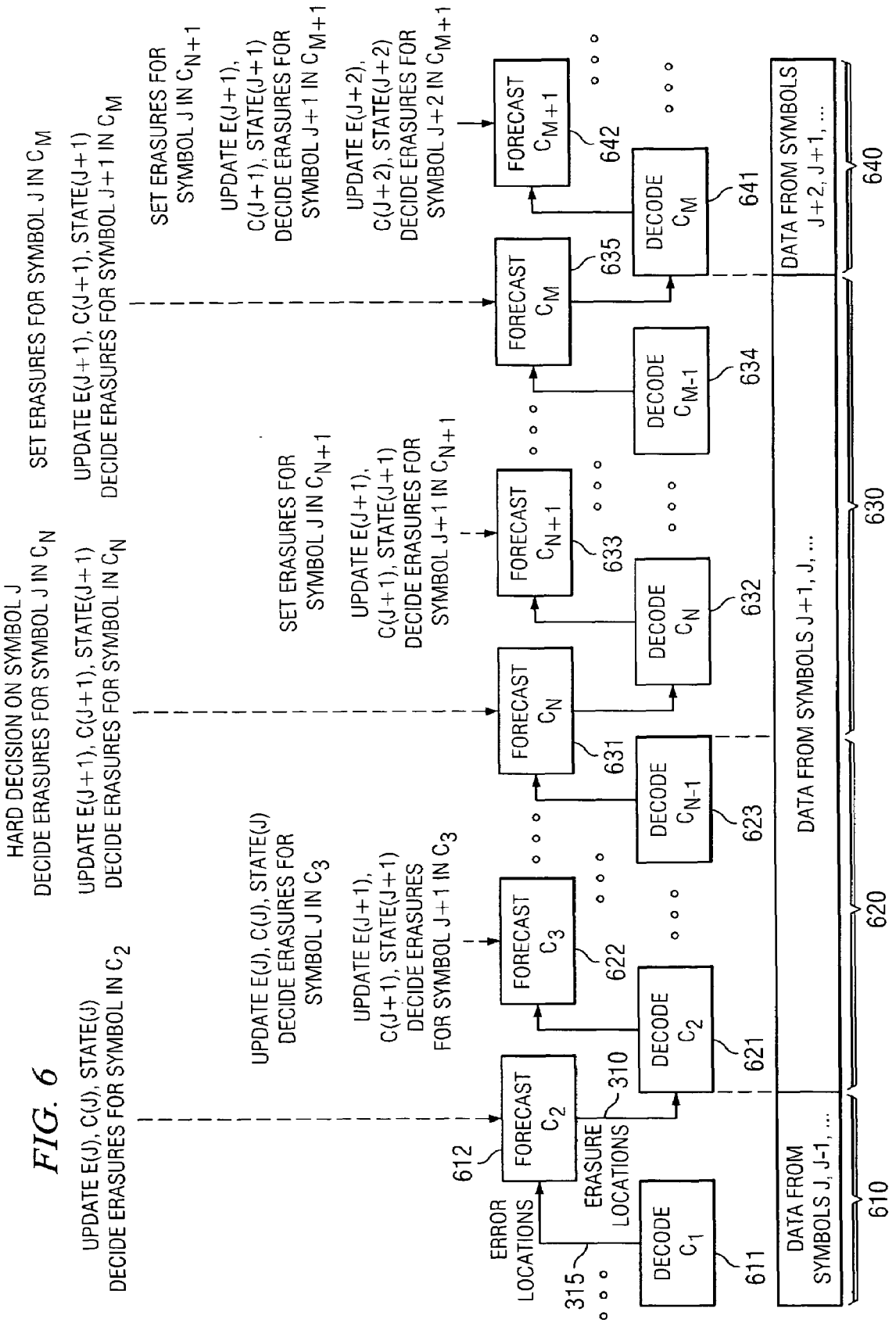


FIG. 6
HARD DECISION ON SYMBOL J
DECIDE ERASURES FOR SYMBOL J IN C_N
SET ERASURES FOR SYMBOL J IN C_M
UPDATE E(J), C(J), STATE(J)
DECIDE ERASURES FOR SYMBOL IN C_2
UPDATE E(J+1), C(J+1), STATE(J+1)
DECIDE ERASURES FOR SYMBOL IN C_N
UPDATE E(J+1), C(J+1), STATE(J+1)
DECIDE ERASURES FOR SYMBOL J+1 IN C_M
SET ERASURES FOR SYMBOL J IN C_{N+1}
UPDATE E(J+1), C(J+1), STATE(J+1)
DECIDE ERASURES FOR SYMBOL J+1 IN C_{M+1}
UPDATE E(J+2), C(J+2), STATE(J+2)
DECIDE ERASURES FOR SYMBOL J+2 IN C_{M+1}
UPDATE E(J), C(J), STATE(J)
DECIDE ERASURES FOR SYMBOL J IN C_3
SET ERASURES FOR SYMBOL J IN C_{N+1}
UPDATE E(J+1), C(J+1), STATE(J+1)
DECIDE ERASURES FOR SYMBOL J+1 IN C_3
UPDATE E(J+1), C(J+1), STATE(J+1)
DECIDE ERASURES FOR SYMBOL J+1 IN C_{N+1}
DECODE C_1
DECODE C_2
DECODE C_{N-1}
DECODE C_N
DECODE C_{M-1}
DECODE C_M
FORECAST C_2
FORECAST C_3
FORECAST C_N
FORECAST C_{N+1}
FORECAST C_M
FORECAST C_{M+1}
ERROR LOCATIONS
ERASURE LOCATIONS
310
315
611
612
621
622
623
631
632
633
634
635
641
642
DATA FROM SYMBOLS J, J-1, ...
DATA FROM SYMBOLS J+1, J, ...
DATA FROM SYMBOLS J+2, J+1, ...
610
620
630
640

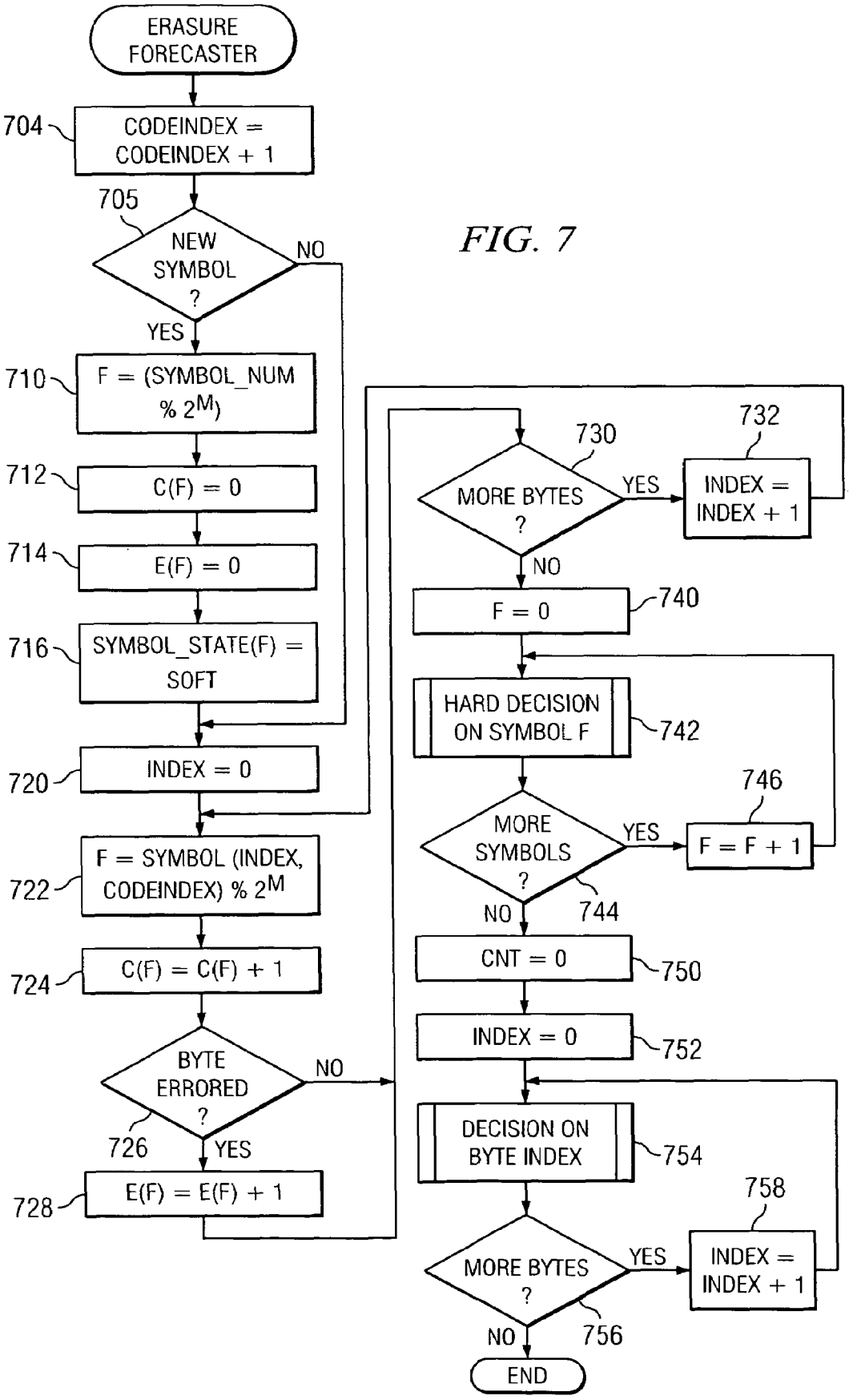

ERASURE FORECASTER
704
CODEINDEX = CODEINDEX + 1
705
NEW SYMBOL ?
NO
YES
710
F = (SYMBOL_NUM % 2^M)
712
C(F) = 0
714
E(F) = 0
716
SYMBOL_STATE(F) = SOFT
720
INDEX = 0
722
F = SYMBOL (INDEX, CODEINDEX) % 2^M
724
C(F) = C(F) + 1
BYTE ERRORED ?
NO
726
YES
728
E(F) = E(F) + 1
730
MORE BYTES ?
YES
732
INDEX = INDEX + 1
NO
F = 0
740
HARD DECISION ON SYMBOL F
742
MORE SYMBOLS ?
YES
746
F = F + 1
NO
744
CNT = 0
750
INDEX = 0
752
DECISION ON BYTE INDEX
754
MORE BYTES ?
YES
758
INDEX = INDEX + 1
NO
756
END

FIG. 7

FIG. 8

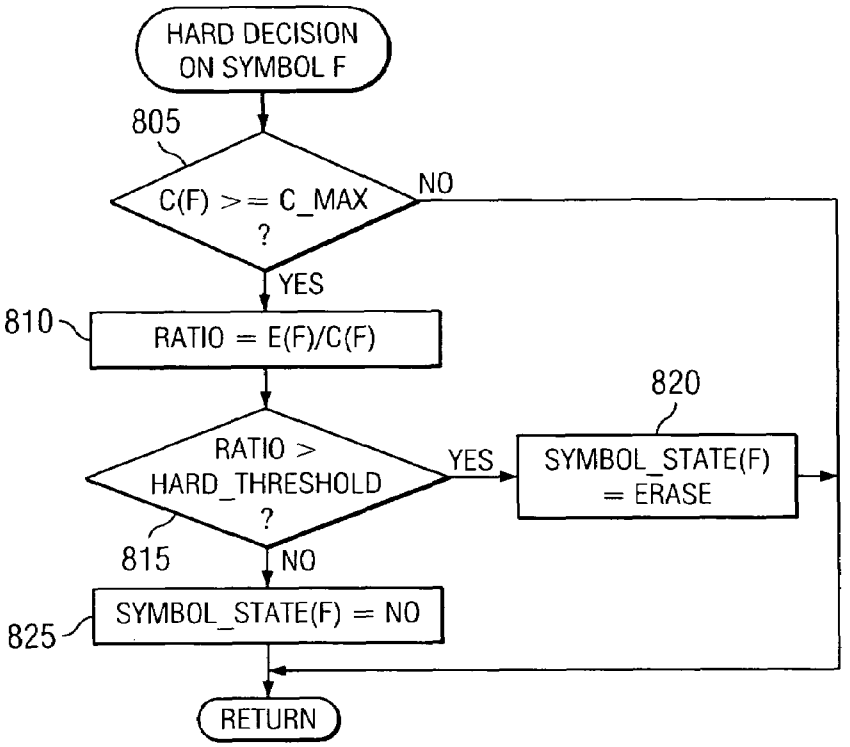
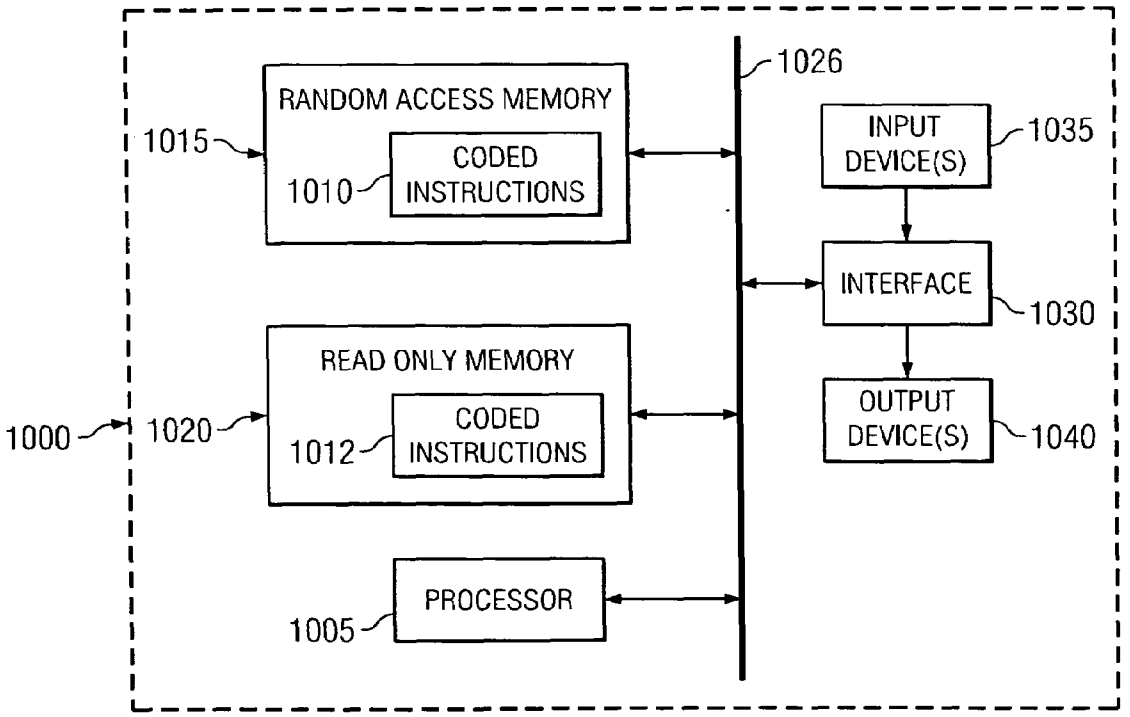

HARD DECISION ON SYMBOL F
805
C(F) >= C_MAX ?
NO
YES
810
RATIO = E(F)/C(F)
820
RATIO > HARD_THRESHOLD ?
YES
SYMBOL_STATE(F) = ERASE
815
NO
825
SYMBOL_STATE(F) = NO
RETURN

FIG. 10


1026
RANDOM ACCESS MEMORY
1015
CODED INSTRUCTIONS
1010
INPUT DEVICE(S)
1035
INTERFACE
1030
READ ONLY MEMORY
1000
1020
CODED INSTRUCTIONS
1012
OUTPUT DEVICE(S)
1040
PROCESSOR
1005

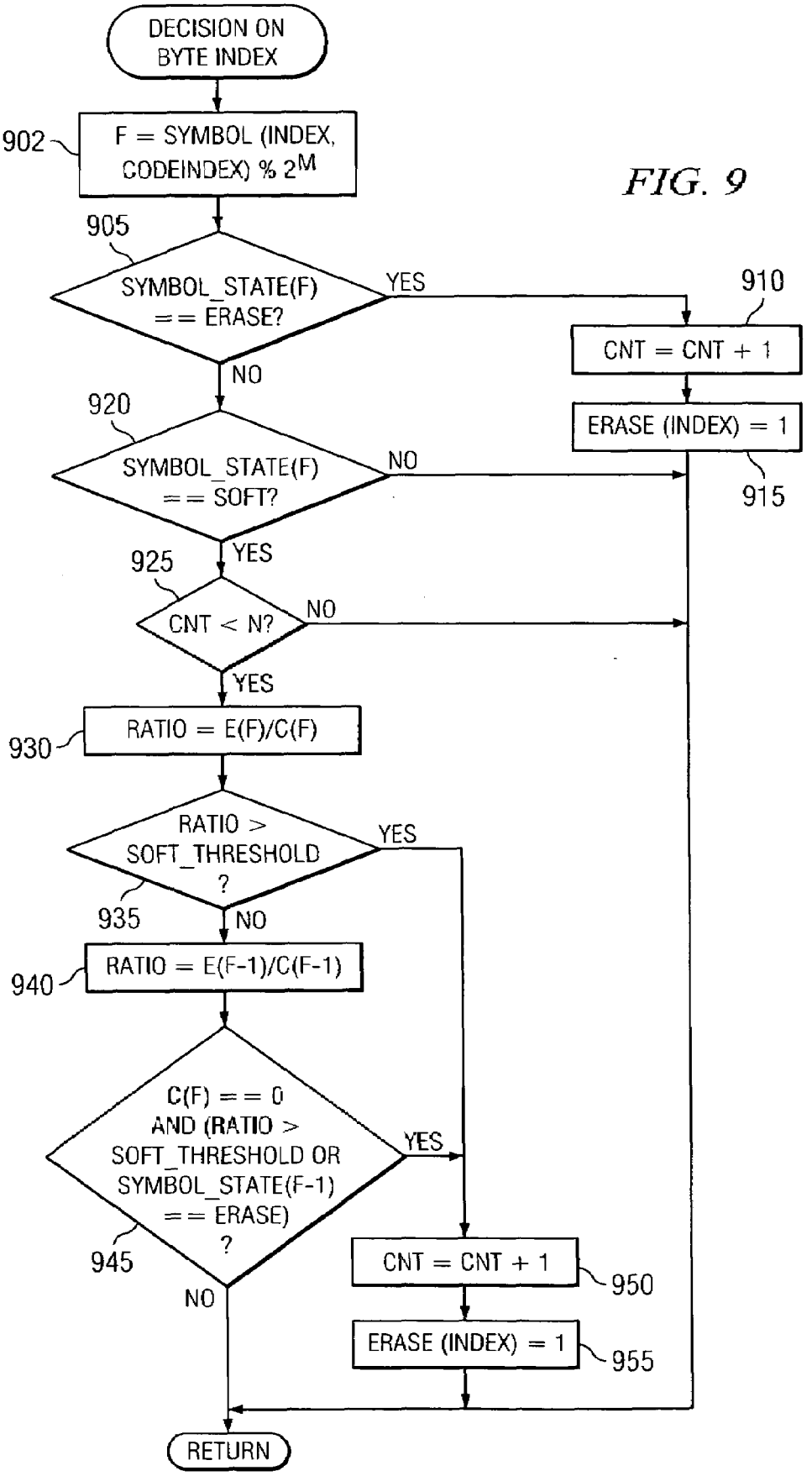

DECISION ON BYTE INDEX
902
F = SYMBOL (INDEX, CODEINDEX) % 2^M
905
SYMBOL_STATE(F) == ERASE?
YES
910
CNT = CNT + 1
ERASE (INDEX) = 1
915
NO
920
SYMBOL_STATE(F) == SOFT?
NO
YES
925
CNT < N?
NO
YES
930
RATIO = E(F)/C(F)
RATIO > SOFT_THRESHOLD ?
YES
935
NO
940
RATIO = E(F-1)/C(F-1)
C(F) == 0 AND (RATIO > SOFT_THRESHOLD OR SYMBOL_STATE(F-1) == ERASE) ?
YES
945
NO
CNT = CNT + 1
950
ERASE (INDEX) = 1
955
RETURN

FIG. 9

METHOD AND APPARATUS TO PERFORM ERASURE FORECASTING IN COMMUNICATION SYSTEMS

FIELD OF THE DISCLOSURE

[0001] This disclosure relates generally to communication systems and, more particularly, to methods and apparatus to perform erasure forecasting in communication systems.

BACKGROUND

[0002] In communication systems and/or networks, data is delivered from a transmitting device to a receiving device via a communications path and/or channel. Due to, for example, noise and/or interference present on the communication path and/or channel, the communications path and/or channel has a non-zero probability of, for instance, introducing an error into and/or a loss of any given portion (e.g., packet, block, word, byte, bit, etc.) of received data. In many communication systems and/or networks some form of error correction is utilized that allows the receiving station to detect and/or correct one or more introduced errors and/or recover lost data. For example, a communication system and/or network may employ systematic forward error correction (FEC) (e.g., Reed-Solomon) that transmits a finite set of original data symbols (e.g., words, bytes, bits, etc.) together with a finite sequence of check and/or redundancy symbols (i.e., additional symbols) that are, generally, computed from the finite set of original data symbols. The original data symbols and the additional symbols are collectively referred to as an error correction codeword or simply a codeword. To provide additional error protection for longer and/or more intrusive noise events (e.g., impulse noise, micro-interruptions, etc.) codewords may be interleaved. The variety and/or depth of interleaving utilized and/or the number of additional symbols included in a codeword determine the number and/or extent of introduced errors and/or lost data that may be detected, corrected and/or recovered by a receiving station.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. **1** is a diagram of an example communication system with a receiver constructed in accordance with the teachings of the invention.

[0004] FIG. **2** illustrates example interleaved data transmission for the example system of FIG. **1**.

[0005] FIG. **3** illustrates an example manner of implementing the example (Reed-Solomon) RS decoder sub-system of FIG. **1**.

[0006] FIG. **4** is an example erasure forecasting state table.

[0007] FIG. **5** illustrates an example manner of implementing the example byte-to-symbol mapper of FIG. **3**.

[0008] FIG. **6** illustrates example operation of the example erasure forecaster of FIG. **3** and/or, more generally, the example RS decoder sub-system of FIG. **1** and/or **3**.

[0009] FIGS. **7**, **8** and **9** are flowcharts representative of example processes that may be used to implement the example erasure forecaster of FIG. **3**.

[0010] FIG. **10** is a schematic illustration of an example processor platform that may be used and/or programmed to execute the example processes illustrated in FIGS. **7-9** to implement the example erasure forecaster of FIG. **3** and/or, more generally, the example RS-decoder sub-system of FIG. **1** and/or **3**.

DETAILED DESCRIPTION

[0011] FIG. **1** is a schematic diagram of an example communication system including communication devices **105** and **110** that communicate via any of a variety of transmission media **115** (e.g., wired, wireless, etc.). To facilitate transmission of user data from the example device **105** to the example device **110** via the transmission medium **115**, the example device **105** includes, among other things, a transmitter sub-system **107**. Likewise, to receive the transmitted data, the example device **110** includes, among other things, a receiver sub-system **112**.

[0012] The example devices **105**, **110** may operate, implement and/or communicate via and/or in accordance with any of a variety of communication standard(s), technology(-ies) and/or method(s). For example, the example devices **105**, **110** of FIG. **1** may implement any of a variety and/or variant of current and/or future digital subscriber line (DSL) technology such as, for example, Asymmetric DSL (ADSL), High-speed DSL (HDSL), Symmetric DSL (SDSL), and/or Very high-speed DSL (VDSL) and utilize a transmission media **115** that includes a telephone line (e.g., a ordinary twisted-pair copper telephone line used to provide Plain Old Telephone System (POTS) services). Such DSL technologies are commonly implemented in accordance with one or more applicable standards such as, for example, the International Telecommunications Union (ITU) standards G.992.1 (a.k.a. G.dmt), G.992.3, G.992.5 for ADSL modems, the ITU standard G.993.2 for VDSL, and/or the ITU standard G.994.1 (G.hs) for modems implementing handshake. Example devices **105**, **110** includes a DSL modem, a DSL access multiplexer (DSLAM), a residential gateway (RG), a personal computer (PC), and/or a set-top box (STB).

[0013] While, for purposes of illustration, the following disclosure is made with respect to example digital subscriber line (DSL) equipment, DSL services, DSL systems and/or the use of ordinary telephone lines for distribution of DSL services, persons of ordinary skill in the art will readily appreciate that the methods and apparatus to perform erasure forecasting disclosed herein may additionally and/or alternatively be applied to any type and/or variety of current and/or future communication equipment, communication services, communication technologies, communication networks and/or communication systems. For example, wireless distribution systems, wired or cable distribution systems, coaxial cable distribution systems, Ultra High Frequency (UHF)/Very High Frequency (VHF) radio frequency systems, satellite or other extra-terrestrial systems, cellular distribution systems, power-line broadcast systems and/or fiber optic networks. Alternatively and/or additionally, combinations of these devices, systems and/or networks may also be used.

[0014] For further purposes of illustration, the following disclosure is made with respect to codewords, interleaved data, encoding, decoding, interleaving and/or de-interleaving based on bytes. However, persons of ordinary skill in the art will readily appreciate that codewords, interleaved data, encoding, decoding, interleaving and/or de-interleaving may

be based on any of a variety of elements and/or symbols such as, for example, bits, words, multiple bytes, packets, etc.

[0015] In further detail, the example transmitter sub-system **107** of FIG. **1** transmits user and/or control data and/or information **120**. The example data **120** may be provided to and/or be otherwise obtained by the example transmitter sub-system **107** and/or, more generally, the example device **105** via any of a variety of interface(s) and/or method(s). An example ADSL modem **105** includes any of a variety of Ethernet interfaces (not shown) to receive data **120** from any of a variety of user device(s) communicatively coupled to the example device **105** (e.g., a PC).

[0016] To apply forward error correction to the data and/or information **120** prior to transmission via the transmission medium **115**, the example transmitter sub-system **107** includes any of a variety of forward error correction encoders **125** such as an RS encoder. During operation of the example transmitter sub-system **107** of FIG. **1**, the data and/or information **120** is passed to the example RS encoder **125**, which applies any of a variety and/or variant of RS FEC to blocks of bytes of the data and/or information **120** to form a sequence of codewords **130**. Using any of a variety of technique(s), method(s) and/or algorithm(s), the example RS encoder **125** of FIG. **1** performs encoding in accordance with methods and/or parameters described and/or specified in, for example, the ITU standards for ADSL modems (e.g., G.992.1, G.992.3, G.992.5).

[0017] To interleave the sequence of codewords **130**, the example transmitter sub-system **107** of FIG. **1** includes any of a variety of interleavers **135**. Using any of a variety of technique(s), method(s) and/or algorithm(s), the example interleaver **135** of FIG. **1** interleaves the sequence of codewords **130** to form interleaved data **140**. Because of the interleaving applied by the example interleaver **135**, each segment and/or period of the interleaved data **140** contains bytes from one or more of the codewords **130**. Likewise, bytes of a particular codeword **130** are spread among one or more segments and/or periods of the interleaved data **140**. As such, the partial and/or whole corruption of a portion of the interleaved data **140** results in corresponding errors in one or more received codewords (e.g., codewords **130**) at a subsequent receiver (e.g., the example receiver sub-system **112**). However, since due to the interleaving each of the affected received codewords **130** have correspondingly fewer corrupted bytes, the likelihood that a RS decoder (e.g., a RS decoder sub-system **175**) at the receiver **112** can detect and/or correct the affected bytes in the affected received codewords **130** is increased. Interleaving, as described above, provides additional protection against, for example, impulse noise and/or micro-interruptions that may affect one or more interleaved periods and/or segments, data frames and/or DMT frames by spreading a correctable number of errors into a correspondingly larger number of received codewords **130**.

[0018] To transmit the interleaved data **140** via the transmission medium **115**, the example transmitter sub-system **107** of FIG. **1** includes any of a variety of transmitters **145**. An example transmitter **145** transmits the interleaved data **140** via discrete-multitone (DMT) symbols and/or signals by performing, among other things, trellis coding, data frame creation, bit-to-tone mappings, constellation encodings, inverse discrete Fourier transforms, parallel-to-serial conversions, upsampling, filtering, digital-to-analog conversions and/or amplification in accordance with current and/or future ITU standards for ADSL modems (e.g., G.992.1, G.992.3, G.992.5). An example relationship between the codewords **130**, the interleaved data **140** and transmitted signals (e.g., DMT symbols) is discussed below in connection with FIG. **2**.

[0019] The example receiver sub-system **112** of FIG. **1** receives and/or decodes signals **150** (e.g., DMT symbols **150**) received via the transmission medium **115**. To receive the signals **150**, the example receiver sub-system **112** of FIG. **1** includes any of a variety of receivers **155**. An example receiver **155** extracts received interleaved data **140** from a received DMT signal and/or symbols **150** by performing, among other things, gain control, filtering, analog-to-digital conversions, down-sampling, equalization, discrete Fourier transforms, serial-to-parallel conversions, constellation decoding, trellis decoding, tone-to-bit mappings and/or payload extraction in accordance with current and/or future ITU standards for ADSL modems (e.g., G.992.1, G.992.3, G.992.5). The example receiver **115** of FIG. **1** and/or, more generally, the example receiver sub-system **112** keep a running count of received DMT symbols **150**. The index of the DMT symbols **150** will be used by the example RS decoder sub-system **175** of FIG. **1** as described below in connection with FIGS. **3-9**. It will be apparent to persons of ordinary skill in the art that to facilitate communication, the example receiver **155** and the example transmitter **145** of FIG. **1** receive and transmit signals using compatible and/or interoperable parameter(s), method(s), technique(s), algorithm(s) and/or in accordance with any of a variety of interoperable current and/or future standards.

[0020] To de-interleave the received interleaved data **140**, the example receiver sub-system **112** of FIG. **1** includes any of a variety of de-interleaver **165**. Using any of a variety of technique(s), method(s) and/or algorithm(s), the example de-interleaver **165** of FIG. **1** deinterleaves the received interleaved data **140** to form a sequence of received codewords **130**. Like the example transmitter **145** and the example receiver **155**, the example interleaver **135** and the example de-interleaver **165** perform interleaving and de-interleaving using compatible and/or interoperable parameter(s), method(s), technique(s), algorithm(s) and/or in accordance with any of a variety of interoperable current and/or future standards. For example, utilizing a common interleaver depth and/or codeword size.

[0021] To decode the received codewords **130**, the example receiver sub-system **112** of FIG. **1** includes a RS decoder sub-system **175** constructed in accordance with the teachings of the invention. The example RS decoder sub-system **175** performs RS decoding to decode the received codewords **130** to obtain received user and/or control data and/or information **120**. In particular, the example RS decoder sub-system **175** of FIG. **1** performs (a) erasure forecasting to identify probable locations of byte errors (i.e., erasures, erasures locations) and (b) RS decoding, error correction and/or error detection based on the erasures to obtain the received user and/or control data and/or information **120**. The example RS decoder sub-system **175** and/or, more generally, the example receiver sub-system **112** of FIG. **1** keep a running count of received codewords **130**. The index of the received codewords **130** is used by the example RS decoder sub-system **175** of FIG. **1** as described below in connection with FIGS. **3-9**. Any of a variety of method(s) and/or technique(s) may be used to limit the number of bits

required to implement the codeword index. For example, the codeword index could be maintain modulo 2^t, where t is chosen based upon the maximum number of received codewords **130** that need be tracked and/or referred to in the receiver sub-system **112** (e.g., at least the product of the maximum number of DMT symbols that may affect any given received codeword **130** and the maximum number of codewords **130** having at least one byte in any given DMT symbol).

[0022] Persons of ordinary skill in the art will appreciate that, although the same reference numerals are used to refer to the data **120**, the codewords **130** and the interleaved data **140**, the data **120**, the codeword **130** and/or the interleaved data **140** at the transmitter **105** and receiver **110** may be different due to noise, errors, etc. For example, the codewords **130** at the receiver **110** represent possibly modified versions of the codewords **130** at the transmitter **105** and, thus, may or may not constitute actual codewords due to, for example, a loss of frame and/or synchronization. However, since the received codewords **130** will be subsequently decoded by the RS decoder sub-system **175** as codewords for ease of discussion they will simply be referred to herein as received codewords **130**.

[0023] If the received codewords **130** contain no byte errors due to noise and/or interference, the received data **120** will be identical to the transmitted data **120**. Additionally or alternatively, if the number of errors in a particular received codeword **130** does not exceed the error correction capability of the RS decoder sub-system **175**, the RS decoder sub-system **175** of FIG. **1** is able to correct the errors and, again, the received data **120** will be identical to transmitted data **120**. Persons of ordinary skill in the art will readily recognize that the error correction capability of the example RS decoder sub-system **175** is R/2 if we don't know the locations of errors, where R is the number of redundancy and/or check bytes added to a transmitted codeword (e.g., the codewords **130**) by a corresponding RS encoder (e.g., the example RS encoder **125** of FIG. **1**). Persons of ordinary skill in the art will also readily recognize that if the locations of errors are know and erasure decoding is performed by the example RS decoder sub-system **175** of FIG. **1**, then the example RS decoder sub-system **175** can have an error correction capability as large as R symbols. However, to perform erasure decoding, the example RS decoder sub-system **175** needs to know, be told, determine and/or estimate which bytes are and/or are likely to be in error.

[0024] As discussed below in connection with FIGS. **3-9**, to obtain increased error correction capability, the example RS decoder sub-system **175** of FIG. **1** performs erasure forecasting to determine and/or predict which bytes of which received codewords have a reasonable likelihood of being in error, and then marks such bytes for erasure during subsequent RS decoding. As used commonly in the industry, such identified error locations are referred to as "erasures" and/or "erasure locations" since the example RS decoder sub-system **175** "erases" the data in the erased locations (i.e., sets the data to zero) prior to the start of RS decoding.

[0025] The RS decoder sub-system **175** of the illustrated example exploits the properties and/or parameters (e.g., convolutional interleaving, triangular interleaving, interleaving depth, codeword size, number of interleaved bit and/or bytes transported in a DMT symbol, etc.) of the example interleaver **135**, the example transmitter **145**, the example receiver **155** and/or the example de-interleaver **165** to detect which, if any, DMT symbols **150** are, and/or are likely to be, affected and/or corrupted by, for example, impulse noise. Once corrupted and/or affected received DMT symbols **150** are detected, the example RS decoder sub-system **175** erases not yet decoded bytes associated with the affected and/or corrupted received DMT symbols **150** (i.e., knows the locations of errored and/or potentially errored bytes), thereby increasing the error correction capability of example RS decoder sub-system **175** by as much as a factor of two. In general, the example RS decoder sub-system **175** of FIG. **1** monitors for actual errors associated with received DMT symbols **150**, uses the actual errors to detect corrupted and/or affected received DMT symbols **150**, and then erases bytes associated with the corrupted and/or affected received DMT symbols **150**. An example implementation of the example RS-decoder sub-system **175** of FIG. **1** is discussed below in connection with FIG. **3**.

[0026] While the methods and apparatus disclosed herein detect error events based on errors associated with DMT symbols **150** and/or erase bytes associated with corrupted DMT symbols **150**, persons of ordinary skill in the art will readily appreciate that the detection of error events and the determination of which bytes to erase may be made based upon any unit, period, segment and/or interval of the interleaved data **140**. For example, error event detection and/or erasure decisions may be based upon DMT symbols **150**, interleaver periods and/or segments, and/or data frames.

[0027] While example devices **105**, **110**, an example transmitter sub-system **107** and an example receiver sub-system **112** have been illustrated in FIG. **1**, the elements, modules, logic, sub-systems and/or devices illustrated in FIG. **1** may be combined, re-arranged, eliminated and/or implemented in any of a variety of ways. Further, the example devices **105**, **110**, the example transmitter sub-system **107** and/or the example receiver sub-system **112** may be implemented by hardware, software, firmware and/or any combination of hardware, software and/or firmware. Moreover, the example devices **105**, **110**, the example transmitter sub-system **107** and/or the example receiver sub-system **112** may include additional elements, modules, logic, sub-systems and/or devices than those illustrated in FIG. **1** and/or may include more than one of any or all of the illustrated elements, modules, subsystems and/or devices. For example, the devices **105**, **110** may include a digital signal processor (DSP), the device **105** may include a receiver sub-system and/or the device **110** may include a transmitter sub-system to allow the device **110** to transmit data and/or information to the device **105**. Additionally or alternatively, the transmitter sub-system **107** may include more than one RS encoder **125** and/or more than one interleaver **135** so that the transmitter sub-system **112** and/or, more generally, the device **105** can support multiple latency paths as described in, for example, the ITU G.992.3 standard.

[0028] FIG. **2** illustrates example relationships between codewords, interleaved data and transmitted data frames and/or DMT symbols for the example system illustrated in FIG. **1**. Starting with a sequence of codewords **130**, three of which are shown in FIG. **2** with reference numerals **205**, **210** and **215**, the example interleaver **135** of FIG. **1** forms interleaved data **140**. The example interleaver **135** of FIG. **1** outputs a segment and/or portion of the interleaved data **140** each time the interleaver **135** operates, three of which are shown in FIG. **2** with reference numerals **220**, **225** and **230**. While the interleaved data segments **220**, **225** and **230** are

illustrated in FIG. **2** as having the same length as the codewords **130**, the interleaved data segments **220**, **225** and **230** need not have the same length and/or size as the codewords **130**. As illustrated in FIG. **2**, example portions **235**, **240** and **245** of the example codeword **205** (e.g., containing one or more bytes) are placed by the interleaver **135** into interleaved data segments **220**, **225** and **230**, respectively. Likewise, the example interleaved data segment **230** includes example portions **245**, **250** and **255** of the example codewords **205**, **210** and **215**, respectively. Persons of ordinary skill in the art will readily appreciate that the number of interleaved data segments **140** that a particular codeword **130** is interleaved into and/or the number of codewords **130** having bytes in a particular interleaved data segment **140** depends upon the interleaving parameter(s) of the interleaver **135** (e.g., interleaver depth d) and/or the number of bytes k in each of the codewords **130**.

[0029] In the illustrated examples of FIG. **1** and/or **2**, a portion of the interleaved data **140** is used to form transmit data frames, two of which are illustrated in FIG. **2** with reference numerals **260** and **265**. In the illustrated example of FIG. **2**, each of the example transmit data frames **260** and **265** include a portion of two interleaved data segments **220**, **225** and/or **230**. The example transmit data frame **260** of FIG. **2** includes (a) a header **270** that contains, for example, control information regarding the data frame **260** and (b) a data payload **275** that contains the one or more portions of one or more interleaved data segments **220**, **225** and/or **230**. Persons of ordinary skill in the art will readily appreciate that the number and/or size of portions of interleaved data **140** used to form the payload (e.g., the payload **275**) of a transmit data frame (e.g., the data frame **260**) depends upon the size of the payload (e.g., number of bits and/or bytes P) and/or the number of bytes N in each of the interleaved codewords **140**.

[0030] In the example transmitter sub-system **107** of FIG. **1**, transmit data frames **260**, **265** are modulated and/or transmitted via the transmission medium **115** to a receiver (e.g., the example receiver sub-system **112**). In the example system of FIG. **1**, the transmitter sub-system **107** transmits and/or modulates the transmit data frames **260**, **265** in accordance with an ADSL standard such as, for example, the ITU G.992.1, G.992.3 and/or G.992.5 standards, where each transmit data frame **260**, **265** is transmitted via one or more DMT symbols. The example data frames **260**, **265** may represent any portion of the data carried by any number of DMT symbols. That is, the number of bits and/or bytes in each of the data frames **260**, **265** need not be the same as the number of bits and/or bytes carried by any particular DMT symbol and, in fact, may be larger or smaller. The number of bits and/or bytes P carried in each DMT symbols depends upon the transmit data rate (e.g., bits per second) of the transmitter sub-system **107**. Moreover, even if the codewords **130** and/or the interleaved data **140** are based on bytes, neither the data frames **260**, **265** nor resultant DMT symbols need be based on bytes but may be based on bits, bytes and/or words. However, any of a variety of alternative and/or additional method(s), algorithm(s), technique(s) and/or standard(s) may be used to transmit and/or modulate transmit data frames (e.g., quadrature amplitude modulation (QAM)).

[0031] At a receiving device (e.g., the example device **110** of FIG. **1**), the process described above is performed in reverse order. Namely, a signal (e.g., the example received DMT symbols **150** of FIG. **1**) is received and/or demodulated by a receiver (e.g., the example receiver **155** of FIG. **1**) to form and/or obtain a received version of the transmit data frames **260**, **265** (i.e., received data frames **260**, **265**). For example, a DMT symbol is received and/or decoded to recover the payload data **275** for any or all of one or more data frames and, thus, one or more portions of one or more interleaved data segments **220**, **225** and/or **230**. If no noise is present on the line, then received data frames **260**, **265** will be substantially similar to the transmit data frames **260**, **265**. Any difference(s) represents errors due to transmission via the transmission medium **115** (e.g., impulse noise, cross-talk noise, background noise, etc.) and/or implementation limitations of the device **105** and/or **110** (clipping, saturation, linearity, etc.). The payloads of received data frames **260**, **265** are used to form received interleaved data (e.g., the example received interleaved data **140** of FIG. **1**) that are de-interleaved by a de-interleaver (e.g., the example de-interleaver **165** of FIG. **1**) to form received codewords (e.g., the received codewords **130** of FIG. **1**). Next, the received codewords **130** are decoded by an RS decoder (e.g., the example RS decoding sub-system **175** of FIG. **1**) to obtain received user and/or control data and/or information (e.g., the example data **120** of FIG. **1**).

[0032] Persons of ordinary skill in the art will readily appreciate that when transmit data frames (e.g., the example frames **260** and **265**) are transmitted via DMT symbols, an impulse noise event can cause signal degradation such that the payload **275** and/or header **270** of one or more transmit data frames **260**, **265** may be partially and/or wholly corrupted. When and/or if such data frame and/or header corruption occurs corresponding portions of received interleaved data **140** and/or received codeword(s) **130** may be wholly and/or partially errored. The number and/or location of affected bytes within the received codeword(s) **130** depends upon the properties and/or parameters of the interleaver **135**, the example transmitter **145**, the example receiver **155** and/or the example de-interleaver **165** (e.g., convolutional interleaving, triangular interleaving, interleaving depth, codeword size, number of interleaved bytes transported in a DMT symbol, etc.).

[0033] Consider an example impulse noise event that corrupts one or more DMT symbols. If sufficient interleaving is applied by the interleaver **135** so that at most R bytes of any received codeword **130** are associated with any or all of the one or more corrupted DMT symbol, collectively, then, if the example RS decoder sub-system **175** of FIG. **1** detects the corrupted DMT symbols, the example RS decoder sub-system **175** can again utilize erasure decoding to correct all errors in the received codewords **130**. In this example scenario, any particular received codeword **130** may have more than R/2 errored bytes (but no more than R) and, thus, RS decoding without the use of erasures may not be able to correctly decode each received codeword **130**. By performing erasure forecasting to detect corrupted DMT symbols, and then exploiting properties of the interleaver to determine appropriate erasure locations, the example RS decoder sub-system **175** of FIG. **1** improves the error correction capabilities of the example device **110**. The RS decoder sub-system **175** of FIG. **1** handles, for example, impulse noise events that corrupt a variable number of DMT symbols.

[0034] FIG. **3** illustrates an example manner of implementing the example RS decoder sub-system **175** of FIG. **1**.

To perform RS decoding, the example RS decoder sub-system **175** of FIG. **3** includes any of a variety of RS decoder **305**. Using any of a variety of method(s), algorithm(s), logic and/or technique(s), the example RS decoder **305** of FIG. **3** performs RS decoding and/or erasure decoding of received codewords **130**. For example, the RS decoder **305** uses Euclid's algorithm and a Chien search to decode the received codewords **130**. In the example of FIG. **3**, received codewords contain a maximum of 255 bytes.

[0035] To improve the error correction capability, the example RS decoder sub-system **175** includes an erasure locations store **310**. The example erasure locations store **310** of FIG. **3** is implemented as sixteen (16) eight (8)-bit registers. However, the erasure locations store **310** may be implemented by any of a variety and/or number of memories, registers, etc. The 256 bits of the example erasure locations store **310** of FIG. **3** indicate whether a respective byte of a given received codeword **130** is to be erased. As discussed below, the erasure locations store **310** will be updated prior to the decoding of each received codeword **130** by the example RS decoder **305**. Using any of a variety of method(s), algorithm(s), logic and/or technique(s), the example RS decoder **305** utilizes the data in the erasure locations store **310** to perform erasure decoding during the decoding of the received codewords **305**.

[0036] To store indications of errored bytes, the example RS decoder sub-system **175** of FIG. **3** includes actual error locations store **315**. The example actual error locations store **315** of FIG. **3** is implemented as sixteen (16) eight (8)-bit registers. However, the actual error locations store **315** may be implemented by any of a variety and/or number of memories, registers, etc. The 256 bits of the example actual error locations store **315** of FIG. **3** indicate whether an error of a respective byte of a given received codeword **130** was detected and/or corrected by the example RS decoder **305**. That is, the example actual error locations store **315** identify byte locations having a different value at the input **130** and output **120** of the example RS decoder **305** and, thus, may include bytes that were corrected by the example RS decoder **305**. The actual error locations store **315** is updated by the example RS decoder **305** after the decoding of each received codeword **130**.

[0037] To determine erasure locations, the example RS decoder sub-system **175** of FIG. **3** includes an erasure forecaster **320**. The example erasure forecaster **320** of FIG. **3**: (a) utilizes the actual error locations store **315** for one or more previously decoded received codewords **130** to determine if and/or which received DMT symbols **150** are affected and/or corrupted, and (b) if received DMT symbols **150** are affected and/or corrupted, sets and/or indicates erasure locations in the erasure locations store **310** for the affected bytes of received codewords **130**. If no DMT symbols **150** are affected and/or corrupted, no erasures are indicated in the erasure locations store **310** by the example erasure forecaster **320**. As discussed below in connection with FIGS. **4-9**, the example erasure forecaster **320** of FIG. **3** utilizes the properties of the interleaver to determine which bytes of which codewords are associated with particular received DMT symbols **150**.

[0038] In the illustrated example of FIG. **3**, the example stores **310** and **315** store erasure locations and actual error locations, respectively for single codewords. However, the stores **310** and/or **315** may store data for more than one codeword. For example, the erasure forecaster **320** may utilize actual error locations from the store **315** for two or more codewords and then determine and/or store erasure locations in the store **310** for the next one or more codewords to be decoded.

[0039] The erasure forecaster **320** of the illustrated example tracks, for each of one or more DMT symbols **150**, the number of previously decoded bytes and the number of errored bytes. An example structure for use in tracking each DMT symbol **150** is discussed below in connection with FIG. **4**. In general, the example erasure forecaster **320** of FIG. **3** uses the ratio of the number of errored bytes to the number of decoded bytes for a particular DMT symbol **150** as a metric of the extent to which that particular DMT symbol **150** is affected and/or corrupted. If the ratio is high enough (e.g., equals or exceeds a predetermined threshold such as 75%), the example erasure forecaster **320** make a soft decision and decides and/or declares that the DMT symbol **150** is corrupted and marks subsequently decoded bytes associated with the DMT symbol **150** for erasure. While the example erasure forecaster **320** of FIG. **3** uses the ratio of the number of errored bytes to the number of decoded bytes to make soft erasure decisions, any decision metric such as comparing the number of errored bytes to a threshold may additionally or alternatively be used. The erasure forecaster **320** may also be selectively configured to use the ratio and/or the number of errored bytes to make erasure decisions. For a DMT symbol **150** that has been declared as corrupted, the example erasure forecaster **320** of FIG. **3** determines if any bytes associated with the DMT symbol **150** are present in the next received codeword **130** to be decoded. If there are bytes associated with the corrupted DMT symbol **150** present in the next received codeword **130**, the example erasure forecaster **320** of FIG. **3** instructs the RS decoder **305** to erase the bytes by, for example, setting the respective bit(s) in the example erasure location registers **310** to one (1).

[0040] Once a pre-determined number of bytes have been decoded for a particular data frame, the example erasure forecaster **320** of FIG. **3** makes a final (i.e., hard) decision whether the DMT symbol **150** is affected and/or corrupted. The final decision for a given DMT symbol **150** is based on the ratio of the number of errored bytes to the number of already decoded bytes for the DMT symbol **150** and is made by comparing the ratio to the same or to a different threshold (e.g., such as 65%). If the ratio equals or exceeds the threshold, then the example erasure forecaster **320** of FIG. **3** marks all subsequent decoded bytes associated with the DMT symbol **150** for erasure via the example erasure location registers **310**. If the ratio does not exceed the threshold, none of the subsequently decoded bytes associated with the DMT symbol **150** are marked for erasure by the example erasure forecaster **320**. While the example erasure forecaster **320** of FIG. **3** uses the ratio of the number of errored bytes to the number of decoded bytes to make hard erasure decisions, any decision metric such as comparing the number of errored bytes to a same or different threshold may additionally or alternatively be used. The erasure forecaster **320** may also be selectively configured to use the ratio and/or the number of errored bytes to make erasure decisions. The example erasure forecaster **320** of FIG. **3** need only track the number of decoded and/or errored bytes for a particular DMT symbol **150** until a hard decision is made.

[0041] Prior to the hard decision for a particular data frame, the example erasure forecaster **320** of FIG. **3** makes

a decision on a codeword by codeword basis (i.e., a soft decision) whether to erase bytes associated with the DMT symbol **150** in the next received codeword. After each received codeword **130** is decoded by the RS decoder **305**, the example erasure forecaster **320** reads the actual error location registers **315** and updates the number of decoded bytes and errored bytes for each DMT symbol **150** having bytes in the received codeword **130** and currently being tracked (i.e., DMT symbol **150** for which no hard decision has been made). Then, for each DMT symbol **150** having one or more bytes in the next received codeword **130**, the example erasure forecaster **320** of FIG. **3** determines which bytes associated with which data frame(s) should be erased and sets the corresponding bits in the example erasure location registers **310**. Like hard decisions, soft decisions are made by comparing the ratio of the number of errored bytes to the number of already decoded bytes for the DMT symbol **150** to a threshold such as 75%. However, unlike hard decisions which apply to the remainder of a data frame, a soft decision only applies to the next received codeword **130**. The threshold used for making soft decisions may be the same or different from that used for making hard decisions. While the example erasure forecaster **320** of FIG. **3** makes both soft and hard erasure decisions, the erasure forecaster **320** may simply utilize either soft or hard decisions.

[0042] As discussed below in connection with FIG. **6**, soft and/or hard decisions for each DMT symbol **150** may be independent, dependent, related and/or inter-coupled. Moreover, time intervals over and/or during which soft and/or hard decisions are made for one or more DMT symbols **150** may be disjoint and/or partially and/or wholly overlap. Consider, for example, a first time interval during which the example erasure forecaster **320** of FIG. **3** tracks and makes soft decisions related to a first data frame. During a second time interval that follows the first time interval, the example erasure forecaster **320** tracks and makes soft decisions related to the first and a second data frame. At the start of a third time interval that follows the second time interval, the example erasure forecaster **320** makes a hard decision regarding corruption of the first data frame. Then, during the remainder of the third time interval, the erasure forecaster **320** continues tracking and making soft decisions related the second DMT symbol **150** and marks erasures (i.e., decides to erase) based on the hard decision for the first data frame. Persons of ordinary skill in the art will readily appreciate that the example erasure forecaster **320** of FIG. **3** may, thus, track and make hard and/or soft decisions for two or more DMT symbols **150** over any combination of overlapping and/or non-overlapping time intervals. Example manners of implementing the example erasure forecaster **320** and/or, more generally, the example RS decoder sub-system **175** of FIG. **3** are discussed below in connection with FIGS. **6-9**.

[0043] If a receiver (e.g., the example receiver sub-system **112** of FIG. **1**) implements multiple latency paths, then erasure forecasting can be performed for the latency paths independently or dependently. If the latency paths are considered separately, then errors are tracked and erasure decisions made for each latency path separately. That is, an impulse noise can be detected and erasures made in one latency path while a second latency path having sufficient impulse noise protection and/or not exhibiting the same interference does not warrant and/or benefit from erasures.

[0044] To store the data necessary and/or useful to track errors and/or make erasure decisions (i.e., erasure forecasting), the example RS decoder sub-system **175** of FIG. **3** includes an erasure forecasting state table **325**. An example data structure to implement the example erasure forecasting state table **325** of FIG. **3** is discussed below in connection with FIG. **4**. The example erasure forecasting state table **325** may be stored in any of a variety of memory(-ies), register(s), etc. **327**. Persons of ordinary skill in the art will also readily appreciate that the maximum number of DMT symbols **150** that may affect any given received codeword **130** (i.e., maximum number of active DMT symbols **150**) depends upon the parameters and/or properties of the interleaving/de-interleaving. Thus, for a given set and/or range of interleaving/de-interleaving parameters and/or properties supported by a given receiver (e.g., the example receiver **110** of FIG. **1**), the maximum number of active DMT symbols **150** for which erasure forecasting is required is correspondingly limited. Accordingly, the example erasure forecasting state table **325** of FIG. **3** stores data associated with active DMT symbols **150**, and overwrites and/or discards data associated with inactive frames (e.g., frames which are no longer for further decoding). In the example RS decoder **175** of FIG. **3**, the maximum number of DMT symbols **150** that are simultaneously considered is a power of 2 (i.e., 2^M), where 2^M is at least equal to the maximum number of active frames. That is, the forecasting state table **325** stores at least enough data to allow the maximum number of active frames to be considered. The example erasure forecasting state table **325** of FIG. **3** is indexed using a DMT symbol **150** counter and/or index modulo 2^M. That is, the lowest M-bits of the frame number can be used to index the example forecasting state table **325**.

[0045] To store parameters that specify the current properties and/or parameters of the RS decoding and/or de-interleaving being applied to the received interleaved data **140** and/or the received codewords **130**, the example RS decoder sub-system **175** of FIG. **3** includes control variables **330**. The control variables **330** may be stored in any of a variety of memory(-ies), register(s), etc. **332**. Example control variables **330** include: (i) interleaver depth d, (ii) codeword size k, (iii) number of interleaved bits and/or bytes P per DMT symbol **150** and/or DMT symbol, (iv) maximum number of erasures per codeword R, (v) threshold for soft erasure decisions and/or (vi) threshold for hard decisions.

[0046] To compute which DMT symbol **150** corresponds to a particular byte of a particular codeword, the example RS decoder sub-system **175** of FIG. **3** includes a byte-to-symbol mapper **335**. Using one or more variables from the example control variables **330**, and a byte index and a codeword index provided by the example erasure forecaster **320**, the example byte-to-symbol mapper **335** of FIG. **3** computes and/or determines the DMT symbol **150** in which the specified byte of the specified codeword was transmitted and/or received. In the illustrated example of FIG. **3**, the byte index identifies each byte within a codeword **130** with the right-most byte of a codeword **130** (i.e., first byte of the codeword **130** out of the de-interleaver **165**) given a byte index of zero (0). The example byte-to-symbol mapper **335** of FIG. **3** may, for example, compute the DMT symbol **150** index corresponding to the k-th byte of the i-th codeword using the following mathematical expression:

$$\text{Frame\_Index} = \left\lfloor \frac{N * i + k * d}{P} \right\rfloor, \quad \text{EQN (1)}$$

where N is the number of bytes per codeword **130**, d is the de-interleaver depth, P is the number of bytes per DMT symbol **150**, and $\lfloor\ \rfloor$ represents the floor operator. An example manner of implementing the example byte-to-symbol mapper **335** of FIG. **3** is discussed below in connection with FIG. **5**.

[0047] In an example receiver (e.g., the example receiver sub-system **112** of FIG. **1**), the example erasure forecaster **320** of FIG. **3** is implemented as hard-coded logic and/or discrete gates, and the example RS decoder sub-system **175** of FIG. **1** and/or **3** is communicatively coupled to any of a variety of processors (e.g., a DSP) for any of a variety of control and/or debug purposes. The example erasure forecaster **320** of the illustrated example may be disabled such that, for example, the communicatively coupled processor may access the actual error locations store **315**, perform erasure forecasting (i.e., track error, error patterns and/or make erasure decisions) and/or provide the contents of the erasure locations store **310**. The communicatively coupled processor can implement any of a variety of additional and/or alternative erasure forecasting algorithm(s), method (s), logic(s), and/or technique(s).

[0048] Additional and/or alternative example methods and apparatus to implement the example erasure forecaster **320**, the example byte-to-symbol mapper **335** and/or, more generally, the example RS decoder sub-system **175** of FIG. **1** and/or **3** are described in U.S. patent application Ser. No. 11/159,476 filed on Jun. 23, 2005 which is hereby incorporated by reference in its entirety.

[0049] While an example RS decoder sub-system **175** has been illustrated in FIG. **3**, the elements, modules, logic, sub-systems and/or devices illustrated in FIG. **3** may be combined, re-arranged, eliminated and/or implemented in any of a variety of ways. Further, the example RS decoder **305**, the example erasure locations store **310**, the example actual error locations store **315**, the example erasure forecaster **320**, the example erasure forecasting state table **325**, the example control variables **330** and/or the example byte-to-symbol mapper **335** may be implemented by hardware, software, firmware and/or any combination of hardware, software and/or firmware. For example, the example erasure forecaster **320** may be implemented as machine accessible instructions executing on any of a variety of processors. Moreover, the example RS decoder sub-system **175** may include additional elements, modules, logic, sub-systems and/or devices than those illustrated in FIG. **3** and/or may include more than one of any or all of the illustrated elements, modules, sub-systems and/or devices. For example, the RS decoder sub-system **175** may include a second RS decoder **305** to decode codewords associated with a second latency path.

[0050] FIG. **4** illustrates an example data structure **325** for storing variables and/or data which is useful to erasure forecasting. The example erasure forecasting state table **325** of FIG. **4** contains a plurality of entries **405** for respective ones of DMT symbols **150** that are being tracked and/or for which erasure decisions are being made. As discussed above, the number of entries **405** is at least the maximum number of active DMT symbols **150** that can contribute at least one byte to any given codeword to be decoded at any given time and is dictated by the set and/or range of encoding/decoding and/or interleaving/de-interleaving parameters supported by the RS decoder sub-system **175** and/or, more generally, the example receiver sub-system **112** of FIG. **1** and/or **3**. In the illustrated example, the number of entries **405** is a power of 2 (i.e., 2^M) and the entries **405** are indexed using a DMT symbol counter and/or index modulo 2^M. That is, the lowest M-bits of the frame number can be used to index the example forecasting state table **325** of FIG. **4**

[0051] To record the actual (i.e., non-modulo) frame number and/or index, each of the example entries **405** has a frame number field **410**. The example frame number field **410** of FIG. **4** contains the contents of the frame number counter as maintained by, for example, the example receiver **155** as discussed above in connection with FIG. **1**.

[0052] To store the count of already decoded bytes for the active DMT symbols **150**, each of the example entries **405** include a count C field **415**. To store the count of errored-decoded bytes for the active DMT symbols **150**, each of the example entries **405** include a count E field **420**. After each received codeword **130** is decoded by the example RS decoder **305**, the example erasure forecaster **320** of FIG. **3** reads the example actual error locations store **315** and updates the count C fields **415** and the count E fields **420** with the corresponding number of decoded bytes and the number or errored-decoded bytes, respectively, for each DMT symbol **150** having bytes in the received codeword **130**. In the illustrated system of FIG. **1**, each DMT symbol **150** can contain a maximum of 4096 bytes (i.e., a maximum of 16-bits for each of 2048 DMT carriers) and, thus, the example count C fields **415** and the example count E fields **420** of FIG. **4** are implemented by twelve (12) bit fields and/or counters.

[0053] To store an indication of the current state of erasure forecasting for the active DMT symbols **150**, the example entries **405** include a state field **425**. The example state fields **425** of FIG. **4** contain one of three values: (i) zero (0) indicating that the corresponding DMT symbol **150** is currently being tracked and soft decisions are being made, (ii) one (1) indicating that a hard decision to erase subsequent bytes associated with the DMT symbol **150** has been made, or (iii) two (2) indicating a hard decision not to erase subsequent bytes associated with the DMT symbol **150** has been made.

[0054] Because once a hard decision is made for a particular DMT symbol **150** the count of the number of decoded bytes and the count of the number of error bytes are no longer needed for the data frame, the example entries **405** of FIG. **4** may instead utilize one of a set of shared decoded byte counters and errored byte counter pairs and the example count C fields **415** and the example count E fields **420** of FIG. **4** may be eliminated. Thus, the example erasure forecaster **320** may implement fewer pairs of counters thereby reducing implementation complexity. For example, the erasure forecaster **320** may implement 2^m pairs of counters, where 2^m is the maximum number of frames that may currently being in a soft decision state and m<M. The counter pair for a particular DMT symbol **150** may be determined as the DMT symbol counter and/or index modulo 2^m.

[0055] While an example data structure **325** has been illustrated in FIG. **4**, any of a variety of additional and/or

alternative data structures, tables, arrays, registers, variables, etc. may be used to store the data and/or information useful to track and/or make erasure decisions. Moreover, the example data structure may include and/or store any of a variety of additional and/or alternative data and/or information associated with any or all of the DMT symbols **150** including, for example, debug information.

[0056] FIG. **5** illustrates an example manner of implementing the example byte-to-symbol mapper **335** of FIG. **3**. The example byte-to-symbol mapper **335** of FIG. **5** implements the example mathematical equation illustrated in EQN (1). Additionally or alternatively, any of the methods and apparatus described in U.S. patent application Ser. No. 11/159,476 may be used to implement the example byte-to-symbol mapper **335** of FIG. **3** and/or **5**.

[0057] To compute the numerator of EQN (1), the example byte-to-symbol mapper **335** of FIG. **5** includes multipliers **505** and **510**, and an adder **515**. The example multiplier **505** of FIG. **5** multiplies the number of bytes per codeword N with the codeword index i and the example multiplier **510** of FIG. **5** multiplies the interleaver depth d with the byte index k. The example adder **515** of FIG. **5** adds the outputs of the multipliers **505** and **510** together.

[0058] To divide the output of the example adder **515** (i.e., the numerator of the example EQN (1)), the example byte-to-symbol mapper **335** of FIG. **5** includes a divider **520**. The example divider **520** of FIG. **5** divides the output of the example adder **515** by the bytes per frame P. To compute the floor of an output of the example divider **520**, the example the byte-to-symbol mapper **335** of FIG. **5** includes a floor operator **525**. The example floor operator **525** of FIG. **5** removes any fractional portion of the output value of the divider **525** to obtain the nearest integer value less than or equal to the output of the divider **520**.

[0059] While an example byte-to-symbol mapper **335** has been illustrated in FIG. **5**, the elements, modules, logic, sub-systems and/or devices illustrated in FIG. **5** may be combined, re-arranged, eliminated and/or implemented in any of a variety of ways. For example, the multipliers **505** and **510** may be implemented using a single multiplier. Further, the example byte-to-symbol mapper **335** may be implemented by hardware, software, firmware and/or any combination of hardware, software and/or firmware. Moreover, the example byte-to-symbol mapper **335** may include additional elements, modules, logic, subsystems and/or devices than those illustrated in FIG. **5** and/or may include more than one of any or all of the illustrated elements, modules, sub-systems and/or devices.

[0060] FIG. **6** illustrates an example operation of the example erasure forecaster **320** and/or, more generally, the example RS decoder sub-system **175** of FIG. **1** and/or **3**. The operation of the erasure forecaster **320** is illustrated in FIG. **6** over four (4) example time intervals **610**, **620**, **630** and **640**. As illustrated in FIG. **6**, during the example time interval **610**, the example RS decoder sub-system **175** is processing received codewords **130** containing data associated with DMT symbols **150***j*, *j*−1, *j*−2, etc. Starting with a received codeword C_1, the example RS decoder **305** decodes the received codeword C_1 as shown with reference numeral **611** and determines actual error location information **315** for the decoded received codeword C_1. Based on the error location information **315** for codeword C_1, the example erasure forecaster **320** updates the count of decoded bytes and the count of errored-decoded bytes for DMT symbol **150***j*, and then makes a soft decision regarding DMT symbol **150***j* for the next codeword C_2 as shown with reference numeral **612**. The example erasure forecaster **320** may also update counters and/or make soft and/or hard erasure decisions for DMT symbols **150***j*−1, *j*−2, etc. Based upon the erasure decisions, the erasure forecaster **320** sets the values of the erasure location registers **310** for codeword C_2.

[0061] For simplicity of understanding, throughout the remainder of the discussion regarding FIG. **6**, the passing of error locations via the actual error locations store **315** and erasure locations via the erasure locations store **310** between the RS decoder **305** and the erasure forecaster **320** will not be explicitly discussed. Persons of ordinary skill in the art will readily appreciate that it continues in a substantially similar fashion to that explained above. Moreover, while error tracking, soft and/or hard erasure decisions and/or setting erasures associated with DMT symbols **150***j*, *j*+1 and *j*+2 are discussed below, persons of ordinary skill in the art will also readily appreciate that error tracking, soft and/or hard erasure decisions and/or setting erasures for DMT symbols **150***j*−1, *j*−2, *j*−3 may also be occurring but, for simplicity of understanding, will also not be discussed below. However, persons of ordinary skill in the art will readily appreciate that error tracking, soft and/or hard erasure decisions and/or setting erasures for DMT symbols **150***j*−1, *j*−2, *j*−3, etc. may be occurring along with those for DMT symbols **150***j*, *j*+1, *j*+2, etc. depending upon the particular DMT symbols **150** contributing bytes to a presently considered codeword.

[0062] As illustrated in FIG. **6**, during the example time intervals **620** and **630**, the example RS decoder sub-system **175** is processing received codewords **130** containing data associated with DMT symbols **150***j*+1, *j*, *j*−1, etc. Starting with a received codeword C_2, the example RS decoder **305** decodes the received codeword C_2 as shown with reference numeral **621**. Based on the actual error location information for the decoded codeword C_2, the example erasure forecaster **320** updates the count of decoded bytes and the count of errored-decoded bytes for DMT symbols **150***j*+1 and *j*, makes soft decisions regarding DMT symbols **150***j* and *j*+1, and then sets erasures for bytes associated with DMT symbols **150***j* and *j*+1 for the next codeword C_3 based on the soft decisions as shown with reference numeral **622**.

[0063] Processing continues similarly till the decoding of a received codeword C_{N-1} as shown with reference numeral **623**. The example codeword C_{N-1} is the last codeword of the example time interval **620**.

[0064] Based on the actual error location information for the decoded codeword C_{N-1}, the example erasure forecaster **320** updates the count of decoded bytes and the count of errored-decoded bytes for DMT symbols **150***j*+1 and *j*. With the decoding of codeword C_{N-1} in the example of FIG. **6**, the count of the number of decoded bytes associated with DMT symbol **150***j* exceeds a count threshold, the example erasure forecaster **320** makes a hard decision regarding DMT symbol **150***j* and sets erasures for the next codeword C_N for bytes associated with DMT symbol **150***j* based on the hard decision as shown with reference numeral **631**. The erasure forecaster **320** also makes another soft decision for DMT symbol **150***j*+1, and sets erasures based on the soft decision for DMT symbol **150***j*+1 for bytes associated with frame j+1 for the next codeword C_N.

[0065] The RS decoder **305** then decodes codeword C_N as shown with reference number **632**. Based on the actual error

location information for the decoded codeword C_N, the example erasure forecaster **320** updates the count of decoded bytes and the count of errored-decoded bytes for DMT symbol **150***j*+1, sets erasures for the next codeword C_{N+1} for bytes associated with DMT symbol **150***j* based on the previously made hard decision, makes another soft decision for DMT symbol **150***j*+1, and sets erasures based on the soft decision regarding frame j+1 for bytes associated with DMT symbol **150***j*+1 the next codeword C_{N+1} as shown with reference numeral **633**.

[0066] Processing continues similarly until the decoding of a received codeword C_{M-1} as shown with reference numeral **634**. The example codeword C_{M-1} is the last codeword of the example time interval **630**. Based on the error location information for the decoded codeword C_{M-1}, the example erasure forecaster **320** updates the count of decoded bytes and the count of errored-decoded bytes for DMT symbol **150***j*+1, sets erasures for the next codeword C_M for bytes associated with DMT symbol **150***j* based on the previously made hard decision, makes yet another soft decision for DMT symbol **150***j*+1, and set erasures based on the soft decision for DMT symbol **150***j*+1 for bytes associated with DMT symbol **150***j*+1 for the next codeword CM as shown with reference numeral **635**.

[0067] As illustrated in FIG. **6**, during the example time interval **640**, the example RS decoder sub-system **175** is processing received codewords **130** containing data associated with DMT symbols **150***j*+2, *j*+1, *j*, etc. The RS decoder **305** decodes codeword C_M as shown with reference number **641**. Based on the actual error location information for the decoded codeword C_M, the example erasure forecaster **320** updates the count of decoded bytes and the count of errored-decoded bytes for DMT symbols **150***j*+2 and *j*+1, sets erasures for the next codeword C_{M+1} for bytes associated with DMT symbol **150***j* based on the previously made hard decision, makes a soft decision for DMT symbols **150***j*+2 and *j*+1, and sets erasures based on the soft decisions for bytes associated with DMT symbols **150***j*+2 and *j*+1 for the next codeword C_{M+1} as shown with reference numeral **642**.

[0068] While an example operation has been illustrated in FIG. **6**, persons of ordinary skill in the art will readily recognize that the methods and apparatus disclosed herein can be used to track and/or make erasure decisions for a wide variety of conditions, examples and/or systems. For example, at reference numeral **621**, where codeword C_2 has a first byte associated with DMT symbol **150***j*+1, and at reference numeral **622**, where error tracking and/or erasure decisions are first made for DMT symbol **150***j*+1, the example erasure forecaster **320** of FIG. **3** could also make a hard decision regarding DMT symbol **150***j*. In this example, a single pair of counters to count the number of decoded bytes and the number of errored bytes is sufficient and the example forecasting state table **325** can be accordingly simplified. That is, the tracking of errors and/or the making of erasure decisions proceed serially rather than in parallel.

[0069] In another example, at reference numeral **622**, the erasure forecaster **320** uses the error location information for frames j and j+1 collectively to make a simultaneous hard erasure decision regarding frames j and j+1. In this example, the erasure forecaster **320** is looking for error events that corrupt and/or affect exactly two DMT symbols **150**. Once a hard decision is made to erase bytes associated with frames j and j+1, the erasure forecaster **320** waits until all bytes associated with frames j and j+1 have been decoded before tracking error location information to identify another noise event. If a hard decision is made not to erase bytes associated with frames j and j+1, the error location information for frame j+1 is used as the starting point for making a hard decision related to DMT symbols **150***j*+1 and *j*+2; once the first byte associated with DMT symbol **150***j*+2 is decoded.

[0070] FIGS. **7**, **8** and **9** are flowcharts representative of example processes that may be used to implement the example erasure forecaster **320** and/or, more generally, the example RS decoder sub-system **175** of FIG. **1** and/or **2** to perform error tracking and/or make erasure decisions (i.e., erasure forecasting). The example processes of FIGS. **7**, **8** and/or **9** may be implemented using an application specific integrated circuit (ASIC), a programmable logic device (PLD), a field programmable logic device (FPLD), discrete logic, discrete gates, registers, hardware, firmware, etc. Alternatively, some or all of the example processes of FIGS. **7**, **8** and/or **9** may be executed by a processor, a controller and/or any other suitable processing device (e.g., the example processor **1005** discussed below in connection with FIG. **10**). For example, the example processes of FIGS. **7**, **8** and/or **9** may be embodied in coded instructions stored on a tangible medium such as a flash memory, read-only memory (ROM) and/or random access memory (RAM) associated with the processor. Also, some or all of the example flowcharts of FIGS. **7**, **8** and/or **9** may be implemented manually or as combinations of any of the foregoing techniques, for example, a combination of firmware and/or software and hardware. Further, although the example processes of FIGS. **7-9** are described with reference to the flowcharts of FIGS. **7-9**, persons of ordinary skill in the art will readily appreciate that many other methods of implementing the example erasure forecaster **320** and/or, more generally, the example RS decoder sub-system **175** of FIG. **1** and/or **2** to perform erasure forecasting may be employed. For example, the order of execution of the blocks may be changed, and/or some of the blocks described may be changed, eliminated, sub-divided, or combined. Additionally, persons of ordinary skill in the art will appreciate that the example processes of FIGS. **7**, **8** and/or **9** may be carried out sequentially and/or carried out in parallel by, for example, separate processing thread(s), processor(s), device(s), circuit(s), etc.

[0071] The example process of FIG. **7** begins when a received codeword **130** is decoded by the example RS decoder **305** and the RS decoder **305** determines actual error location information and writes it to the actual error location store **315**. An erasure forecaster (e.g., the example erasure forecaster **320** of FIG. **2**) increments a count of the received codewords (i.e., the codeword index) (block **704**).

[0072] The erasure forecaster **320** determines if a new DMT symbol **150** has one or more bytes in the just decoded codeword (block **705**). If the just decoded codeword has one or more bytes from a new DMT symbol **150** (block **705**), the erasure forecaster determines the corresponding index into the erasure forecasting state table **325** by computing the modulo 2^M of the DMT symbol **150** number where 2^M is the maximum number of active DMT symbols **150** (block **710**). The erasure forecaster than sets, for the new active DMT symbol **150**, the count of received decoded bytes to zero (block **712**), the count of errored decoded bytes to zero (block **714**) and the state to soft decision (e.g., zero (0)) (block **716**). Control then proceeds to block **720**.

[0073] If a new DMT symbol **150** has not started (block **705**), control proceeds to block **720** and skips blocks **710**,

712, 714 and 716. At block 720, the erasure forecaster sets an index variable to zero (0) to presently consider the first byte of the just decoded codeword (block 720). Using for example, the example mathematical expression illustrated in EQN (1) or the example byte-to-symbol mapper 335 of FIG. 3 and/or 5 to compute the DMT symbol number modulo 2^M corresponding to the current codeword (i.e., codeword index) and byte (i.e., index) (block 722). The erasure forecaster then increments the count of bytes decoded for the computed DMT symbol number (block 724) and determines if the presently considered byte of the currently indexed codeword was received errored (block 726).

[0074] If the presently considered byte was received in error (e.g., as identified in the actual error location store 315) (block 726), the erasure forecaster increments the count of errored bytes for the computed DMT symbol number (block 728). If the presently considered byte was not received in error (block 726), control proceeds to block 730 while skipping block 728.

[0075] At block 730, the erasure forecaster determines if all bytes of the codeword have been processed (block 730). If not all bytes have been processed (block 730), the erasure forecaster increments the byte index so that the next byte of the just decoded codeword is considered (block 732) and control returns to block 722 to process the next byte. If all bytes have been processed (block 730), control proceeds to block 740.

[0076] At block 740, the erasure forecaster sets an index into an erasure forecasting state table (e.g., the example state table 325 of FIG. 3 and/or 4) to zero (0) (block 740). Using, for example, the example process of FIG. 8, the erasure forecaster makes a hard decision regarding erasures for the presently considered DMT symbol 150 (block 742). If not all active DMT symbols 150 have been processed (e.g., $F<2^M-1$) (block 744), the erasure forecaster increments the index to consider the next active DMT symbol 150 (block 746) and control returns to block 742 to process the next active DMT symbol 150. If all active DMT symbol 150 have been processed (block 744), control proceeds to block 750.

[0077] In the illustrated example of FIG. 7, the erasure forecaster at blocks 740, 742, 744 and/or 746 processes each entry of the erasure forecasting state table. Additionally or alternatively, at blocks 740, 742, 744 and/or 746 the erasure forecaster can only process those DMT symbols 150 having at least one byte in presently considered codeword (i.e., just decoded). For example, at block 722 the erasure forecaster could track and/or record which DMT symbols 150 had at least one byte in the presently considered byte such that only those DMT symbols 150 need be processed at blocks 740, 742, 744 and/or 746. For example, the erasure forecaster could determine the smallest DMT symbol number and the largest DMT symbol number that correspond to the range of DMT symbols 150 having at least one byte in the presently considered codeword. The erasure forecaster could alternatively determine the smallest DMT symbol number of a DMT symbol having at least one byte in the presently considered codeword and the number of DMT symbols having at least one byte in the presently considered codeword.

[0078] At block 750, the erasure forecaster sets a count of the number of erasures marked for the next codeword to zero (block 750) and sets an index variable to zero (0) to presently consider the first byte of the next codeword (block 752). Using for example, the example process of FIG. 9, the erasure forecaster makes an erasure decision for the presently considered byte of the next codeword (block 754). If not all bytes have been processed (block 756), the erasure forecaster increments the byte index so that the next byte of the next codeword is considered (block 758) and control returns to block 754 to make an erasure decision for the next byte of the next codeword. If all bytes have been processed (block 756), control exits from the example process of FIG. 7.

[0079] The example process of FIG. 8 begins, for example, when called from the example process for FIG. 7 to make a hard erasure decision for a DMT symbol 150 F. The erasure forecaster compares the number of already decoded bytes C(F) associated with DMT symbol 150 F with a count threshold C_MAX (block 805). If the count of decoded bytes C(F) equals or exceeds the threshold C_MAX (block 805), the erasure forecaster computes the ratio of the number of errored received bytes to the number of decoded bytes (block 810). If the ratio equals or exceeds a hard decision threshold (block 815), the erasure forecaster sets the erasure state to indicate that all subsequent bytes of DMT symbol 150 F should be erased (block 820). If the ratio does not exceed the threshold (block 815), the erasure forecaster sets the erasure state to indicate that all subsequent bytes of DMT symbol 150 F should not be erased (block 825). At block 815, the erasure forecaster may, additionally or alternatively, check the state of a configuration flag and/or variable that indicates whether the ratio and/or a comparison of the number of errored received bytes should be used to make the hard decision. Control then returns from the example process of FIG. 8 to, for example, the example process of FIG. 7.

[0080] If the count of decoded bytes C(F) is less than the threshold C_MAX (block 805), then control returns from the example process of FIG. 8 to, for example, the example process of FIG. 7.

[0081] The example process of FIG. 9 begins, for example, when called from the example process for FIG. 7 to make a soft erasure decision for a presently considered byte of the next codeword to be decoded. Using for example, the example expression illustrated in EQN (1) or the example byte-to-symbol mapper 335 of FIG. 3 and/or 5, the erasure forecaster computes the DMT symbol number modulo 2^M corresponding to the next codeword to be decoded and the presently considered byte (block 902). If the state of corresponding DMT symbol 150 indicates that a hard decision to erase subsequent bytes of the DMT symbol 150 was previously made (block 905), the count of the number of bytes thus far marked for erasure is incremented (block 910) and the byte is marked for erasure (block 915). Control then returns from the example process for FIG. 9 to, for example, the process of FIG. 7.

[0082] If a hard decision to erase the corresponding DMT symbol 150 was not made (block 905), the erasure forecaster checks if the erasure state of the corresponding DMT symbol 150 indicates that soft decisions are being made (block 920). If soft decisions are not being made (i.e., a hard decision not to erase the corresponding DMT symbol 150 was previously made) (block 920), control returns from the example process for FIG. 9 to, for example, the process of FIG. 7.

[0083] If soft decisions are currently being made for the corresponding DMT symbol 150 (block 920), the erasure forecaster determines if the number of bytes of the next codeword already marked for erasure is less than the maxi-

mum number of erasures supported by the RS decoder **305** (i.e., the number of redundancy bytes) (block **925**). If no more bytes can be marked for erasure (block **925**), control returns from the example process for FIG. **9** to, for example, the process of FIG. **7**.

[0084] If at least one more byte can be erased (block **925**), the erasure forecaster compares the ratio of the number of errored bytes and the number of already decoded bytes to a soft decision threshold (block **930**). If the ratio equals or exceeds a threshold (block **935**), the count of the number of bytes thus far marked for erasure is incremented (block **950**) and the byte is marked for erasure (block **955**). At block **935**, the erasure forecaster may, additionally or alternatively, check the state of a configuration flag and/or variable that indicates whether the ratio and/or a comparison of the number of errored received bytes should be used to make the hard decision. Control then returns from the example process for FIG. **9** to, for example, the process of FIG. **7**.

[0085] If the ratio does not exceed the threshold (block **935**), the erasure forecaster computes the ratio of the number of errored bytes and the number of decoded bytes for the previous DMT symbol **150** (block **940**). If the number of bytes received for the current DMT symbol **150** is zero (0) and if the prior DMT symbol **150** is erasing due to a soft decision (i.e., the ratio for the previous DMT symbol **150** equals or exceeds the threshold) or a hard decision (block **945**), the count of the number of bytes thus far marked for erasure is incremented (block **950**) and the byte is marked for erasure (block **955**). In this way, if a previous DMT symbol **150** is being erased then a starting decision to erase the next DMT symbol **150** is made. At block **945**, the erasure forecaster may, additionally or alternatively, check the state of a configuration flag and/or variable that indicates whether the ratio and/or a comparison of the number of errored received bytes should be used to make the hard decision. Control then returns from the example process for FIG. **9** to, for example, the process of FIG. **7**.

[0086] FIG. **10** is a schematic diagram of an example processor platform **1000** that may be used and/or programmed to implement the example erasure forecaster **320** and/or, more generally, the example RS decoder sub-system **175** of FIG. **1** and/or **2**. For example, the processor platform **1000** can be implemented by one or more general purpose processors, cores, microcontrollers, etc.

[0087] The processor platform **1000** of the example of FIG. **10** includes a general purpose programmable processor **1005**. The processor **1005** executes coded instructions **1010** and/or **1012** present in main memory of the processor **1005** (e.g., within a RAM **1015** and/or within a ROM **1020**). The processor **1005** may be any type of processing unit, such as a processor from the TI® family of DSPs, cores, processors and/or microcontrollers. The processor **1005** may execute, among other things, the example processes of FIGS. **7**, **8** and/or **9** to perform erasure forecasting. The processor **1005** is in communication with the main memory (including the ROM **1020** and the RAM **1015**) via a bus **1025**. The RAM **1015** may be implemented by dynamic RAM (DRAM), Synchronous DRAM (SDRAM), and/or any other type of RAM device, and ROM may be implemented by flash memory and/or any other desired type of memory device. Access to the memory **1015** and **1020** maybe controlled by a memory controller (not shown). The RAM **1015** may be used to store, for example, the actual error locations store **315**, the erasure locations store **310**, the erasure forecasting state table **325** and/or the control variables **330** of FIG. **3** and/or **4**.

[0088] The processor platform **1000** also includes an interface circuit **1030**. The interface circuit **1030** may be implemented by any type of interface standard, such as an external memory interface, serial port, general purpose input/output, etc. One or more input devices **1035** and one or more output devices **1040** are connected to the interface circuit **1030**. The input devices **1035** and/or output devices **1040** may be used to, for example, implement interfaces to, for and/or between any or all of the example RS decoder **305**, the example erasure locations store **310**, the example actual error locations store **315**, the erasure forecaster **320**, the example erasure forecasting state table **325**, the example control variables **330** and/or the example byte-to-symbol mapper **335**.

[0089] Although certain example methods, apparatus and articles of manufacture have been described herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all methods, apparatus and articles of manufacture fairly falling within the scope of the appended claims either literally or under the doctrine of equivalents.

1. A method comprising:
analyzing a first decoding error associated with first interleaved data during a first time interval; and
analyzing a second decoding error associated with second interleaved data during a second time interval, wherein the second time interval at least begins before making a first decision whether to erase a first element associated with the first interleaved data.

2. A method as defined in claim **1**, wherein the first element associated with the first interleaved data is at least one of a word, a byte or a bit.

3. A method as defined in claim **1**, wherein analyzing the first decoding error and the second decoding error are performed independently.

4. A method as defined in claim **1**, further comprising making a second decision whether to erase a second element associated with the first interleaved data prior to a beginning of the second time interval.

5. (canceled)

6. A method as defined in claim **1**, wherein analyzing the first decoding error associated with the first interleaved data comprises:
decoding a first codeword associated with the first interleaved data;
receiving a first error indication for a second element of the first codeword; and
deciding whether to erase the first element based on the first error indication, the first element associated with a second codeword.

7. (canceled)

8. (canceled)

9. A method as defined in claim **6**, wherein deciding whether to erase the first element based on the first error indication comprises:
determining a count of decoded codeword elements associated with the first interleaved data;
adding the first error indication to a count of errors;
determining a ratio of the count of errors and the count; and
erasing the first element if the ratio exceeds a threshold.

10. (canceled)

11. A method as defined in claim 6, further comprising:

de-interleaving data received in at least the first and second interleaved data to obtain the first and the second codewords; and

decoding the second codeword based upon the erasure decision for the first element.

12-21. (canceled)

22. An apparatus comprising:

a forward error correction (FEC) decoder to decode a first codeword and to provide a first error indication for the first codeword;

an erasure forecaster to make an erasure decision for a second codeword based on the first error indication; and

an erasure forecasting state table including a first field associated with first interleaved data and a second field associated with second interleaved data, the second codeword containing a first element from the first interleaved data and a second element from the second interleaved data.

23. An apparatus as defined in claim 22, wherein forward error correction (FEC) decoder is a Reed-Solomon (RS) decoder supporting erasure decoding.

24. An apparatus as defined in claim 22, wherein the element of the first interleaved data is at least one of a word, a byte or a bit.

25. An apparatus as defined in claim 22, further comprising a byte-to-symbol mapper to determine which of the first and the second interleaved data is associated with a third element of the second codeword.

26. An apparatus as defined in claim 22, wherein the first field contains at least one of a count of decoded elements, a count of the errored elements, an erasure decision state or a frame number.

27. An apparatus as defined in claim 22, wherein the first field contains a count of decoded elements and the erasure forecasting state table further includes a third field that contains a count of errored elements associated with the first interleaved data, and a fourth field that contains an erasure decision state associated with the first interleaved data.

28. (canceled)

29. (canceled)

30. An apparatus as defined in claim 22, further comprising:

a receiver to process a received DMT symbol to extract an interleaved codeword; and

a de-interleaver to de-interleaver the interleaved codeword to form the first and the second codewords.

31. An article of manufacture storing machine accessible instructions which, when executed, cause a machine to:

decide during a first time interval whether to erase a first element of a first codeword, the first element received in a first data frame;

decide during the first time interval whether to erase a second element of the first codeword, the second element received in a second frame; and

decode the first codeword during a second time interval using the erasure decisions for the first and second elements, the second time interval occurring after the first time interval.

32. An article of manufacture as defined in claim 31, wherein the machine accessible instructions, when executed, cause the machine to:

decode a second codeword during a third time interval that precedes the first time interval; and

determine during the first time interval whether an error occurs in a third element of the second codeword, the third element received in the second frame, and wherein deciding whether to erase the second element is based upon the determined error of the third element.

33. An article of manufacture as defined in claim 31, wherein the machine accessible instructions, when executed, cause the machine to decide during the first time interval whether to erase the first element of the first codeword by:

determining if an error occurs in a fourth element of a second codeword, the fourth element received in the first frame; and

deciding whether to erase the first element based upon the determined error of the fourth element.

34. An article of manufacture as defined in claim 31, wherein the machine accessible instructions, when executed, cause the machine to decide during the first time interval whether to erase the first element of the first codeword by making a final decision during a third time interval to erase all elements associated with the first frame, the third time interval preceding the first time interval.

35. An article of manufacture as defined in claim 31, wherein the machine accessible instructions, when executed, cause the machine to decode the second codeword based upon the determined erasures of the second elements of the first and the second frames.

36. An article of manufacture as defined in claim 31, wherein the machine accessible instructions, when executed, cause the machine to decide during the first time interval whether to erase the first element of the first codeword by:

determining if the first frame is corrupted; and

erasing the first element if the first frame is corrupted.

37. (canceled)

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