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(54) **Title:** CHANNEL ESTIMATION FOR COMMUNICATION SYSTEMS

(57) **Abstract:** An improved channel estimation is disclosed. In one embodiment, initial channel estimation is performed using known training data sequence. The data packet received is demodulated based on the initial channel estimates, de-interleaved and decoded. The decoded data is then is re-encoded, interleaved and modulated to generate additional training symbols for updating the channel estimates throughout the received data packet.

CHANNEL ESTIMATION FOR COMMUNICATION SYSTEMS

BACKGROUND

I. Field of Invention

[1001] The invention generally relates to communication systems, and more particularly to channel estimation in communication systems with coherent receivers.

II. Description of the Related Art

[1002] In digital communication, information is translated into digital data referred to as bits. A transmitter modulates an input bit stream into a waveform for transmission over a communication channel and a receiver demodulates the received waveform back into bits, thereby recovering the information. In an ideal communication system, the data received would be identical to the data transmitted. However, in reality, distortions or noise may be introduced during the transmission of data over a communication channel from the transmitter to the receiver. If the distortion is significant, the information may not be recoverable from the data received at the receiver.

[1003] Channel estimation is one technique used to compensate for the distortion introduced in data during its transmission. Channel characteristics are obtained at the receiver and are used to compensate for the distortion during demodulation. More particularly, a channel response of the communication channel is estimated based on transmissions of a known pattern called training sequences. Training sequences having constant data are used. For example, the data contents of the training data sequence are stored in the receiver and is embedded in each data sequence transmitted by the transmitter. At the receiver, the channel response can then be estimated by processing the training data sequence received in a distorted manner and the training data sequence stored in undistorted form. This response is applied in the demodulation and decoding of the data.

[1004] Accordingly, channel estimation is important in digital communication systems. When implemented, a limited number of training data sequence is typically used. However, estimates based on a few training data sequences often fail to give satisfactory performance. Therefore, there is a need for a more reliable, satisfactory and/or efficient channel estimation.

SUMMARY

[1005] Embodiments described allow an improved channel estimation. In one embodiment a decoder is configured to decode data based on a channel response; and a channel estimating module coupled to the decoder is configured to determine the channel response using at least one training symbol, and to update the channel response based on the decoded data.

[1006] The channel estimating module may comprise a first channel estimator configured to determine the channel response using at least one training symbol; and a second channel estimator configured to generate at least one modulation symbol based on the decoded data and to update the channel estimation using the at least one modulation symbol. The second channel estimator may comprise an encoder configured to re-encode the decoded data, an interleaver coupled to the encoder and configured to interleave the re-encoded data; and a modulation mapping module coupled to the interleaver and configured to map the interleaved data into a modulation symbol.

[1007] Alternatively, the channel estimating module may comprise a channel estimator configured to determine the channel response using at least one training symbol; and a symbol generator coupled to the channel estimator, the symbol generator configured to generate at least one modulation symbol based on the decoded data; and wherein the channel estimator is configured to update the channel response using the at least one modulation symbol. The symbol generator may comprise an encoder configured to re-encode the decoded data, an interleaver coupled to the encoder and configured to interleave the re-encoded data; and a modulation mapping module coupled to the interleaver and configured to map the interleaved data into a modulation symbol.

[1008] In another aspect, apparatus and method comprises means for decoding data based on a channel response; and means for determining the channel response using at least one training symbol, and to update the channel response based on the decoded data. The means for determining the channel response may comprise means for estimating the channel response using at least one training symbol; means for generating at least one modulation symbol based on the decoded data; and means for updating the channel estimate using the at least one modulation symbol. Also, the means for generating the at least one modulation symbol may comprise means for re-

encoding the decoded data; means for interleaving the re-encoded data; and means for mapping the interleaved data into a modulation symbol.

[1009] In a further aspect, apparatus for channel estimation comprises means for decoding data based on a channel response; and a machine readable medium comprising a code segment for determining the channel response using at least one training symbol, and for updating the channel response based on the decoded data. The code segment for determining the channel response may comprise code segment for estimating the channel response using at least one training symbol; code segment for generating at least one modulation symbol based on the decoded data; and code segment for updating the channel response using the at least one modulation symbol. The code segment for generating the at least one modulation symbol may comprise code segment for re-encoding the decoded data; code segment for interleaving the re-encoded data; and code segment for mapping the interleaved data into a modulation symbol.

BRIEF DESCRIPTION OF THE DRAWINGS

[1010] Various embodiments will be described in detail with reference to the following drawings in which like reference numerals refer to like elements, wherein:

[1011] Figure 1 shows a transmitter in a communication system;

[1012] Figure 2 shows a receiver in a communication system;

[1013] Figure 3 shows a channel estimating module;

[1014] Figure 4 shows another channel estimating module;

[1015] Figure 5 shows a training symbol generator that can be implemented in a channel estimating module;

[1016] Figure 6 shows a method for generating a training symbol for channel estimation; and

[1017] Figure 7 shows a method for channel estimation.

DETAILED DESCRIPTION

[1018] Multicarrier communication systems compensate for distortions in data transmitted through a multi-path or non-ideal communication channel. To counteract or compensate for distortions that may have been introduced in the signal, channel estimates are used in receivers to adjust the received signal.

[1019] Accordingly, the embodiments described provide an improved channel estimation in such communication systems, by generating training symbols for channel estimation at a receiver. Generally, data that is decoded at the receiver is re-encoded and mapped to modulation symbols. The modulation symbols are then used as training symbols in the estimation of the channel response. Here, data at the receiver may be decoded using an initial channel response that is estimated based on training symbol(s) received at the receiver from a transmitter. The receiver then generates modulation symbols from the decoded data and the modulation symbols are used as additional training symbols to update the initial channel response.

[1020] In the description below, the embodiments may be described as a process which is depicted as a flowchart, a flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged. A process is terminated when its operations are completed. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination corresponds to a return of the function to a calling function or a main function.

[1021] As disclosed herein, the term "communication channel" refers to both wireless and wireline communication channels. Examples of wireless communication channels are radio, satellite and acoustic communication channel. Examples of wireline communication channels include, but is not limited to optical, copper, or other conductive wire(s) or medium. The term "look-up table" refers to data within a database or various storage medium. Storage medium may represent one or more devices for storing data, including read only memory (ROM), random access memory (RAM), magnetic disk storage mediums, optical storage mediums, flash memory devices and/or other machine readable mediums for storing information. The term "machine readable medium" includes, but is not limited to portable or fixed storage devices, optical storage devices, wireless channels and various other mediums capable of storing, containing or carrying instruction(s) and/or data. Also, for purposes of explanation, the embodiments will be described with reference to Orthogonal Frequency Division Multiplexing (OFDM) systems. However, it will be well understood that the invention can be applied to other types of systems that require channel estimation.

[1022] OFDM is an example of a multicarrier communication technique that is well known. Generally, OFDM is a digital modulation technique that splits a signal into multiple sub-signals which are transmitted simultaneously at different frequencies. OFDM uses overlapped orthogonal signals to divide a channel into many sub-channels that are transmitted in parallel. Because OFDM allows high data rate transmission over degraded channels, OFDM has been successful in numerous wireless applications, such as in high speed local area networks (LANs).

[1023] Therefore, in OFDM systems, the entire frequency bandwidth used for the transmission of signals is subdivided into a plurality of frequency subcarriers. By appropriately designing modulation symbol periods, adjacent frequency subcarriers are respectively orthogonal to each other. Orthogonality is a property of a set of functions such that the integral of the product of any two members of the set taken over the appropriate interval is zero. More specifically, orthogonal channels or frequencies are statistically independent and do not interfere with each other. As a result, orthogonality allows a receiver to demodulate a selected sub-carrier without demodulating other subcarriers that are transmitted in parallel through multiplexed communication channels. As a result, there is no cross-talk among subcarriers and inter-symbol-interference (ISI) is significantly reduced.

[1024] If there is an accurate estimate of the channel characteristics that can be used to adjust the received signal, the OFDM system performance can be improved by allowing for coherent demodulation. Accordingly, training sequences known as pilot symbol patterns or training symbols are transmitted by the transmitter. The training symbols are known to the receiver such that the receiver is able to perform channel estimation.

[1025] Figure 1 shows one embodiment of a transmitter 100 for use in OFDM systems. Transmitter 100 comprises a scrambler 110, an encoder 120, an interleaver 130, a modulation mapping module 140, an inverse fast fourier transform (IFFT) module 150, a pulse shaping module 160 and an up-converter 170. Transmitter 100 receives a data packet and the data rate at which the packet is to be transmitted. Scrambler 110 scrambles and encoder 120 encodes the received packet. Encoder 120 may be a convolutional encoder or some other known encoder that allows error correction encoding.

[1026] The encoded bits are grouped into a block, and each block is then interleaved by interleaver 130 and mapped to a sequence of modulation symbols by modulation mapping module 140. The encoded and interleaved bit stream of a selected length is grouped into various numbers of bits depending upon the modulation. Typically, the bit stream is grouped into one of 1, 2, 4 or 6 bit(s) and converted into a sequence of complex numbers representing a modulation symbol in Bi-phase shift keying (BPSK) modulation, Quadrature phase shift keying (QPSK) modulation, 16 Quadrature amplitude modulation (QAM) or 64-QAM respectively. BPSK, QPSK and QAM are modulation techniques well known in the art and will not be discussed in detail.

[1027] Each modulation symbol is then assigned to a sub-carrier and inverse fast fourier transformed. This results in time-domain samples of a single OFDM symbol. Here, a cyclic prefix can be added to each symbol. Pulse shaping is then performed by pulse shaping module 160 and the symbols are up-converted by up-converter 170 for transmission through a communication channel. Here, a programmable pulse shaping may be used.

[1028] In addition to the modulation symbols, the data packet may comprise other information. For example, headers, leadings and/or preambles may be appended as necessary to the packet before the scrambling. The header information may comprise the data rate and packet length information. The contents of the header are typically not scrambled. Also, short and long preambles may be generated and added to the data packet. The short preamble comprises a repetitive number of short training sequences used for synchronization such as timing acquisitions and coarse frequency acquisitions. The long preamble comprises a repetitive number of long training sequences used for fine frequency acquisitions. The long training sequences are also the training symbols that may be used for channel estimation.

[1029] Various number and choice of training symbols may be added to the data packet. In many systems, modulation symbols are used as the training symbols. Accordingly, they may be pre-computed and stored such that transmission can begin without interleaving and IFFT delay. Also, for a more accurate measurement of channel characteristics, a larger number of training symbols are generally required. However, due to a limited bandwidth and more particularly to a delay involved in the channel estimation process, a lesser number of training symbols are used. In LANs, for example, two training symbols are typically transmitted and used to estimate the channel response.

[1030] Existing channel estimation techniques use this limited number of training symbols to obtain an estimate of the channel response. Therefore, the channel response may often be inaccurate and/or unreliable, thereby failing to give satisfactory performance. In the described embodiments, new training symbols are generated at the receiver, thereby allowing a more accurate measurement of the channel characteristics.

[1031] Figure 2 shows one embodiment of a receiver 200 that is capable of generating training symbol(s) for use in OFDM systems. The receiver 200 comprises a radio frequency/intermediate frequency (RF/IF) front-end 210, a synchronizing module 280, a fast fourier transform (FFT) module 220, a de-modulation module 230, a de-interleaver 240, a decoder 250, a descrambler 260 and a channel estimating module 270. It should be noted here that Figure 2 shows a simplified block diagram of a receiver. A more typical commercial receiver may comprise additional elements such as a storage medium (not shown) and a processor (not shown) to control one or more RF/IF front-end 210, synchronizing module 280, FFT module 220, de-modulation module 230, de-interleaver 240, decoder 250, descrambler 260 and channel estimating module 270.

[1032] RF/IF front end 230 receives data through a communication channel. The synchronizing module 280 looks for or detects a new packet, and tries to acquire time synchronization and frequency synchronization. One of several known techniques for detecting a new packet can be used. For example, synchronizing module 280 may comprise a time synchronizer to synchronize the signal to the beginning of the block and a frequency offset corrector to correct the signal for any offset errors that occur between the transmitter oscillator and the receiver oscillator. The signal is then input to FFT module 220 and converted from time domain to frequency domain. FFT is performed after removing the cyclic prefix as necessary. Channel estimating module 270 receives the frequency domain signal and provides a channel estimate based on the training symbols. The frequency domain signal also may be input to a phase locked loop (PLL) that provides phase error correction in adjusting the received signal. The demodulated signal is de-interleaved by de-interleaver 240 and decoded by decoder 250. Decoder 250 may be a Viterbi decoder. The decoded data is then descrambled by descrambler 260 to recover the original data information. An additional buffer may also be implemented to hold the samples while the signal field is being decoded.

[1033] More particularly, when processing a new packet, the short preambles are obtained and discarded from the data packet before FFT processing. The obtained short preamble is used to perform time synchronization. After FFT processing, the long preambles are obtained and used to perform channel estimation for each sub-carrier. Initial channel estimate(s) can be obtained based on the transmitted training symbols. Thereafter, training symbols are generated by the channel estimating module 270 and can be used in obtaining subsequent channel estimates. A buffer may be implemented to store the packet during timing synchronization before FFT processing.

[1034] Channel estimating module 270 performs channel estimation based on training symbol(s) and the frequency domain signal. For example, after FFT processing, a signal for a sub-carrier can be represented in Equation [1] as follows,

[1035] $Y_n = H_n X_n + N_n$ [1]

[1036] where n denotes the time index ($n = 0, 1, 2, \ldots$), X_n is the transmitted modulation symbol or the training symbol, H_n is the channel coefficient and N_n is the noise. Here, if the channel is static or varies very slowly, $H_n = H$ for all n where H is a constant. The following iterative algorithm in Equation [2] is one of many techniques that can be used in the channel estimation of each sub-carrier, where $\hat{H}_n$ is the estimated channel response.

$$\hat{H}_n = \frac{1}{(n+1)}\left[n\hat{H}_{n-1} + \frac{Y_n}{\hat{X}_n}\right] \qquad [2]$$

[1037] In Equation [2], $n = 0, 1, 2, 3, \ldots$ and $\hat{H}_{-1} = 0$. The channel response is initially estimated using the transmitted training symbols and additional training symbols are generated to improve the initial channel estimates. For example, if two training symbols were transmitted, the training symbols $\hat{X}_0$ and $\hat{X}_1$ corresponding to $n = 0$ and $n = 1$ are known for estimating the initial channel estimates $\hat{H}_0$ and $\hat{H}_1$. Thereafter, subsequent training symbols are obtained and the channel estimates can be updated iteratively using Equation [2] to improve the initial channel estimates.

[1038] Channel estimating module 270 may stop the iteration after a finite number of iterations, at some appropriate n, for example $n = 16$ or 32. In such a case, the value of $1/(n+1)$ can be obtained from a database, storage medium or look-up table. Also, different iterative algorithms can be used. For example, iterative algorithms that are better suited for tracking, such as a first order Infinite Impulse Response (IIR) filter type or Least mean square (LMS) type algorithm, can be used. The recursive equation for the IIR filter type can be expressed as follows in Equation [3],

$$\hat{H}_n = (1-\alpha)\hat{H}_{n-1} + \alpha\left(\frac{Y_n}{\hat{X}_n}\right) \qquad [3]$$

[1039] where $n = 0, 1, 2, 3, \ldots$ α is the filter coefficient and $\hat{H}_{-1} = 0$. Based on Equation [3], the channel response may initially be estimated using the transmitted training symbols and additional training symbols may be generated to improve the initial channel estimates. For example, if two training symbols were transmitted, the training symbols $\hat{X}_0$ and $\hat{X}_1$ corresponding to $n = 0$ and $n = 1$ are known for estimating the initial channel estimates $\hat{H}_0$ and $\hat{H}_1$.

[1040] Alternatively, one algorithm can be used for estimating the initial channel estimates based on the known training symbols while another algorithm is used for subsequent channel estimates. Furthermore, complex division can be converted to a simple complex multiplication and two real multiplications by using a database, storage medium or look-up table for calculating the value of $1/X$. Accordingly, channel estimating module 300 determines a channel response using one or more training symbols.

[1041] Figure 3 shows an embodiment of a channel estimating module 300 comprising a channel estimator 310, a symbol generator 320 and a delay buffer 330. Channel estimator 310 performs initial channel estimation to obtain initial channel estimates based on the transmitted training symbol(s). The initial channel estimates are forwarded to demodulation module 230. New training symbols are generated by symbol generator 320 and forwarded to channel estimator 310. The operations of symbol generator 320 will be described more in detail later with reference to Figures 5 and 7. Channel estimator 310 then performs subsequent channel estimation based on the new and/or additional training symbols to update the initial channel estimates.

Here, channel estimator 310 may use an iterative algorithm, such as for example Equation [2] or [3], to update the channel estimates. Also, channel estimator 310 may stop the update at a finite number of iterations. Delay buffer 330 temporarily stores the frequency domain signal from FFT 220 while the new training symbol is being generated.

[1042] Figure 4 shows another embodiment of a channel estimating module 400 comprising a first channel estimator 410, a second channel estimator 420 and a delay buffer 430. First channel estimator 410 performs initial channel estimation to obtain initial channel estimates based on the transmitted training symbols. The initial channel estimates are forwarded to demodulation module 430. In this embodiment, second channel estimator 420 generates new training symbols and performs subsequent channel estimation based on the new and/or additional training symbols to update the initial channel estimates. Here, second channel estimator 420 may also use an iterative algorithm, such as for example Equation [2] or [3], to update the channel estimates. Second channel estimator 420 may be implemented with a symbol generator that is analogous to symbol generator 320 for generating new training symbols. Moreover, second channel estimator 420 may stop the update at a finite number of iterations and delay buffer 430 temporarily stores the frequency domain signal from FFT 220 while the additional training symbol is being generated.

[1043] In channel estimating modules 300 and 400, the training symbol can be generated in a process that is analogous to the process of generating the modulation symbols at the transmitter. Accordingly, the output from decoder 250 is processed into modulation symbols and used as new training symbols. Figure 5 shows one embodiment of a symbol generator 500 that can be implemented in symbol generator 320 and/or second channel estimator 420 of channel estimating modules 300 and 400, respectively. Symbol generator 500 comprises an encoder 510, an interleaver 520 and modulation mapping module 530. The operation will be described with reference to a method 600 for generating a training symbol.

[1044] After the received data packet is demodulated, de-interleaved and decoded, the decoded data is re-encoded by the encoder 510 (610), interleaved by interleaver 520 (620) and modulated into modulation symbols by modulation mapping module 530 (630). The modulated symbols can then be used as training symbols. Here, due to the delay through the de-interleaving, decoding, re-encoding and interleaving process, Y_n

may be stored in delay buffers 330 and 430 as shown in Figures 3 and 4. Therefore, new training symbols can be generated at a receiver for use in systems such as OFDM systems that need channel estimation.

[1045] More particularly, Figure 7 shows a decoding method 700 for use in OFDM systems. When a new packet is received (710), a determination is made if training symbols are available (720). If available, the training symbols are obtained (730) and a channel response is initially estimated using the obtained training symbols (740). The data is decoded using the channel response (750). If there are no more training symbols available (720), additional training symbols are generated by re-encoding, interleaving and mapping the decoded data to modulation symbols (760-780). The channel response is then updated using the modulation symbol as new training symbols (790) and the data is decoded using the updated channel response (750). Here, the channel response may be updated using an iterative algorithm and the updates may be stopped at a finite number of iterations.

[1046] As described, the channel estimates can be improved continuously in an iterative manner throughout the received data packet using the decoder output. A robust channel estimator can significantly improve the performance of a multicarrier system such as OFDM based modulation system. Using the decoder output, more reliable estimates of the transmitted symbols can be generated and used as additional training symbols for the channel estimation in a recursive manner. As the decoding progresses through the packet, the channel estimates continue to improve with the help of already decoded symbols, thereby improving the chance of subsequent symbols and the whole packet being correctly decoded.

[1047] Moreover, it should noted here that the elements of receiver 200 as shown in Figure 3 may be rearranged without affecting the operation of the receiver. Similarly, elements of channel estimating module 300 and/or 400 may also be rearranged without affecting the channel estimating operation. Furthermore, one or more elements of channel estimating module 300 and/or 400 may be implemented by hardware, software, firmware, middleware, microcode, or any combination thereof.

[1048] When implemented in software, firmware, middleware or microcode, the program code or code segments to perform the necessary tasks may be stored in a storage medium (not shown). A processor may perform the necessary tasks. A code segment may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, etc.

[1049] The foregoing embodiments are merely examples and are not to be construed as limiting the invention. The present teachings can be readily applied to other types of apparatuses, methods and systems. The description of the invention is intended to be illustrative, and not to limit the scope of the claims. Therefore, many alternatives, modifications, and variations will be apparent to those skilled in the art without departure from the scope of the invention as set forth in the appended claims.

CLAIMS

What is claimed is:

1. Apparatus in a communication system comprising:

a decoder configured to decode data based on a channel response; and

a channel estimating module coupled to the decoder, the channel estimating module configured to determine the channel response using at least one training symbol, and to update the channel response based on the decoded data.

2. The apparatus as in claim 1, wherein the channel estimating module comprises:

a first channel estimator configured to determine the channel response using at least one training symbol; and

a second channel estimator configured to generate at least one modulation symbol based on the decoded data and to update the channel response using the at least one modulation symbol.

3. The apparatus as in claim 2, wherein the second channel estimator comprises:

an encoder configured to re-encode the decoded data;

an interleaver coupled to the encoder, the interleaver configured to interleave the re-encoded data; and

a modulation mapping module coupled to the interleaver, the modulation mapping module configured to map the interleaved data into a modulation symbol.

4. The apparatus as in claim 1, wherein the channel estimating module comprises:

a channel estimator configured to determine the channel response using at least one training symbol; and

a symbol generator coupled to the channel estimator, the symbol generator configured to generate at least one modulation symbol based on the decoded data; and wherein the channel estimator is configured to update the channel response using the at least one modulation symbol.

5. The apparatus as in claim 4, wherein the symbol generator comprises:

an encoder configured to re-encode the decoded data;

an interleaver coupled to the encoder, the interleaver configured to interleave the re-encoded data; and

a modulation mapping module coupled to the interleaver, the modulation mapping module configured to map the interleaved data into a modulation symbol.

6. The apparatus as in any one of the preceding claims, wherein the channel estimating module updates the channel response using an iterative algorithm based on the decoded data.

7. The apparatus as in claim 6, wherein the channel estimating module stops the update after a finite number of iterations.

8. The apparatus as in claim 6 or claim 7 as dependent thereon, further comprising a look-up table and wherein the channel estimating module updates the channel response using the look-up table.

9. A method for channel estimation in a communication system comprising:

estimating a channel response using at least one training symbol,

decoding data based on the channel response; and

updating the channel response based on the decoded data.

10. The method as in claim 9, wherein estimating the channel response comprises:

estimating the channel response using at least one training symbol;

generating at least one modulation symbol based on the decoded data; and

updating the channel response using the at least one modulation symbol.

11. The method as in claim 10, wherein generating at least one modulation symbol comprises:

re-encoding the decoded data;

interleaving the re-encoded data; and

mapping the interleaved data into a modulation symbol.

12. The method as in claim 9 or any one of claims 10-11 as dependent thereon, wherein updating the channel response comprises updating the channel response using an iterative algorithm based on the decoded data.

13. The method as in claim 12, wherein updating the channel response further comprises stopping the update after a finite number of iterations.

14. The method as in claim 12 or claim 13 as dependent thereon, wherein updating the channel response further comprises updating the channel response using a look-up table.

15. Apparatus for channel estimation comprising:

means for decoding data based on a channel response; and

means for determining the channel response using at least one training symbol, and for updating the channel response based on the decoded data.

16. The apparatus as in claim 15, wherein the means for determining the channel response comprises:

means for estimating the channel response using at least one training symbol;

means for generating at least one modulation symbol based on the decoded data; and

means for updating the channel response using the at least one modulation symbol.

17. The apparatus as in claim 16, wherein the means for generating the at least one modulation symbol comprises:

means for re-encoding the decoded data;

means for interleaving the re-encoded data; and

means for mapping the interleaved data into a modulation symbol.

18. The apparatus as in claim 15 or any one of claims 16-17 as dependent thereon, wherein the means for determining the channel response updates the channel response using an iterative algorithm based on the decoded data.

19. The apparatus as in claim 18, wherein the means for determining the channel response stops the update after a finite number of iterations.

20. The apparatus as in claim 18 or claim 19 as dependent thereon, further comprising a look-up table and wherein the means for determining the channel response updates the channel response using the look-up table.

21. Apparatus for channel estimation comprising:

means for decoding data based on a channel response; and

a machine readable medium comprising a code segment for determining the channel response using at least one training symbol, and for updating the channel response based on the decoded data.

22. The apparatus as in claim 21, wherein the code segment for determining the channel response comprises:

code segment for estimating the channel response using at least one training symbol;

code segment for generating at least one modulation symbol based on the decoded data; and

code segment for updating the channel response using the at least one modulation symbol.

23. The apparatus as in claim 22, wherein the code segment for generating the at least one modulation symbol comprises:

code segment for re-encoding the decoded data;

code segment for interleaving the re-encoded data; and code segment for mapping the interleaved data into a modulation symbol.

24. The apparatus as in claim 21 or any one of claims 22-23 as dependent thereon, wherein the code segment for determining the channel response updates the channel response using an iterative algorithm based on the decoded data.

25. The apparatus as in claim 24, wherein the code segment for determining the channel response stops the update after a finite number of iterations.

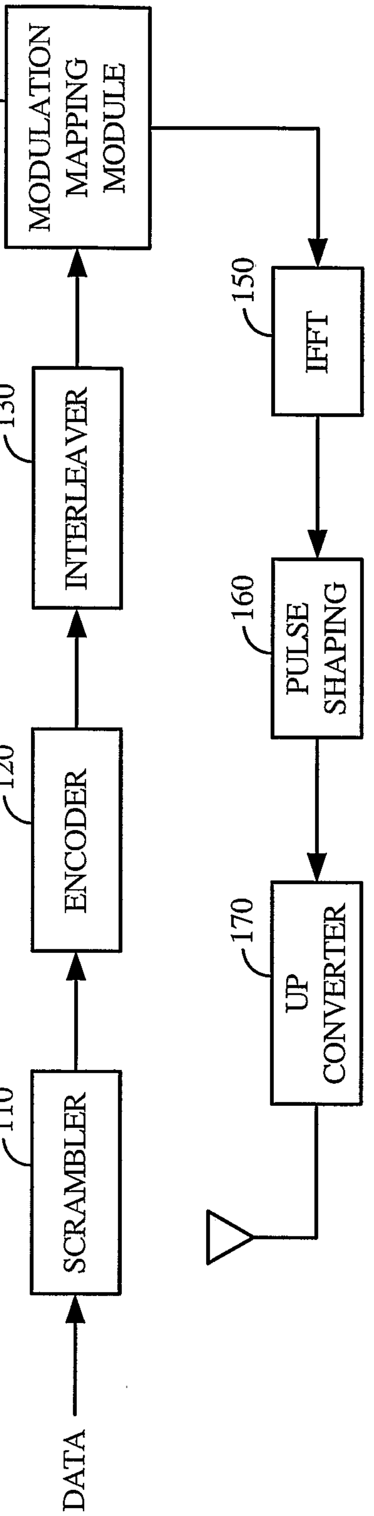

DATA
110
SCRAMBLER
120
ENCODER
130
INTERLEAVER
140
MODULATION MAPPING MODULE
150
IFFT
160
PULSE SHAPING
170
UP CONVERTER

FIG. 1

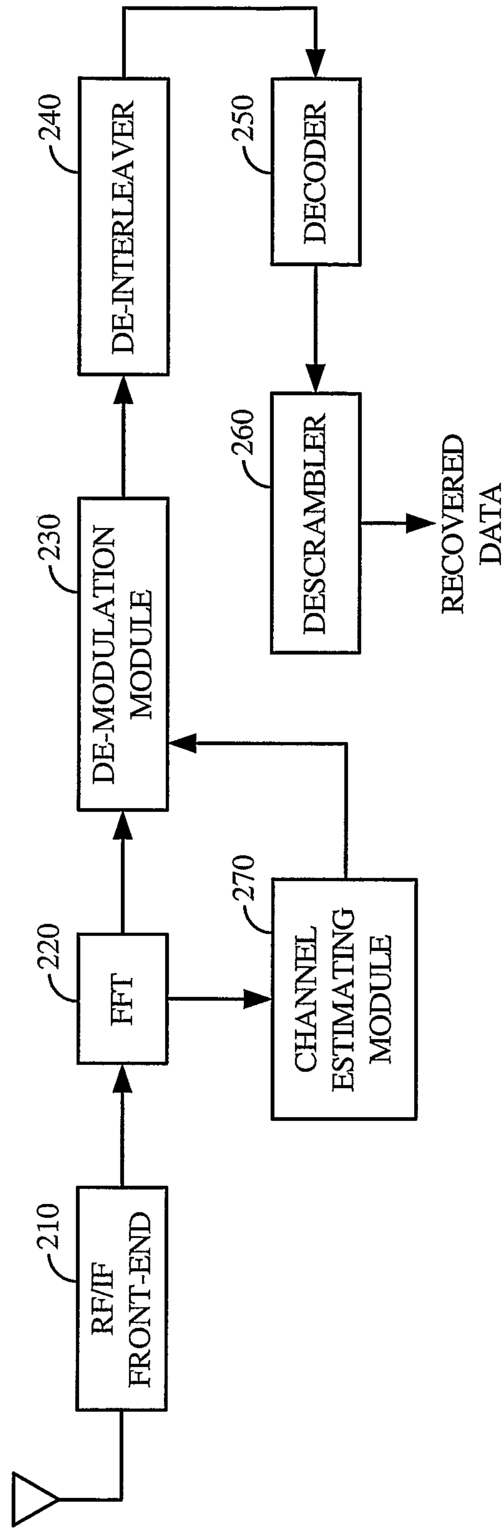

210
RF/IF FRONT-END
220
FFT
230
DE-MODULATION MODULE
240
DE-INTERLEAVER
250
DECODER
260
DESCRAMBLER
RECOVERED DATA
270
CHANNEL ESTIMATING MODULE

FIG. 2

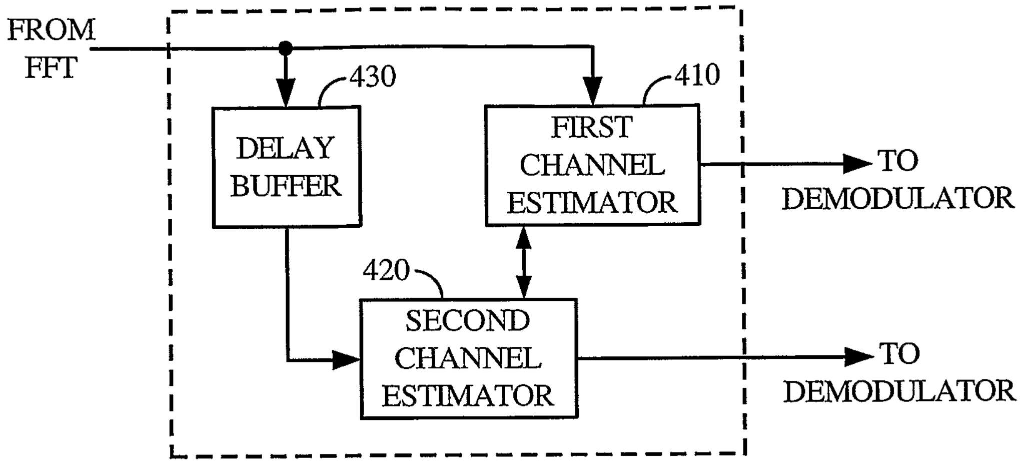


FIG. 4

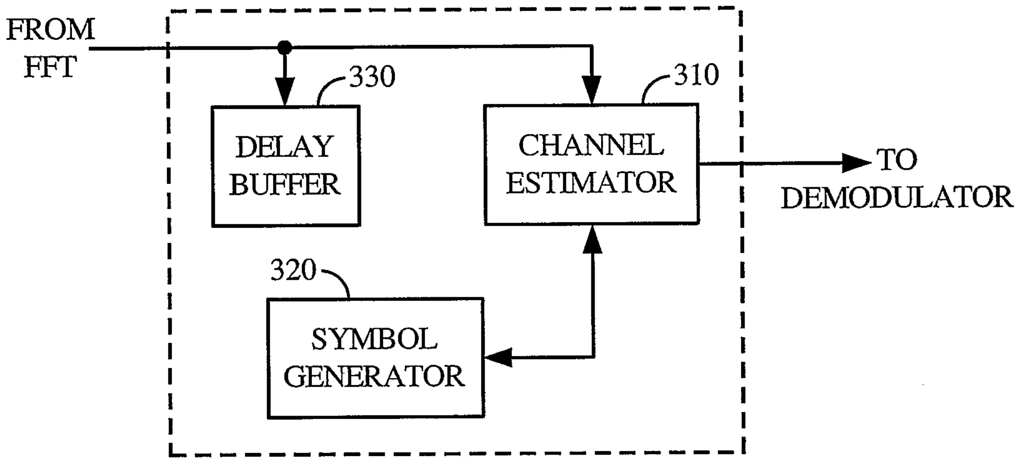


FIG. 3

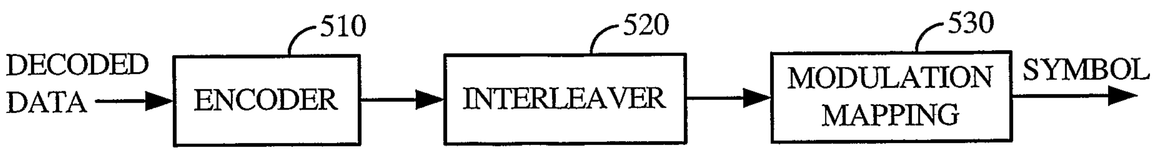


FIG. 5

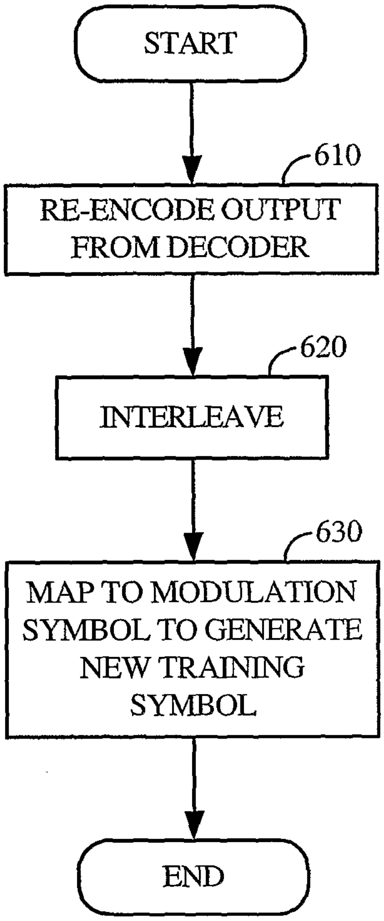
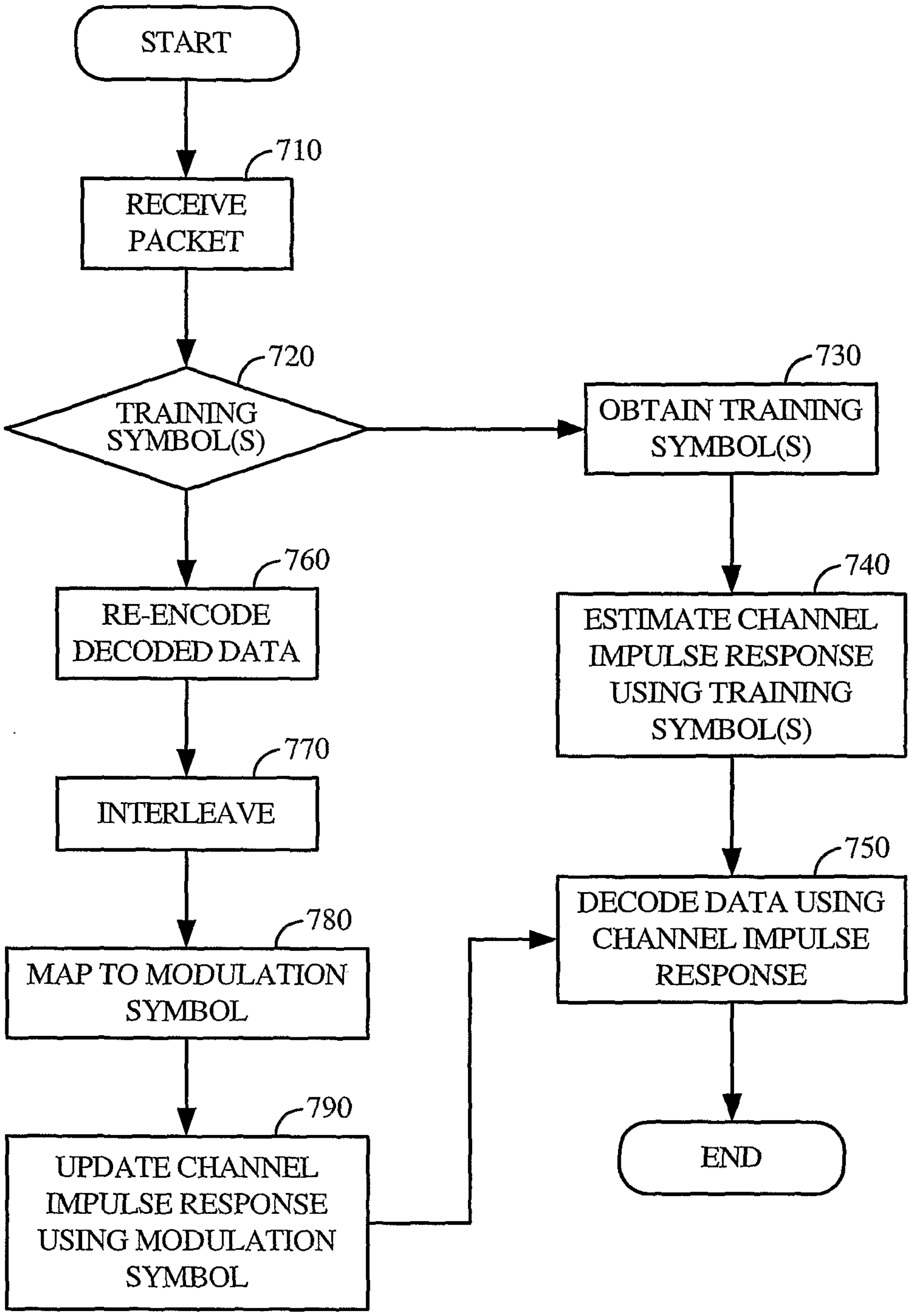

START
610
RE-ENCODE OUTPUT FROM DECODER
620
INTERLEAVE
630
MAP TO MODULATION SYMBOL TO GENERATE NEW TRAINING SYMBOL
END

FIG. 6



START
710
RECEIVE PACKET
720
TRAINING SYMBOL(S)
730
OBTAIN TRAINING SYMBOL(S)
760
RE-ENCODE DECODED DATA
740
ESTIMATE CHANNEL IMPULSE RESPONSE USING TRAINING SYMBOL(S)
770
INTERLEAVE
750
DECODE DATA USING CHANNEL IMPULSE RESPONSE
780
MAP TO MODULATION SYMBOL
790
UPDATE CHANNEL IMPULSE RESPONSE USING MODULATION SYMBOL
END

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/27803

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H04B 1/69, 1/76, 7/10
US CL : 375/144, 347, 348, 332, 140, 316

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 375/144, 347, 348, 332, 140, 316

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,487,255 B1 (ARSLAN et al.) 26 November 2002 (26.11.2002); Figure1, Figure 3, Figure 5, Figure 6	1, 4, 9, 15, 16, 21
A	US 6,625,236 B1 (DENT et al.) 23 September 2003 (23.09.2003); Figure 2 & Figure 3; Column 10, line s 14-67; Column 11, lines 19-67; Column 13, lines 13-37.	1, 5, 6, 7
A	US 5,687,198 A (SEXTON et al.) 11 November 1997 (11.11.1997); Figure 2; Figure 3; Column 4, lines 35-60; Claims 1 & 2.	1, 2, 22
A	US 5,329,547 A (LING) 12 July 1994 (12.07.1994)	1-12, 15-18 & 21-24
A	US 6,125,136 A (JONES et al.) 26 September 2000 (26.09.2000)	1-12, 15-18 & 21-24
A	US 6,625,201 B1 (STIRLING-GALLACHER) 23 September 2003 (23.09.2003).	1-12, 15-18, 21-24
A	US 5,822,380 A (BOTTOMLEY) 13 October 1998 (13.10.1998)	1-12, 15-18 & 21-24
A	US 6,587,517 B1 (LI et al.) 01 July 2003 (01.07.2003)	1-12, 15-18 & 21-24

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 2003 (24.11.2003)	05 DEC 2003

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450	Sudhanshu C. Pathak
Facsimile No.	Telephone No. (703)-305-0341

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/27803

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claim Nos.: 13, 14, 19, 20 & 25
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.