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TIME DIVERSITY AUTOMATIC REPEAT REQUEST (ARQ) EQUALIZATION SCHEME

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT FLETCHER A. BLACKMON, employee of the United States Government, citizen of the United States of America and resident of Forestdale, County of Barnstable, Commonwealth of Massachusetts, has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to an automatic repeat request ("ARQ") scheme for use in communication systems employing an adaptive equalization receiver structure.

2. Description of the Prior Art

Typically, coherent techniques used in underwater acoustic telemetry employ coherent signals such as MPSK and MQAM that are processed by an adaptive decision feedback equalizer. Diversity methods such as spatial diversity (multiple spatial channels, e.g. hydrophone array) may be used in conjunction with the equalizer to improve bit error rate performance or to sustain error rates at lower signal to noise ratios. There are, however, times when the channel introduces too many errors into a transmission packet such that the receiver cannot equalize and

decode the received data packet without a residual number of errors remaining. In these cases, an ARQ system is used to request the transmitter to resend the data one or more times. The new data is resent and processed individually and independently of the other retransmissions until the message can be decoded satisfactorily or the number of repeat requests has been exceeded. Other prior art ARQ schemes use incoherent addition of the equalized receiver outputs from several retransmissions of the same packet to enhance performance. However, incoherent addition of the equalized outputs of several retransmitted data packets is not as effective and efficient as joint/coherent equalization. One prior art scheme is disclosed in Jarvis U.S. Patent No. 6,295,312 uses a constant version of time diversity. However, such a scheme reduces the data rate of a communication system indiscriminately.

SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to provide a time diversity automatic repeat request (ARQ) equalization system and method that have superior performance in comparison to prior art techniques.

Other objects and advantages of the present invention will be apparent from the ensuing description.

The present invention is directed to a system and method for effecting time diversity automatic repeat request (ARQ)

equalization. In accordance with the present invention, the original data signal and retransmitted data signals for one or more spatial channels, which follow the entire message, are input into the equalizer in a joint equalization scheme to coherently and jointly equalize the original data signal and retransmitted data signals to provide an equalized signal. The equalized signal is then decoded to provide an equalized and decoded signal. The equalized and decoded signal is then processed to determine if the error characteristics are acceptable. The communication system can be operated without diversity or with spatial diversity, only using automatic repeat request (ARQ) equalization as needed.

Stated another way, the present invention provides a method and system for combining time-separated copies of data packets using joint adaptive equalization to improve single packet error performance wherein the first occurrence of the data packet has unacceptable error characteristics. At the end of a transmission of many different data packets, an unacceptable data packet is flagged and held in memory so it and one or more retransmitted versions of the data packet can be coherently and jointly equalized.

Thus, in one aspect, the present invention is directed to a method for processing communication signals comprising providing a data signal based on a communication signal transmitted from a transmitting source, processing the data signal to determine if

the data signal has acceptable error characteristics, requesting retransmission of the data signal if the data signal does not have acceptable error characteristics, jointly and coherently equalizing the data signal and retransmitted data signal to produce an equalized signal, decoding the equalized signal to produce an equalized and decoded signal, processing the equalized and decoded signal to determine if the equalized and decoded signal has acceptable error characteristics, and repeating the requesting, equalizing, decoding and processing steps as long as the equalized and decoded signal has unacceptable error characteristics. In a preferred embodiment, the method further includes the step of providing a predetermined limit of requests for retransmission and ceasing the repetition of the requesting, equalizing, decoding and processing steps if the number of requests for retransmission reaches the predetermined limit. The step of providing the data signal comprises digitizing a communication signal transmitted by the transmitting source, and receiving and processing the digitized communication signal to provide the data signal.

In a related aspect, the present invention is directed to a communication system comprising a data signal providing resource to provide a data signal based on a communication signal transmitted from a transmitting source, an error analysis resource to determine if the data signal has acceptable error characteristics and request retransmission of the data signal if

the data signal does not have acceptable error characteristics, a multi-channel adaptive equalizer to coherently and jointly equalize the data signal and the retransmitted data signal to produce an equalized signal, a decoder to decode the equalized signal to provide an equalized and decoded signal, and an error signal analysis resource to process the equalized and decoded signal to determine if the equalized and decoded signal has acceptable error characteristics and request another retransmission of the data signal if the equalized and decoded signal does not have acceptable error performance.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of the present invention will become more readily apparent and may be understood by referring to the following detailed description of an illustrative embodiment of the present invention, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of a communication system in accordance with the invention;

FIG. 2 is a block diagram of an adaptive equalizer shown in FIG. 1; and

FIG. 3 is a diagram of a plurality of data packets of a data packet stream that are processed by the communication system of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, there is shown communication system 10 of the present invention. Communication system 10 generally comprises analog-to-digital (A/D) converter 12 and receiver front end 14. Analog-to-digital (A/D) converter 12 digitizes transmitted communication signals 16 that are transmitted from a transmission source (not shown). The digitized signals 16 are then input into receiver front end 14. Receiver front end 14 performs filtering and correlation operations on the digitized signals. Receiver front end 14 is known in the art and is therefore not described in detail. Receiver front end 14 outputs the digitized signals as data packets. Typically, there will be a stream of data packets resulting from reception of transmitted communication signals 16 from the transmitting source (not shown).

Referring to FIG. 1, communication system 10 further comprises memory or cache 18, equalizer 24, decoder 42 and error analysis resource 45. In order to facilitate understanding of the invention, the ensuing description commences with a discussion of error analysis resource 45. Error analysis resource 45 determines whether the error characteristics of each data packet are acceptable or unacceptable based on criteria that is stored or pre-programmed into error analysis resource 45. If the data packet has no errors or has acceptable error characteristics, then error analysis resource 45 outputs an

equalized and decoded final data stream, indicated by reference number 48, for use by other system components 49, such as a display or a data archive. On the other hand, if a particular data packet does not have acceptable error characteristics, error analysis resource 45 flags the erroneous data packet, outputs request-for-retransmission signal 46 to enable the transmitting source (not shown) to retransmit the signal from which that particular erroneous data packet was derived, and outputs error signal 47 that indicates the error characteristics are unacceptable. Error signal 47 is input into memory or cache 18. The original, erroneous data packet is also temporarily stored in memory or cache 18. Once all other data packets are received, analyzed for errors, and then flagged or cleared, the retransmission of data packets begins.

Referring to FIGS. 1 and 2, the preferred embodiment and function of equalizer 24 will now be discussed. In order to facilitate understanding of the invention, the ensuing description is in terms of just one data packet out of a plurality or stream of data packets as being erroneous. Thus, the original, erroneous data packet is released from memory 18 and is input into a corresponding input of multi-channel coherent/joint adaptive equalizer 24 while the retransmitted data packet is simultaneously input into a corresponding input of equalizer 24. Multi-channel adaptive equalizers are known in the art. One such equalizer is described in U.S. Patent No.

6,295,312, the disclosure of which patent is incorporated herein by reference. Equalizer 24 comprises a plurality of inputs 26 and a corresponding plurality of signal processing channels 28. Each signal processing channel 28 comprises feedforward circuitry which is known in the art. Equalizer 24 further comprises feedback circuit 30, summing circuit 32, decision rule circuit 34, and summing circuit 36. The output of decision rule circuit 34 is input into both feedback circuit 30 and summing circuit 36. Summing circuit 36 outputs an equalized stream of symbols that represent equalized signal 40.

Referring to FIGS. 1 and 2, equalized signal 40 is input into decoder 42. Decoder 42 comprises a de-interleaver, known in the art, which decodes equalized signal 40 to provide an equalized and decoded signal 44. Equalized and decoded signal 44 is then input into error analysis resource 45 to determine whether equalized and decoded signal 44 has acceptable error characteristics. If equalized and decoded signal 44 has acceptable error characteristics, then equalized and decoded signal 44 is routed to other system components 49 of system 10 as described in the foregoing description. On the other hand, if error analysis resource 45 determines that equalized and decoded signal 44 does not have acceptable error characteristics, error analysis resource 45 issues a request-for-retransmission signal 46 and an error signal 47 that indicates equalized and decoded signal 44 does not have acceptable error characteristics. As a

result, the transmitting source (not shown) retransmits the signal from which the erroneous data packet was derived. The retransmitted signal is digitized by analog-to-digital converter 12 and received by receiver front end 14. The original data packet, the first retransmitted data packet, and the second retransmitted data packet are then simultaneously input into corresponding inputs of equalizer 24. Equalizer 24 coherently and jointly equalizes the original data packet and the two retransmitted data packets to provide an equalized signal 40 as described in the foregoing description. Equalized signal 40 is input into decoder 42 which, in response, outputs equalized and decoded signal 44. Equalized and decoded signal 44 is then input into error analysis resource 45 which processes equalized and decoded signal 44 and also implements a quality check to determine whether equalized and decoded signal 44 has acceptable error characteristics. If the equalized and decoded signal 44 has acceptable error characteristics, error analysis resource 45 outputs the equalized and decoded signal, indicated by reference number 48, for use by other system components 49, and an error signal 47 that indicates that equalized and decoded signal 44 has acceptable error characteristics. On the other hand, if error analysis resource 45 determines that equalized and decoded signal 44 does not have acceptable error characteristics, then error analysis resource 45 issues another signal 46 that requests a third retransmission of the data packet and also outputs error

signal 47 that indicates that the error characteristics are unacceptable. The process of requesting retransmission of the data packet continues until either (i) equalized and decoded signal 44 has acceptable error characteristics (i.e. no errors or acceptable errors), or (ii) the number of requests for retransmissions reaches a predetermined limit. The predetermined limit is defined by a digital data signal that is stored or programmed into error analysis resource 45.

Error analysis resource 45 can be realized by any suitable technique, e.g., check-sum, CRC, etc., and can be configured with commercially available integrated circuits or discrete components. The original, erroneous data packet signal as well as all retransmitted data packets are temporarily stored in memory or cache 18 and retrieved for the joint equalization process. Once the joint equalization and decoding steps are complete, the data stored in memory 18 can be transferred to a permanent data storage device for future reference or can be erased.

The following explanation of the operation of communication system 10, in conjunction with Figures 1-3, will facilitate understanding of the invention. A transmitting source (not shown) transmits communication signals that are digitized by analog-to-digital converter 12. These digitized signals are received by receiver front end 14 which, in response, outputs a series of N data packets 50A, 50B, 50C……50N. Error analysis

resource 45 determines if any of these data packets has errors. For purposes of example, if error analysis resource 45 determines that data packet 50B has errors therein or that the error characteristics are not acceptable, error analysis resource 45 flags data packet 50B and outputs error signal 47 that indicates the error characteristics are not acceptable. Error signal 47 is input into memory 18 and data packet 50B is stored in memory 18 until all other data packets are received and processed by error analysis resource 45. If error analysis resource 45 determines that no other data packet has errors therein, then the equalization and decoding process begins. Consequently, error analysis resource 45 outputs a request-for-retransmission signal 46 to cause the transmitting source (not shown) to retransmit the signal with data packet 50B therein. The retransmitted data packet 50B and the original, erroneous data packet 50B are then input into equalizer 24. Equalizer 24 coherently and jointly equalizes retransmitted data packet 50B and the original, erroneous data packet 50B to produce equalized signal 40. Equalized signal 40 is then input into decoder 42 which provides an equalized and decoded signal 44. Equalized and decoded signal 44 is then processed by error analysis resource 45. If error analysis resource 45 determines either there are no errors or the error characteristics are acceptable, error analysis resource 45 outputs error signal 47 that indicates that equalized and decoded signal 44 has no errors therein, or has acceptable error

characteristics, and outputs the equalized and decoded signal, now indicated by reference number 48, for use by other communication system components 49. On the other hand, if error analysis resource 45 determines that the error characteristics are not acceptable, then error analysis resource 45 outputs request-for-retransmission signal 46 and error signal 47 that indicates that equalized and decoded signal 44 has unacceptable errors. In response, the transmitting source (not shown) retransmits a second signal that contains data packet 50B. Next, the original, erroneous data packet 50B, the first retransmitted data packet 50B and the second retransmitted data packet 50B are input into equalizer 24 for joint and coherent equalization. In response, equalizer 24 outputs equalized signal 40 which is then input into decoder 42 as described in the foregoing description. Decoder 42 outputs the equalized and decoded signal 44 which is then input into error analysis resource 45. Error analysis resource 45 then processes equalized and decoded signal 44 to determine whether equalized and decoded signal 44 has acceptable or unacceptable error characteristics. If error analysis resource 45 determines that equalized and decoded signal 44 either does not have any errors or has acceptable error characteristics, then equalized and decoded signal 44 is output as signal 48 and is routed to other communication system components 49. In such a case, error signal 47 would indicate that the error characteristics are acceptable. The process of

requesting retransmission of data packet 50B and determining whether the resulting equalized and decoded signal 44 has acceptable error characteristics continues until either it is determined that equalized and decoded signal 44 has no errors (or acceptable error characteristics) or the predetermined limit of requests for retransmissions has been reached. If the predetermined limit of requests for retransmissions has been reached, then the most recent equalized and decoded signal 44 is allowed to be routed and used by the other communication system components 49.

The particular embodiment of communication system 10 shown in FIG. 1 is just one example, and it is to be understood that various modifications and alternate circuit configurations which also implement the method of the present invention are possible. Thus, the circuitry or system configurations described herein should not be interpreted as limiting the scope of the invention in any way. Communication system 10 can be realized as a monolithic integrated circuit or with commercially available PC, microprocessor, FPGA and DSP components.

The present invention provides several advantages. Specifically, the error performance is superior to the prior art incoherent ARQ techniques. In the present invention, coherent time diversity equalization and decoding are applied as needed as opposed to using time diversity at all times. Therefore, the overall data rate is increased by almost a factor of two above

the prior art continuous-time diversity scheme. Also, in the time diversity ARQ scheme of the present invention, joint equalization and decoding can be used until the errors within a data packet have been reduced to an arbitrarily small amount, or a predetermined retransmit limit value has been reached.

The principles, preferred embodiments and modes of operation of the present invention have been described in the foregoing specification. The invention which is intended to be protected herein should not, however, be construed as limited to the particular forms disclosed, as these are to be regarded as illustrative rather than restrictive. Variations and changes may be made by those skilled in the art without departing from the spirit of the invention. Accordingly, the foregoing detailed description should be considered as exemplary in nature and not as limiting the scope and spirit of the invention as set forth in the attached claims.

Attorney Docket No. 83090

TIME DIVERSITY AUTOMATIC REPEAT REQUEST (ARQ) EQUALIZATION SCHEME

ABSTRACT OF THE DISCLOSURE

A method and system are provided for processing communication signals. In one embodiment, the method has the steps of providing a data signal based on a communication signal transmitted from a transmitting source, processing the data signal to determine if the data signal has acceptable error characteristics, requesting retransmission of the data signal if the data signal does not have acceptable error characteristics, coherently and jointly equalizing the data signal and the retransmitted signal to produce an equalized signal, decoding the equalized signal to provide an equalized and decoded signal, processing the equalized and decoded signal to determine if the equalized and decoded signal has acceptable error characteristics, and repeating the requesting, equalizing, decoding and processing steps as long as the equalized and decoded signal has unacceptable error characteristics.

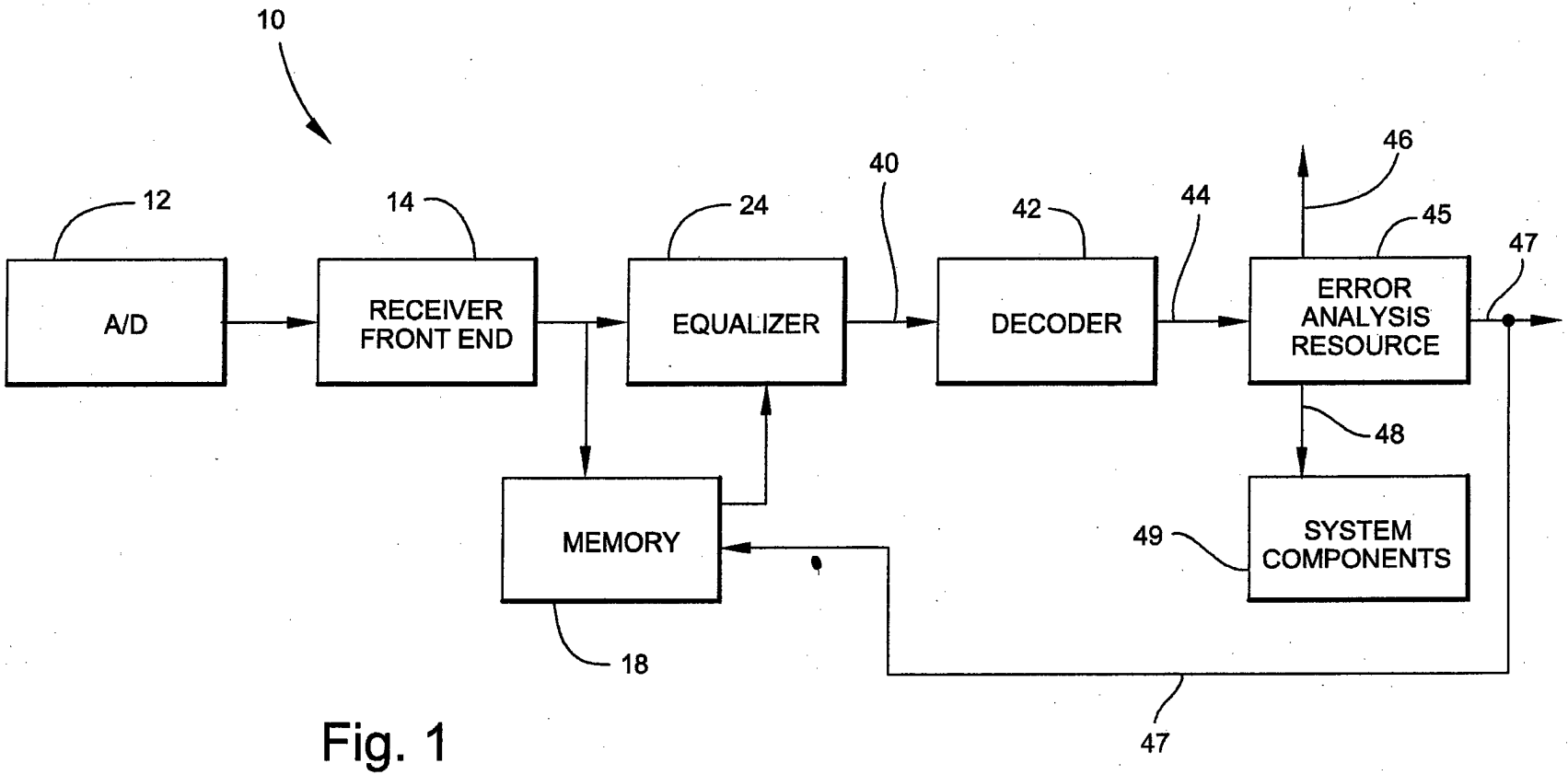
10
12
A/D
14
RECEIVER FRONT END
24
EQUALIZER
40
42
DECODER
44
46
45
47
ERROR ANALYSIS RESOURCE
48
49
SYSTEM COMPONENTS
MEMORY
18
47

Fig. 1

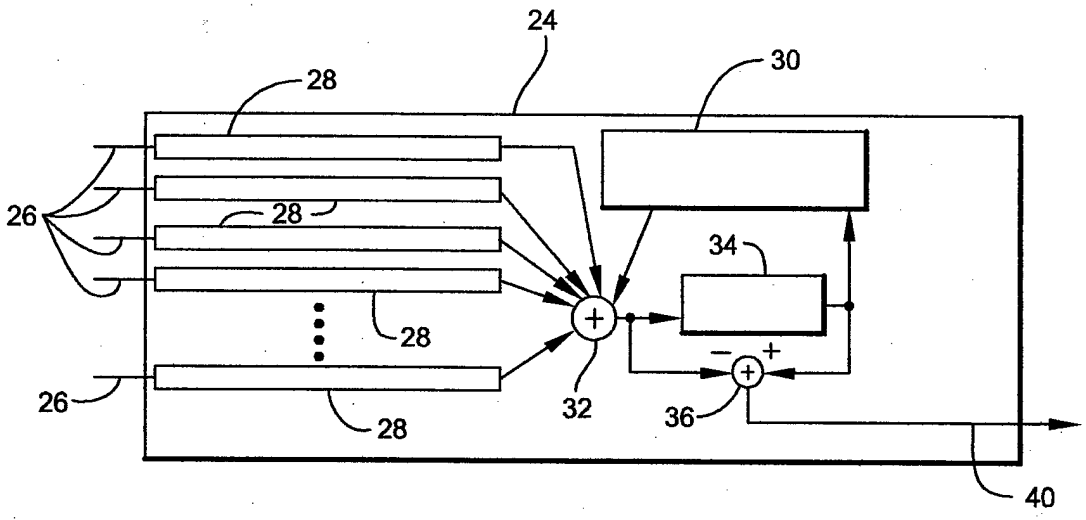

Fig. 2

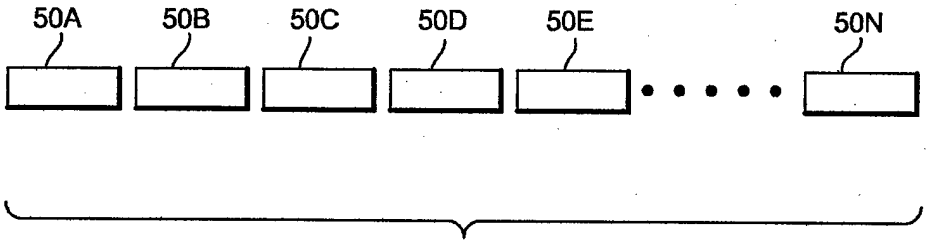

Fig. 3