

METRIC CORRECTION FOR MULTI USER DETECTION, FOR LONG CODES DS-CDMA

TECHNICAL FIELD

This invention relates to channel decoders, and more
5 particularly to applying metric correction to the log-
likelihood ratio (LLR) of transmitted symbols.

BACKGROUND

For multiple component codes, optimal decoding is often
a very complex task, and may require large periods of time,
10 not usually available for on-line decoding. In order to
overcome this problem, iterative decoding techniques have
been developed. Rather than determining immediately whether
received bits are zero or one, the receiver assigns each bit
a value on a multi-level scale representative of the
15 probability that the bit is one.

A soft input channel decoder requires having at its
input the log-likelihood ratio (LLR) of the transmitted
symbols, or some approximation of the LLR of the transmitted
symbols. When using biphase phase shift keying (BPSK), a
20 large positive value of the LLR indicates that the
transmitted symbol is a "1" with high probability. A large
negative value of the LLR indicates that the transmitted
symbol is a "-1" with high probability. A low LLR magnitude
implies low confidence in the value of the symbol. The

channel decoder then utilizes the sequence of LLR values to decode the transmitted information in a manner that minimizes the error probability. This is possible because the LLR value of each symbol is directly related to the noise and interference that distorted the transmission the corresponding symbol.

Data represented on the multi-level scale is referred to as "soft data," and iterative decoding is usually soft-in/soft-out, i.e., the decoding process receives a sequence of inputs corresponding to probabilities for the bit values and provides as output corrected probabilities taking into account constraints of the code. Generally, a decoder which performs iterative decoding, uses soft data from former iterations to decode the soft data read by the receiver.

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DESCRIPTION OF DRAWINGS

Figure 1 is a block diagram of the general structure of a receiver according to one embodiment of the invention.

Figure 2 illustrates the process of normalizing the detector output to obtain the LLR according to one embodiment of the invention.

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Figure 3 is a block diagram illustrating the calculation of the variance of the multiple access interference term (MAI) using an analytical technique according to one embodiment of the invention.

Figure 4 is a block diagram illustrating the estimation of the variance of the multiple access interference term (MAI) using an empirical technique according to one embodiment of the invention.

5 Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

One embodiment of the present invention determines the LLR value for long-code direct sequence code division multiple access (DS-CDMA). In direct sequence spread spectrum, the stream of information to be transmitted is divided into small pieces, each of which is allocated across the spectrum to a frequency channel. A data signal at the point of transmission is combined with a higher data-rate bit sequence (chipping code) that divides the data according to a spreading ratio. The redundant chipping code helps the signal resist interference and also enables the original data to be recovered if data bits are damaged during transmission. The use of long codes results in interference being proportional to the cross-correlations between the spreading sequences of the different users. These spreading sequences change from symbol to symbol, resulting in a change in the level of multiple access interference (MAI) from symbol to symbol. By using the present invention, the

performance of a conventional rake receiver may be improved, especially when the noise level is low and the dominant source of the signal degradation is the MAI.

Figure 1 is a block diagram of the general structure of a receiver 100 according to one embodiment of the invention. A signal is received at an antenna 105 and is then converted to baseband in a radio frequency (RF) to baseband converter 110. The baseband signal is then received by a multiuser detection (MUD) or Rake receiver 115. The term multiuser
10 Detection (MUD) is applied to receivers that take into account the structure of the multiple access interference in CDMA systems. A Rake receiver uses several baseband correlators to individually process several signal multipath components. The correlator out-puts are combined to achieve
15 improved communications reliability and performance. The MUD or Rake produce output symbols based on the baseband signals. These output symbols are provided to the metric correction section 120. The goal of the metric correction is to normalize the Rake or MUD output to obtain the LLR
20 metric in order to provide the channel decoder 125 with the appropriate metric. For long code CDMA, this normalization is performed on a symbol-by-symbol basis because of the time varying nature of the interference.

For BPSK signaling, the LLR of the n^{th} symbol is given
25 by the following equation 1:

$$LLR(n) = \log \left[\frac{p(r(n)/s(n)=1)}{p(r(n)/s(n)=-1)} \right] = \frac{1}{2\sigma_T^2(n)} [(r(n)-g(n))^2 - (r(n)+g(n))^2] = -\frac{2r(n)g(n)}{\sigma_T^2(n)}$$

Equation 1

where:

$r(n)$ is the detector output of the n^{th} symbol;

5 $g(n)$ is the time varying gain associated with the
desired signal; and

$\sigma_T^2(n)$ is the total noise variance.

This equation assumes additive white Gaussian noise,
which is the common practice in the DS-CDMA setting.

10 However, modifications for other noise and multiple access
interference distributions are possible and well known in
the art. Further, extensions to other symbol constellations
and to different modulations may be performed.

Figure 2 illustrates the process 200 of normalizing the
15 detector output to obtain the LLR according to one
embodiment of the invention. The process 200 begins in a
START block 205. Proceeding to block 210, the process 200
receives the output symbol from the Multiuser Detection or
the Rake receiver. The output symbol is composed of three
20 terms:

, The desired signal term, which is $g(n)$ multiplied by
the transmitted symbol;

The multiple access interference (MAI) term which is assumed to be a white Gaussian process whose variance is denoted by $\sigma_I^2(n)$; and

The noise term that is assumed to be a white Gaussian process whose variance is denoted by $\sigma_N^2(n)$.

Proceeding to block 215, the process 200 determines the normalization factor. The normalization factor is determined by calculating the gain of the desired term $g(n)$. The variances $\sigma_N^2(n)$ and $\sigma_I^2(n)$ are then calculated. The total noise variance $\sigma_T^2(n)$ is then determined using the following equation:

$$\sigma_T^2(n) \equiv \sigma_I^2(n) + \sigma_N^2(n)$$

The normalization factor is then determined by placing the values of $g(n)$ and $\sigma_T^2(n)$ into Equation 1.

Proceeding to block 220, the process 200 multiplies the normalization factor by the output symbol to determine the metric correction 120. The metric correction 120 is then provided to the channel decoder 125 in block 225. After the channel decoder 125 receives the metric correction 120, the process 200 terminates in the END block 230.

Figure 3 is a block diagram 300 illustrating the calculation of the variance of the multiple access interference term (MAI) using an analytical technique according to one embodiment of the invention. As shown

above, the exact expression for the LLR is calculated while taking into account the time varying nature of the interference, yet approximating the interference to be Gaussian. The Gaussian approximation is common with MAI, and is a consequence of the central limit theorem when applied to the despreading operation. When multi-user detection (MUD) is employed, the calculation of the LLRs is even more complicated, as the detection itself is time varying following the variation of the MAI. As shown in the block diagram 300, the MAI Variance Calculation receives a variety of inputs such as the cross correlation between spreading sequences, other users gain, MUD weight vectors, and channel taps estimates. These inputs are used to calculate the MAI variance $\sigma_I^2(n)$.

Figure 4 is a block diagram 400 illustrating the estimation of the variance of the multiple access interference term (MAI) using an empirical technique according to one embodiment of the invention. The MAI Variance Calculation receives a variety of inputs such as the cross correlation between spreading sequences, the output symbol, MUD weight vectors, and channel taps estimates. These inputs are used to estimate the MAI variance $\sigma_I^2(n)$. An estimation error is provided in a

feedback loop to continually refine the estimation of the MAI variance.

By determining and applying the metric correction 120, the gain of a MUD receiver may be preserved. For example, in the Wideband Code Division Multiple Access (WCDMA) standard 25.101 case 4 channel set-up, a gain of about 3 dB can be achieved with a conventional minimum mean-squared error multiuser detection (MMSE MUD) at the uncoded bit error rate (BER) level compared to the rake receiver. However, the 3 dB gain is lost when examining the block error rate (BLER) performance. By applying the metric correction, the 3 dB gain is obtained for the BLER performance.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A method of normalizing an output of a receiver,
the method comprising:

determining a normalization factor; and

5 applying the normalization factor to the output of the
receiver.

2. The method of Claim 1, further comprising
normalizing each symbol output from the receiver.

3. The method of Claim 1, further comprising
10 obtaining a metric correction factor from the normalization
factor.

4. The method of Claim 1, further comprising
providing the metric correction factor to a channel decoder.

5. The method of Claim 1, further comprising
15 determining the log likelihood ratio (LLR) according to the
following equation:

$$LLR(n) = -\frac{2r(n)g(n)}{\sigma_T^2(n)}$$

where:

$r(n)$ is the detector output of the n^{th} symbol;

20 $g(n)$ is the time varying gain associated with the
desired signal; and

$\sigma_T^2(n)$ is the total noise variance..

6. The method of Claim 5, further comprising determining the total noise variance analytically.

7. The method of Claim 5, further comprising
5 determining the total noise variance empirically.

8. The method of Claim 1, further comprising employing multiuser detection to obtain the output of the receiver.

9. A receiver comprising:
10 a detector which receives transmitted information and provides one or more output symbols based on the transmitted information;

a metric correction section which normalizes the one or more output symbols to obtain a metric; and

15 a channel decoder which receives the metric from the metric correction section, the channel decoder utilizing the metric to decode the transmitted information.

10. The receiver of Claim 9, wherein the detector is a multiuser detector.

20 11. The receiver of Claim 9, wherein the detector is a rake detector.

12. The receiver of Claim 9, wherein the metric is a log likelihood ratio.

13. The receiver of Claim 9, wherein the metric correction section determines a normalization factor to
5 apply to the output symbols of the detector.

14. The receiver of Claim 9, wherein the detector is a long code CDMA detector.

15. The receiver of Claim 14, wherein the metric correction section normalizes each output symbol on a symbol
10 by symbol basis.

16. The receiver of Claim 9, wherein the metric of a log likelihood ratio for BPSK signaling is determined from the following equation:

$$LLR(n) = -\frac{2r(n)g(n)}{\sigma_T^2(n)}$$

15 where:

$r(n)$ is the detector output of the n^{th} symbol;

$g(n)$ is the time varying gain associated with the desired signal; and

$\sigma_T^2(n)$ is the total noise variance..

20 17. The receiver of Claim 16, wherein the total noise variance is determined analytically.

18. The receiver of Claim 16, wherein the total noise variance is determined empirically.

19. A method comprising:

receiving one or more output signals from a detector;

5 determining a normalization factor for each of the one or more output signals;

multiplying each of the one or more output signals by the corresponding normalization factor to obtain a metric correction; and

10 providing the metric correction for each symbol to a channel decoder.

20. The method of Claim 19, further comprising decoding a transmission using the metric correction.

21. The method of Claim 19, further comprising
15 determining the metric correction log likelihood ratio metric according to the following equation:

$$LLR(n) = -\frac{2r(n)g(n)}{\sigma_T^2(n)}$$

where:

$r(n)$ is the detector output of the n^{th} symbol;

$g(n)$ is the time varying gain associated with the desired signal; and

$\sigma_1^2(n)$ is the total noise variance..

22. The method of Claim 21, further comprising
5 determining the total noise variance analytically.

23. The method of Claim 21, further comprising
determining the total noise variance empirically.