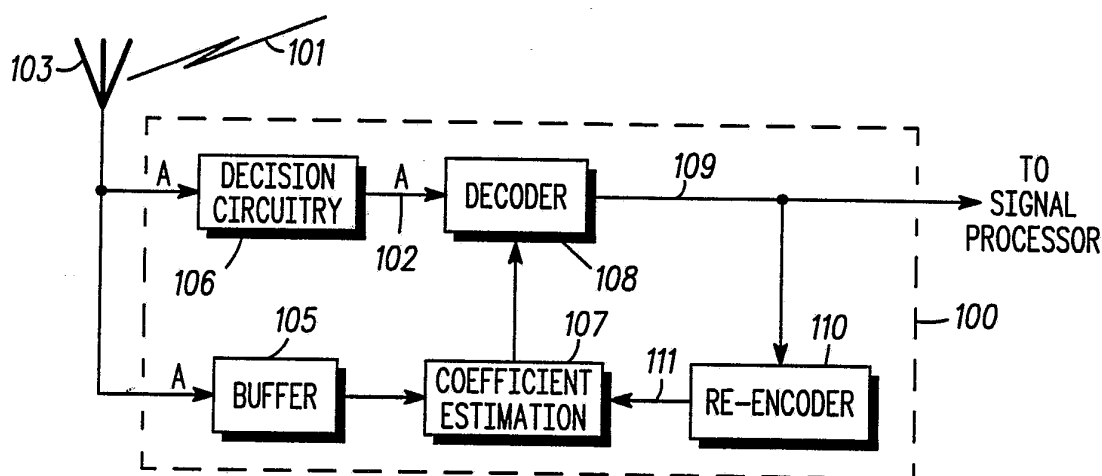




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(54) Title: METHOD AND APPARATUS FOR ESTIMATING SIGNAL WEIGHTING PARAMETERS IN A RECEIVER

**(57) Abstract**

A receiver (100) has improved signal weighting parameter estimation. The receiver receives a signal (101) having encoded data and decodes the data contained within the signal (101). The decoded data output is then re-encoded using a technique similar to that used by the transmitter. The re-encoded data is then used to calculate a signal weighting parameter which in turn, is used to modify a stored replica of signal (101). The modified version of the stored replica is then decoded to yield a more accurate estimate of the information contained within the signal (101) at receiver (100).

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**METHOD AND APPARATUS FOR
ESTIMATING SIGNAL WEIGHTING
PARAMETERS IN A RECEIVER**

5

Related Invention

Reference is made to U.S. Patent Application No. (Docket #CE02287R), "Method and Apparatus for Estimating Signal
10 Weighting Parameters in a Diversity Receiver" in behalf of Rasky et al., filed on the same date herewith, containing related subject matter and assigned to the assignee of the present invention.

15

Field of the Invention

This invention relates generally to estimation of signal parameters in a receiver and more specifically to the estimation
20 of signal parameters in a receiver for use in soft-decision decoding.

Background of the Invention

25 Soft-decision decoding is widely used within digital communications due to the performance gains which result from considering channel information within the decoding process. In order to realize the entire available gain, accurate information about a channel, or a signal transmitted, must be
30 available to the receiver. However, since the structure of the channel is typically unknown, the channel parameters required to realize the entire available gain must be estimated by the receiver.

For an arbitrary binary communication channel with time-varying channel gain and noise variance, the channel can be modeled as:

$$\mathbf{r} = \mathbf{p}_0 \mathbf{x}_s + \mathbf{n} \quad (1)$$

5 where \mathbf{r} is the received signal vector, \mathbf{p}_0 is the channel gain (diagonal) matrix, \mathbf{x}_s is the transmitted signal vector, and \mathbf{n} is the noise vector. Typically, a maximum likelihood decoder attempts to find the value of s , where s is some sequence, for
10 which the probability density function of the vector (given that \mathbf{x}_s was transmitted) is largest. At this point, the maximum likelihood decoder declares that \mathbf{x}_s was the transmitted message.

Since the probability density function of the vector \mathbf{r} is a function of both the channel gain and the noise variance, it is
15 apparent that an accurate estimate of both the channel gain and the noise variance is required if valid soft-decision information is to be determined. However, the validity of the estimates of the channel gain and the noise variance is directly related to the accuracy of the estimates of the variance of the received signal
20 power, $\sigma_r^2(k)$, and the variance of the received error signal, $\sigma_e^2(k)$, with respect to transmitted signal $\mathbf{x}_s(k)$. While $\sigma_r^2(k)$ is simply related to the received signal power, $\sigma_e^2(k)$ is not as easy to obtain since, at the receiver, the transmitted sequence $\mathbf{x}_s(k)$ is not available. Current techniques attempt to circumvent this
25 problem by assuming that for a specific symbol in the received sequence of the signal, the error signal is the difference between the received signal and the closest constellation point (CCP). While this technique is adequate if the CCP corresponds to the transmitted signal, in cases where it does not (i.e., the channel
30 has caused an error), the estimate of $\sigma_e^2(k)$ can be highly inaccurate.

Thus, a need exists for a new method and apparatus for estimating the variance of the received error signal $\sigma_e^2(k)$ which

provides a significant increase in accuracy by fully utilizing the information available at the receiver.

5

Summary of the Invention

A communication system has a transmitter and a receiver, the transmitter transmitting a signal having undergone encoding at the transmitter. The signal has data
10 contained within the signal. The receiver receives the encoded signal, generates at least a first signal weighting parameter related to the encoded signal and modifies the received encoded signal with the at least a first generated signal weighting parameter related to the signal. The receiver then decodes the
15 modified received encoded signal to produce a first decoded signal, re-encodes the first decoded signal, and generates at least a second signal weighting parameter related to the signal utilizing the re-encoded signal.

20

Brief Description of the Drawings

FIG. 1 generally depicts, in block diagram form, a generic receiver which implements improved parameter estimation in
25 accordance with the invention.

FIG. 2 generally depicts an I-Q constellation which may be used to represent a signal after demodulation.

FIG. 3 generally depicts, in block diagram form, a generic receiver implementing known and unknown data for improved
30 parameter estimation in accordance with the invention.

Detailed Description of a Preferred Embodiment

FIG. 1 generally depicts, in block diagram form, a generic receiver which implements improved parameter estimation in accordance with the invention. Links denoted by A in FIG. 1 are used only in the initial iteration. The receiver 100 receives a signal 101 transmitted by a transmitter (not shown). Signal 101 is an encoded signal, where in the preferred embodiment, the encoding includes an interleaving process. Signal 101 is received by an antenna 103 and input into decision circuitry 106. Decision circuitry 106 transforms the received signal into an received encoded vector 102 which represents signal 101 in vector form. Decision circuitry 106 is comprised of all necessary demodulation hardware and also performs hard-decision making or soft-decision making.

FIG. 2 generally depicts an I-Q constellation which may be used to represent signal 101 after demodulation. In the preferred embodiment, the constellation depicted in FIG. 2 is for a quaternary phase-shift keying (QPSK) or quaternary amplitude modulation (QAM) modulated signal 101. However, alternate embodiments may employ other types of modulation such as, inter alia, BPSK, 8PSK, 16QAM. As depicted in FIG. 2, the I-Q constellation is comprised of four constellation points 200-203 which represent the four possible hard-decisions which may be output by decision circuitry 106 if hard-decision making is employed. Also depicted in FIG. 2 is the transmitted signal 101 depicted in vector form by vector 206. Vector 206 represents the ideal transmission and the transmission that receiver 100 would receive in ideal situations. However, due to errors introduced by the corresponding channel, a typical vector \mathbf{r} received by receiver 100 is vector 208. Vector 208 represents what receiver 100 received, and thus what it thinks is correct. Obviously, if vector 206 represents the signal transmitted, and vector 208 represents what the receiver 100 received (i.e., thinks was transmitted),

considerable error is introduced by both the propagation medium and receiver 100.

Soft-decision making in receiver 100 is helpful in decoder 108 in mitigating the errors introduced by the propagation medium and receiver 100. At this point, a brief overview of soft-decision decoding theory is instructive. Recall that an arbitrary binary communication channel with time-varying channel gain and noise variance can be modeled as

$$r = p_o x_s + n$$

where r is the received signal vector, p_o is the channel gain (diagonal) matrix, x_s is the transmitted signal vector, and n is the noise vector. Also, if the probability density function of the vector r given that x_s was transmitted is $Q(r|s)$, when given the received signal vector r , the maximum likelihood decoder finds the value of s for which $Q(r|s)$ is largest and declares that x_s was the transmitted signal. In order to further define the structure of the soft-decision decoder, several assumptions are made. First, assume that each element, or symbol k , of x_s , denoted by $x_s(k)$, is an independent identically distributed (i.i.d.) binary random variable taking values $\pm\sqrt{C}$ with equal probability. Also, assume that each element of the noise vector n is an independent Gaussian random variable with zero mean and variance $\sigma_n^2(k)$. With this assumption,

$$Q(r|s) = \prod_k \frac{1}{\sqrt{2\pi\sigma_n^2(k)}} \exp \left(-\frac{(r(k) - p_o(k)x_s(k))^2}{2\sigma_n^2(k)} \right) \quad (2)$$

where the channel gain has been included with the transmitted sequence in order to facilitate the modeling of this channel.

Since the natural logarithm function is monotonically increasing, maximizing $Q(r|s)$ is equivalent to maximizing

$$\ln Q(r|s) = \ln \prod_k \frac{1}{\sqrt{2\pi}\sigma_n(k)} \exp \left(-\frac{(r(k) - p_o(k)x_s(k))^2}{2\sigma_n^2(k)} \right)$$

$$\ln Q(r|s) = \sum_k \ln \frac{1}{\sqrt{2\pi}\sigma_n(k)} - \sum_k \left(\frac{(r(k) - p_o(k)x_s(k))^2}{2\sigma_n^2(k)} \right)$$

$$\ln Q(r|s) = \sum_k \ln \frac{1}{\sqrt{2\pi}\sigma_n(k)} - \sum_k \left(\frac{(r^2(k) - 2r(k)p_o(k)x_s(k) + p_o^2(k)x_s^2(k))}{2\sigma_n^2(k)} \right) \quad (3)$$

Now, recalling that $x_s^2(k) = c$, all terms which do not explicitly depend on $x_s(k)$ can be neglected since they do not affect the decision of the decoder. Thus, the maximum likelihood decoder seeks the value of s which maximizes:

$$\sum_k \frac{p_o(k)}{\sigma_n^2(k)} r(k)x_s(k) \quad (4)$$

where the weighting parameter $\alpha(k)$, in the preferred embodiment, for signal 101 is given by:

$$\alpha(k) = \frac{p_o(k)}{\sigma_n^2(k)} \quad (5)$$

In alternate embodiments, other methods for combining the channel gain, $p_o(k)$, and noise variance, $\sigma_n^2(k)$, to form signal weighting parameter $\alpha(k)$ may be employed. Likewise, parameters other than channel gain $p_o(k)$ and noise variance $\sigma_n^2(k)$ may be utilized to calculate signal weighting parameter $\alpha(k)$.

Continuing, as previously indicated, accurate estimates of the channel gain $p_o(k)$ and noise variance $\sigma_n^2(k)$ are necessary if valid soft-decision information is to be determined. To better understand the improved estimation techniques in accordance with the invention, a short review of current estimation techniques is instructive. Assume that all signals are real

values. At the receiver, only the received signal $r(k)$ is available. Noting that $r(k)$ has zero mean, it is possible to define the received signal variance as:

$$\sigma_r^2(k) = E[r^2(k)]$$

$$\sigma_r^2(k) = E[(p_o(k)x_s(k) + n(k))^2]$$

$$\sigma_r^2(k) = E[p_o^2(k)x_s^2(k)] + E[2p_o(k)x_s(k)n(k)] + E[n^2(k)] \quad (6)$$

Taking the expectations, recalling that $n(k)$ and $x_s(k)$ are independent and zero mean, yields:

$$\sigma_r^2(k) = cp_o^2(k) + \sigma_n^2(k) \quad (7)$$

Define the error signal as $e_s(k) = r(k) - x_s(k)$, then in the same manner as for the received signal variance $\sigma_r^2(k)$, the variance of the error signal $\sigma_e^2(k)$ may be determined as:

$$\sigma_e^2(k) = E[e_s^2(k)]$$

$$\sigma_e^2(k) = E[(r(k) - x_s(k))^2]$$

$$:$$

$$:$$

$$\sigma_e^2(k) = c(p_o(k) - 1)^2 + \sigma_n^2(k) \quad (8)$$

Now a straight forward algebraic manipulation of (7) and (8) yields:

$$p_o(k) = \frac{\sigma_r^2(k) - \sigma_e^2(k) + c}{2c} \quad (9)$$

and using this result

$$\sigma_n^2(k) = \sigma_r^2(k) - cp_o^2(k). \quad (10)$$

The calculation of the expectations is taken over a number of bits for which the channel gain and noise variance parameters do not vary appreciably. In the preferred embodiment, the communication system is a slow-frequency hopping (SFH) code-division multiple access (CDMA) communication system where the number of bits for which the channel gain and noise variance parameters don't vary appreciably is the period of a single frequency hop. For a background on frequency hopping in communication systems, reference is made to George Calhoun, *Digital Cellular Radio*, U.S.A., 1988 at pages 344-351. Continuing, in alternate embodiments, the communication system may be, inter alia, a continuous data communication system or a time-division multiple access (TDMA) communication system. Specifically for TDMA communication systems, the number of bits for which the channel gain and noise variance parameters don't vary appreciably may be the entire period of a timeslot for short timeslot systems. One such system is the Groupe Special Mobile (GSM) Pan-European Digital Cellular System. For other TDMA systems having longer timeslots, for example the United States Digital Cellular (USDC) System, a "windowing" technique may be employed to minimize parameter variation during the period of the expectation as required. Several common windowing techniques include, inter alia, rectangular windowing and exponential decay windowing.

Recall that the error signal is given by $e_s(k)$, and the ideal transmitted signal $x_s(k)$ is given by vector 206 of FIG. 2. If the channel is severely corrupted, the received signal $r(k)$ could be the vector 208. Typically, receivers assume that for a given symbol k in a data sequence, the error signal is the difference between the received signal and the closest constellation point (CCP). Thus, referring to FIG. 2, if the received signal $r(k)$ is vector 208, a typical receiver's estimation of the error signal would be Δ_2 , since it is closest to constellation point 203.

However, the constellation point which should be used, as it corresponds to the ideal transmitted vector 206, is constellation point 201. This being the case, the actual error in the receiver is Δ_1 and not Δ_2 . This type of discrepancy, between the error the receiver thinks it sees and what it should see, is what the present invention seeks to improve.

Now referring back to FIG. 1, output from decision circuitry 106 is received encoded vector 102 which may be weighted (for example by CCP soft-decision making) or may not be weighted (hard-decision making). Received encoded vector 102 is input into a decoder 108, which in the preferred embodiment includes de-interleaving and Viterbi decoding. In alternate embodiments, many types of error correction codes, and consequently decoders, may be incorporated. Referring back to FIG. 2, the error in the receiver, assuming vector 206 is what was actually transmitted and vector 208 represents what receiver 100 thinks was transmitted, is represented by Δ_2 . If this error signal were used to calculate the variance of the error signal for later use in calculating the signal weighting parameter $\alpha(k)$, the weighting of signal 101 in receiver 100 would be grossly inaccurate. Referring back to FIG. 1, output from decoder 108 is a decoded received vector 109 which, by virtue of the error correction coding in decoder 108, has fewer errors than does received encoded vector 102. Decoded received vector 109, which after the initial iteration is a first decoded received vector, is then re-encoded in accordance with the invention. In the preferred embodiment, the re-encoder 110 re-encodes the first decoded received vector in a manner using the same technique as that used by the transmitter (not shown).

Output from re-encoder 110 is modified received vector 111, which, after this first iteration, is a first modified received vector. Modified received vector 111 is a better estimate of signal 101 than is received encoded vector 102. Modified received vector 111 enters soft-decision block 107 where a signal weighting

parameter $\alpha(k)$ is calculated using modified received vector 111. Since, at this point, modified received vector 111 contains information about signal 101, receiver 100 knows that the CCP technique used initially was incorrect. Receiver 100 corrects for this by now using constellation point 201 for calculation of signal weighting parameter $\alpha(k)$, thus giving a more accurate estimate of transmitted signal $x_s(k)$ represented by vector 206. In the preferred embodiment, signal weighting parameter $\alpha(k)$ is a soft-decision weighting parameter, which will be used to further weight or modify a stored replica of signal 101. At this time, the newly calculated signal weighting parameter represents a second signal weighting parameter. Calculation of the second signal weighting parameter is performed in soft-decision block 107 using modified received vector 111 where it is used to modify a stored replica of signal 101 retrieved from buffer 105. The modified stored replica is then decoded, resulting at this point in a second decoded received vector. By virtue of the first iteration through re-encoder 110 and soft decision block 107, the second decoded received vector has fewer errors than did first decoded received vector 109 since the first iteration allowed receiver 100 to learn information about signal 101, and more specifically about the data contained within signal 101. By iterating in this manner, receiver 100 is able to make a better estimate of what signal 101 looked like, and can thus more accurately reconstruct signal 101 at receiver 100.

A first iteration through the re-encoder 110 and into soft-decision block 107 will obviously help receiver 100 learn more about signal 101. However, although it may be adequate, receiver 100 is not limited to only a single iteration. In fact, each time receiver 100 undergoes an iteration, it corrects more and more of the errors introduced by both the propagation medium and receiver 100 with respect to signal 101. At some number of iterations, however, the amount of errors that decoder 108 is able to correct will decrease and will eventually reach a point of

diminishing return since receiver 100 will reach a point where there are no longer any errors possible for receiver 100 to correct with respect to signal 101. The number of iterations that receiver 100 undergoes is dependent upon the performance requirements of receiver 100.

In an alternate embodiment, receiver 100 could have a limited amount of knowledge about signal 101, specifically about data contained within signal 101. For example, signal 101 could be a burst signal within a time-division multiple access (TDMA) communication system which has a fully-known amount of information. This information may be, but is not limited to, continuous sequences such as a preamble, midamble, or a postamble. In this scenario, receiver 100 would use the fully-known amount of information as the estimate of x_s in the determination of the error signal and, consequently, improve the accuracy of the signal weighting parameter. The receiver 100 would use the fully-known amount of information in place of the corresponding $x_s(k)$ sequence for these bits. This would result in the generation of completely accurate soft-decision information over the span of these bits. This information could be combined with signal weighting parameters derived from the unknown data bits using the previously discussed CCP techniques to form a signal weighting parameter which would be used to scale signal 101 in the first decoding iteration. In latter iterations, the signal weighting parameter from the known data bits could be combined with weighting parameters derived from the unknown data bits using the previously discussed re-encoding technique.

In another embodiment, signal 101 could be a signal which has a partially-known amount of information, for example, inter alia, a digital voice color code (DVCC) sequence. In this scenario, the soft-decision information may not be as accurate since the receiver does not explicitly know the corresponding $x_s(k)$ sequence; it simply knows that these symbols belong to a particular subset. Consequently, the signal

weighting parameters would be calculated via a modified technique in which the error signal and hence the signal weighting parameter would be calculated in the previously described manner for the unknown data bits while for the
5 partially known bits the error term and hence the signal weighting parameter would be calculated using only the constellation points within the set of allowable values. These two weighting parameters would then be combined to form a signal weighting parameter which would be used to scale signal 101.

10 FIG. 3 generally depicts, in block diagram form, a generic receiver 300 implementing fully-known or partially-known data and unknown data for improved parameter estimation in accordance with the invention. As depicted in FIG. 3, signal 101, antenna 103, buffer 105, decision circuitry 106, decoder 108, and
15 re-encoder 110 may be the same as those shown in FIG. 1. During a first iteration, signal 101 enters antenna 103 where signal 101 is routed to decision circuitry 106 and a first signal weighting parameter is generated. In the preferred embodiment, the first signal weighting parameter is a soft-
20 decision weighting parameter. In alternate embodiments, however, first signal weighting parameter may be the result of a hard-decision. Continuing, decision circuitry 106 transforms the received signal into an received encoded vector 102 which represents signal 101 in vector form. Received encoded vector 102
25 is then input into decoder 108 where it is decoded. Output from decoder 108 is a first decoded signal 109 which is re-encoded by re-encoder 110. Output from re-encoder 110 is modified received vector 111, which, after this first iteration, is a first modified received vector. It is at this point where the operation of receiver
30 300 deviates from that of receiver 100 of FIG.1. As depicted in FIG. 3, signal 101 is stored in buffer 105 which is physically the same buffer but is separated in FIG. 3 for convenience. Since signal 101 has either fully-known or partially-known data, the weights from this known data can be calculated in block 300

directly from a stored replica of signal 101. However, since there are a remainder of unknown bits, to obtain an estimate of these unknown bits, modified received vector 111 is combined with the unknown bits stored in buffer 105 to generate weights from the
5 unknown bits. This is done in block 306. Outputs from block 300 and 306 are then combined in combine block 303 to yield a second signal weighting parameter which has essentially modified a stored replica of received signal 101. Output from combine block 303 is a modified received signal 309 which is then re-decoded to
10 produce a second decoded signal having additional information about data contained within signal 101.

What we claim is:

Claims

- 5 1. In a communication system having a transmitter and a receiver, the transmitter transmitting a signal having undergone encoding at the transmitter, the signal having data contained within the signal, a method of estimating signal weighting parameters in the receiver, the method comprising the steps of:
- 10 receiving the encoded signal;
 generating at least a first signal weighting parameter related to the encoded signal;
- 15 modifying the received encoded signal with said at least a first generated signal weighting parameter related to the signal;
- decoding the modified received encoded signal to produce a first decoded signal;
- 20 re-encoding the first decoded signal; and
 generating at least a second signal weighting parameter related to the signal utilizing said re-encoded signal.

2. The method of claim 1 further comprising the steps of:

modifying a stored replica of the encoded signal
with said at least a second generated signal weighting
parameter; and

decoding the modified stored replica of the encoded
signal to produce a second decoded signal.

3. The method of claim 1 wherein said second decoded signal
is utilized to reconstruct the signal in the receiver.

4. In a communication system having a transmitter and a receiver, the transmitter transmitting a signal having undergone encoding at the transmitter, a method of estimating signal weighting parameters in a receiver, the
5 method comprising the steps of:

receiving the encoded signal;

transforming said received encoded signal into a received encoded vector representing the encoded signal;

10 modifying said received encoded vector with a first signal weighting parameter calculated using said received encoded vector;

15 decoding said received encoded vector modified by said first signal weighting parameter to produce a first decoded received vector;

re-encoding said first decoded received vector to produce a first re-encoded received vector;

20 modifying a stored replica of said received encoded signal with a second signal weighting parameter calculated using said first re-encoded received vector; and

decoding said modified stored replica of said received encoded vector to produce a second decoded received vector.

5. An apparatus for estimating signal weighting parameters in a receiver, the apparatus comprising:

5 means for receiving an encoded signal transmitted from a transmitter;
first means, coupled to said means for receiving, for making signal weighting parameter decisions based on said received signal;
10 means, coupled to said means for making decisions, for decoding said received signal based on said decisions;
means, coupled to said means for decoding, for re-encoding said decoded received signal; and
15 second means, coupled to said means for re-encoding and said received signal, for making signal weighting parameter decisions based on said re-encoded received signal.

6. The apparatus of claim 5 wherein said first means for making signal weighting parameter decisions further comprises means for making one of either a hard-decision or a soft-decision.
- 5
7. The apparatus of claim 5 wherein said second means for making signal weighting parameter decisions based on said re-encoded received signal further comprises means for weighting said received signal with said signal weighting parameter decisions to produce a signal utilized to reconstruct the signal in the receiver.
- 10

8. A receiver for estimating signal weighting parameters, the receiver employed in a slow-frequency hopping (SFH) communication system, the receiver comprising:

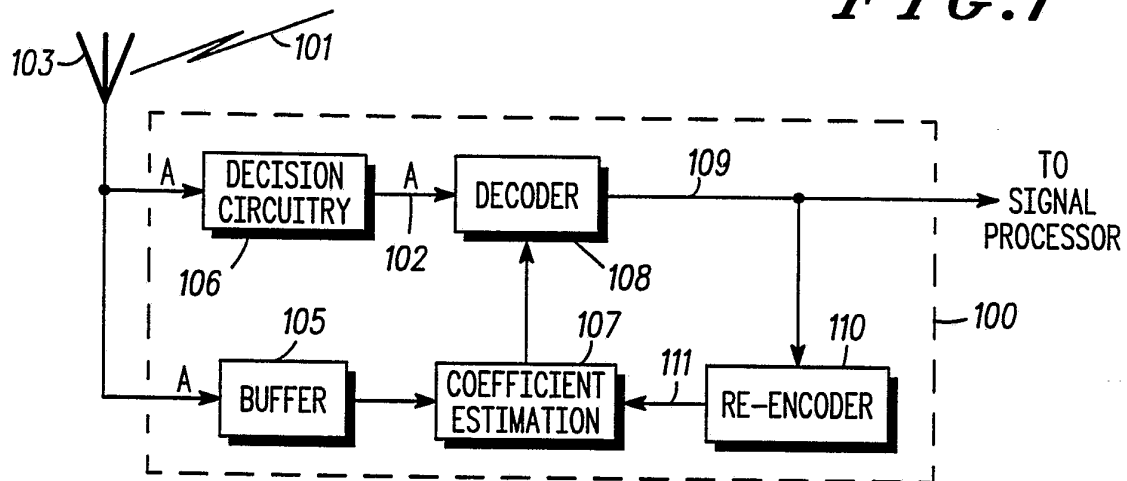
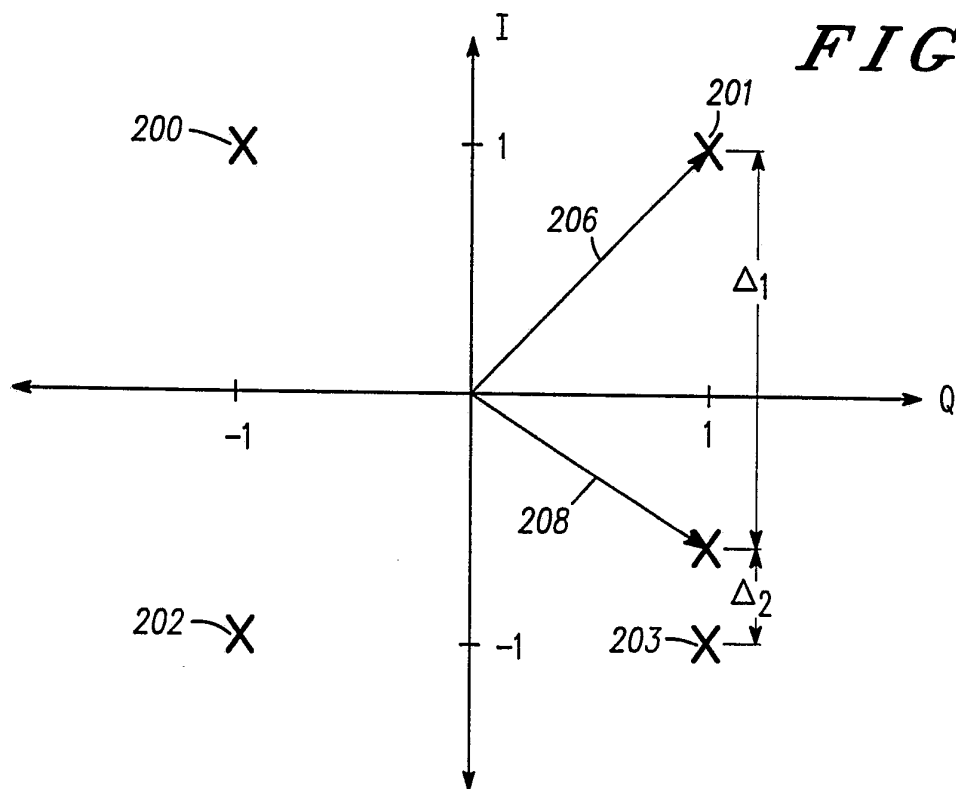
- 5 means for receiving a frequency-hopped signal transmitted from a transmitter;
- first means, coupled to said means for receiving, for making signal weighting parameter decisions based on said received signal;
- 10 means, coupled to said means for making decisions, for decoding said received signal based on said decisions;
- means, coupled to said means for decoding, for re-encoding said decoded received signal; and
- 15 second means, coupled to said means for re-encoding and said received signal, for making signal weighting parameter decisions based on said re-encoded received signal.

9. The receiver of claim 8 wherein said receiver is employed in a code-division multiple access (CDMA) communication system.

10. A receiver for estimating signal weighting parameters, the receiver employed in a time-division multiple access (TDMA) communication system, the receiver comprising:

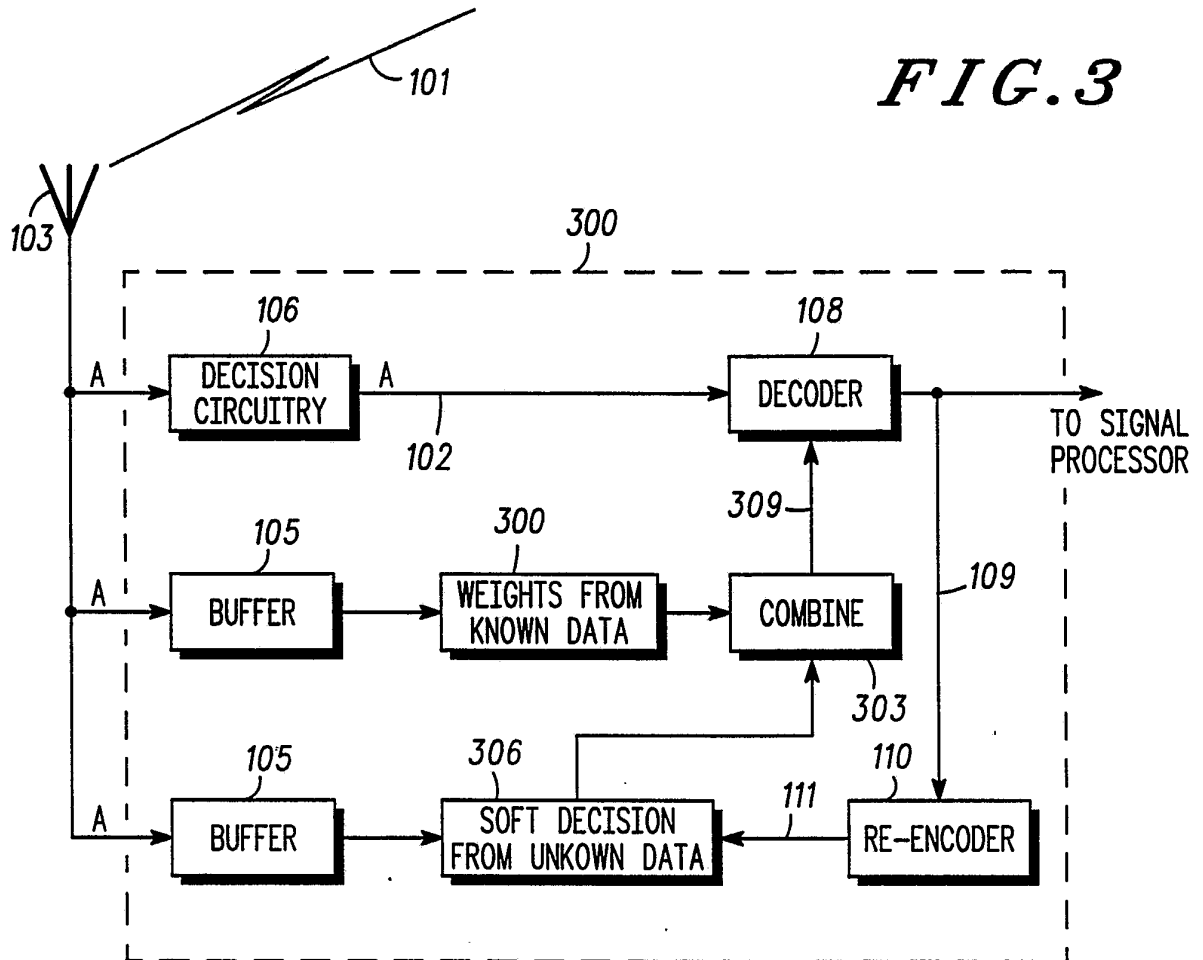
5 means for receiving an encoded signal, transmitted from a transmitter, during a first TDMA timeslot;
 first means, coupled to said means for receiving, for making signal weighting parameter decisions based on said received signal;
10 means, coupled to said means for making decisions, for decoding said received signal based on said decisions;
 means, coupled to said means for decoding, for re-encoding said decoded received signal; and
 second means, coupled to said means for re-encoding and said received signal, for making signal
15 weighting parameter decisions based on said re-encoded received signal.

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FIG. 1*FIG. 2*

2/2

FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/01154

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H03D 1/04; H03K 5/01

US CL :375/99,58

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. : 375/57/51; 455/226.3

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)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,031,195 (CHEVILLAT ET AL.) 09 July 1991.	1-10
A	US, A, 4,631,735 (QURESHI) 23 December 1986.	1-10
A,P	US, A, 5,157,697 (ANVARI ET AL.) 20 October 1992.	1-10

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

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11 MAY 1993

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