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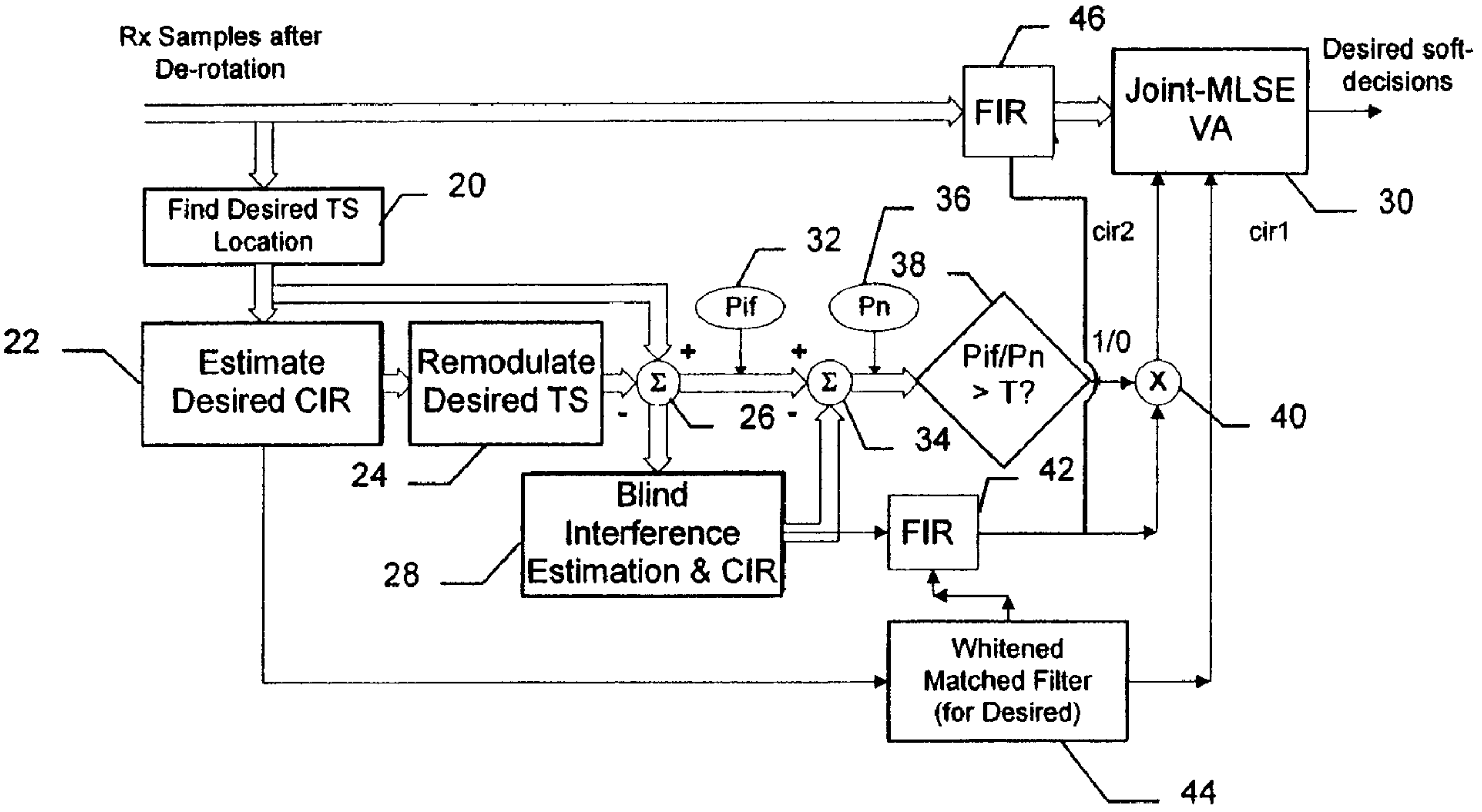

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JOINT DEMODULATION TECHNIQUES FOR INTERFERENCE CANCELLATION

Field of the Invention

The present invention relates to wireless communications systems, such as cellular communications systems, and, more particularly, to filtering received wireless signals to reduce unwanted interference.

Brief Description of the Drawings

FIG. 1 is a flow diagram of a Single Antenna Interference Cancellation (SAIC) enabled Joint Demodulation (JD) Global System for Mobile Communication (GSM) receiver in accordance with the present invention.

FIG. 2 is a graph of simulated performance results for an SAIC JD receiver in accordance with the present invention and a typical GMSK receiver in accordance with the prior art.

Detailed Description of the Invention

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

The present invention is directed to joint demodulation (JD) receiver structures for use in wireless communications systems, such as in cellular base stations and mobile cellular communications devices, for example. Generally speaking, joint demodulation uses estimates for a channel impulse response (CIR) for a desired signal and a dominant interferer associated therewith. For a GSM implementation, which will be discussed herein, it will be assumed that the dominant interferer is a GMSK modulated signal conforming to the GSM specification.

Some consideration has been given in the prior art to the application of joint demodulation in synchronized wireless networks. See, e.g., "Feasibility Study on Single Antenna Interference Cancellation (SAIC) for GSM Networks," 3GPP TR 45.903 Version 6.0.1, Release 6, European Telecommunications Standards Institute, 2004. That is the more limited case that requires one to assume that the synchronization data sequences of the desired signal and dominant interferer overlap, which in turn makes the estimation of the CIRs possible using previously known techniques. It also requires one to assume that the interferer will be dominant for the entire burst.

As will be discussed further below, the present technique is applicable to both synchronized and unsynchronized networks, in that this technique uses "blind" interferer data and channel estimation techniques rather than making the above-noted assumptions. Once the CIRs have been estimated, a two-dimensional (joint) adaptive Viterbi state structure may be used in the equalizer to estimate the data for both the desired signal and the interferer.

Simulations of the invention have demonstrated greater than 10 dB carrier-to-interference(C/I) improvement at about 0 dB C/I in the raw symbol error rate and frame error rate for 12.2-rate AMR FS speech. In the simulations, a new joint-least-squares based technique was used for channel-offset positioning and desired and interferer CIR estimation. As noted above, this approach is coupled with blind estimation of the interferer data (i.e., with no a-priori knowledge of the interferer's data).

The present JD approach may be particularly advantageous in its ability to provide relatively high gains (i.e., in its ability receive at very low signal-to-noise ratios (SNRs)) when limited a-priori knowledge about the interferer is available, as will be discussed further below. Yet, the Viterbi algorithm complexity may also increase, (depending on the number of states used to model the interferer), thus the processing requirements and the additional complexity of the channel/data estimators may be a factor in some software or hardware implementations.

For the test configuration, a system level Block Error Rate (BLER) simulator was extended to support all of the interferer models/scenarios being used by the 3GPP DARP work group. This extension also allows new interferer models to be developed as needed. The simulations were performed using Matlab.

The joint demodulation approach assumes that the dominant interference component may be modeled as the noisy output of a finite-impulse-response (FIR) (unknown) filter with unknown, binary, random input (interferer) data. In the case of a dominant GMSK-modulated interferer, this assumption holds even if there are additional, weaker interference signals present, which are treated as residual noise. Moreover, this invention may be applied to other interferer modulation types as long as the above modeling assumption holds.

Referring now more particularly to FIG. 1, the steps associated with the joint demodulation approach are as follows. First, a base station training sequence (TS) for the desired signal is found (Block **20**), the CIR for the desired signal is estimated (Block **22**), and the re-modulated desired training sequence is removed from the input samples to form the interferer signal estimate (Block **24**). Furthermore, the "blind" estimation of the interferer CIR and data is performed based upon the interferer signal estimate, at Blocks **26**, **28**. Next, a joint least-squares desired/interferer channel estimation using the desired training sequence and estimated interferer data is performed at Block **30**, as will be discussed further below.

In addition, the foregoing steps may be repeated (or performed in a vectorized form) at multiple input sample offsets (as the timing offset varies). As such, the offset yielding the minimal residual noise power (Pn) may be selected, and a determination may be made as to whether the model applies (i.e., was a significant interferer component (Pif) detected or not), at Blocks **32**, **34**, **36**, and **38**. If so, demodulation is performed using a joint-demodulation (multi-dimensional state) Viterbi algorithm that estimates and removes the interference jointly with the estimation of the desired signal data (Block **30**).

Initially, the desired channel impulse response was estimated using a conventional training-sequence correlation (i.e., "channel-sounding") method, as will be appreciated by those skilled in the art. At low C/I levels, the least-squares method provides the initial desired channel impulse response estimate by multiplying the input samples by a constant (pre-computed) matrix $(A^H A)^{-1} A^H$, where A is the training sequence convolution matrix of the desired signal.

For estimating the interferer, the above-noted SAIC Feasibility Study assumes a synchronous network model. More particularly, this model assumes that the training sequence of the interfering signal is aligned with the desired signal's training sequence within a -1 to +4 symbol offset. In this case, the interferer channel impulse response can be estimated using the training sequence correlation technique (or least squares, since the training sequence data is known) after removing the desired signal's (re-modulated) training sequence from the received samples.

However, to widen the potential applicability of the joint-demodulation approach to the asynchronous network case where the interferer data during the desired signal's training sequence is unknown, blind channel and data estimation and demodulation techniques are used. By way of background in this regard, reference is made to the article by Seshadri entitled "Joint Data and Channel Estimation Using Blind Trellis Search Techniques," IEEE Trans. on Communications, vol. 42, no. 2/3/4, pgs. 1000-1011, and the article by Daneshgaran et al. entitled "Blind Estimation of Output Labels of SIMO Channels Based on a Novel Clustering Algorithm," IEEE Communications Letters, vol. 2, no. 11, November 1998, pgs. 307-309.

One particular difficulty of performing blind interferer estimation is the very small number of "observable" interferer (i.e., noisy) samples during the desired signal's training sequence window. By way of reference, the sequence window is the length of the desired training sequence (for this embodiment of the invention, the training sequence length is 26, as defined by the GSM 05-series standards) less the desired signal's CIR length (5 is chosen by this simulation, however other values between 1 and 7 are possible depending on the channel models as defined by the GSM standards) plus one, or: 26 - 5 + 1 = 22 (twenty-two) in the present example.

This approach uses an algorithm which combines concepts of vector quantization and sequential decoding of convolutional codes. The algorithm is based on only two assumptions: (1) the interferer signal may be modeled with a linear Finite Impulse Response (FIR) source (Block **28**); and (2) the interferer signal is corrupted by residual additive white (i.e., uncorrelated) Gaussian noise (after removing the estimated desired signal) **(FIG 1, 26)**.

With these two assumptions, the algorithm iteratively builds a tree of interferer bit sequence hypotheses. For each new bit added to a bit sequence hypothesis, it computes the new FIR state (or codebook index, as it will be apparent to those skilled in the art of vector quantization) and averages all input samples corresponding to the same state in a particular sequence to estimate the FIR output (codebook value) for that state. The distortion of a bit sequence is what remains after removing the sequence's FIR outputs from the input samples (FIG 1, **36**). After keeping up to W (search width parameter) bit sequences with the lowest distortions, each sequence is extended by another 0/1 bit to yield two new sequences (2W total), and the process of re-estimating FIR outputs of each sequence is repeated followed by keeping the W sequences with minimum distortion. When the sequence length reaches the number of interferer signal samples available (22 for this embodiment of the invention as described above), the sequence with the lowest distortion out of W candidates is chosen.

This above-described algorithm provides the initial interferer data and channel impulse response estimates for subsequent joint least-squares desired signal and interferer channel estimation. At C/I levels below 5dB, the CIR position (offset), and CIR value estimation for the desired and interferer is affected by the cross-correlation of the desired and interferer data sequences. However, using the previously obtained interferer data estimate, a joint least-squares channel estimation is possible that removes (i.e., accounts for) this cross-correlation as follows:

$$\begin{vmatrix} A' \\ B' \end{vmatrix} s = \begin{vmatrix} A'A & B'A \\ A'B & B'B \end{vmatrix} \begin{vmatrix} h \\ g \end{vmatrix},$$

where s contains the input samples during the desired training sequence window (26-5+1=22 as described previously), A (NxLh) and B (NxLg) are the desired signal and interferer data sequence convolution matrices (A is known and constant, B is an estimate for the interferer), and h and g are the desired signal and interferer CIRs respectively that result from solving the above equations with Lh (5 in this embodiment) the length of h, and Lg (3 chosen for this embodiment) the length of g.

Once estimates of the desired and interferer channel impulse responses are available, a two-dimensional state Viterbi algorithm may be applied. For a Euclidean distance metric, the whitened discrete time model filter (WMF) is computed from the estimated desired CIR (block 44). The computation is also applied to the interferer CIR, and the three (Lg) largest resulting taps are used to form the interferer codebook (i.e., a set of possible interferer channel FIR outputs). Of course, other numbers of taps Lh and Lg may also be used in some embodiments.

The resulting desired signal and interferer codebooks are passed to the joint-demodulation Viterbi algorithm. The returned soft-decision metrices include the forward and backward recursion using the difference of the odd/even state minimum metrics at each stage (not path) as the soft decision value and sign.

Turning now to FIG. 2, simulated results for TCH-AFS 12.2 rate speech for a typical urban fading profile at 50km vehicle speeds (TU-50) at the 1950MHz band without the use of frequency hopping and using interferer model DTS1 are shown, as will be appreciated by those skilled in the art. C/I is the average carrier-to-interference ratio.

The dotted lines 50 and 51 represent the SER (symbol error rate) and FER (frame error rates) of the conventional GMSK receiver. The dashed lines 53 and 54 represent the performance of the above-described SAIC-JD receiver. The solid lines 55 and 56 represent the performance of a highercomplexity SAIC-JD receiver in accordance with the invention in which the blind vector quantization of the interferer is performed using recursive least squares (RLS) updates while the interferer symbol sequence hypotheses are formed and evaluated.

As will be appreciated by those skilled in the art, the performance plot demonstrates that both of the SAIC-JD receivers provide significant improvement over the conventional receiver in a high interference environment.

The amount of residual "noise" power remaining in the desired signal's training sequence window after removing the desired (i.e., estimated) samples may be used as a test of model "fit" in some embodiments of this invention. If removing the subsequently estimated interferer does not reduce the residual power significantly, a non-interference signal model may be selected, and vice-versa.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the invention.

CLAIMS:

1. A wireless communications receiver comprising:

at least one antenna receiving signal components of a desired channel having a first training sequence associated therewith and an interfering channel having a random data sequence associated therewith;

a first training sequence detector for receiving the signal components and detecting the first training sequence;

a desired channel impulse response (CIR) estimator for receiving the signal components and estimating a desired signal CIR based upon the detected first training sequence;

a channel matched filter for filtering the received signal based upon the estimated desired channel CIR and the detected first training sequence;

an interference samples estimator that removes the filtered desired signal samples from the received samples

an interfering signal data-estimator that receives the output of the interference samples estimator and:

generates a state tree of interfering bit sequence hypotheses,

updates the estimated finite impulse response (FIR) coefficients for the bits in each sequence in the state tree, and removes the resulting noiseless sample sequence leaving respective residual distortions for each state, and

estimates an interfering channel CIR based upon the state having the lowest residual distortion and the detected second training sequence;

a joint-least-squares CIRs estimator that uses the desired signal training sequence and interferer signal data sequence estimate to obtain the optimal desired and interferer CIRs;

an adaptive Viterbi equalizer coupled to said joint least-squares desired- and interferer-signal CIR estimator.

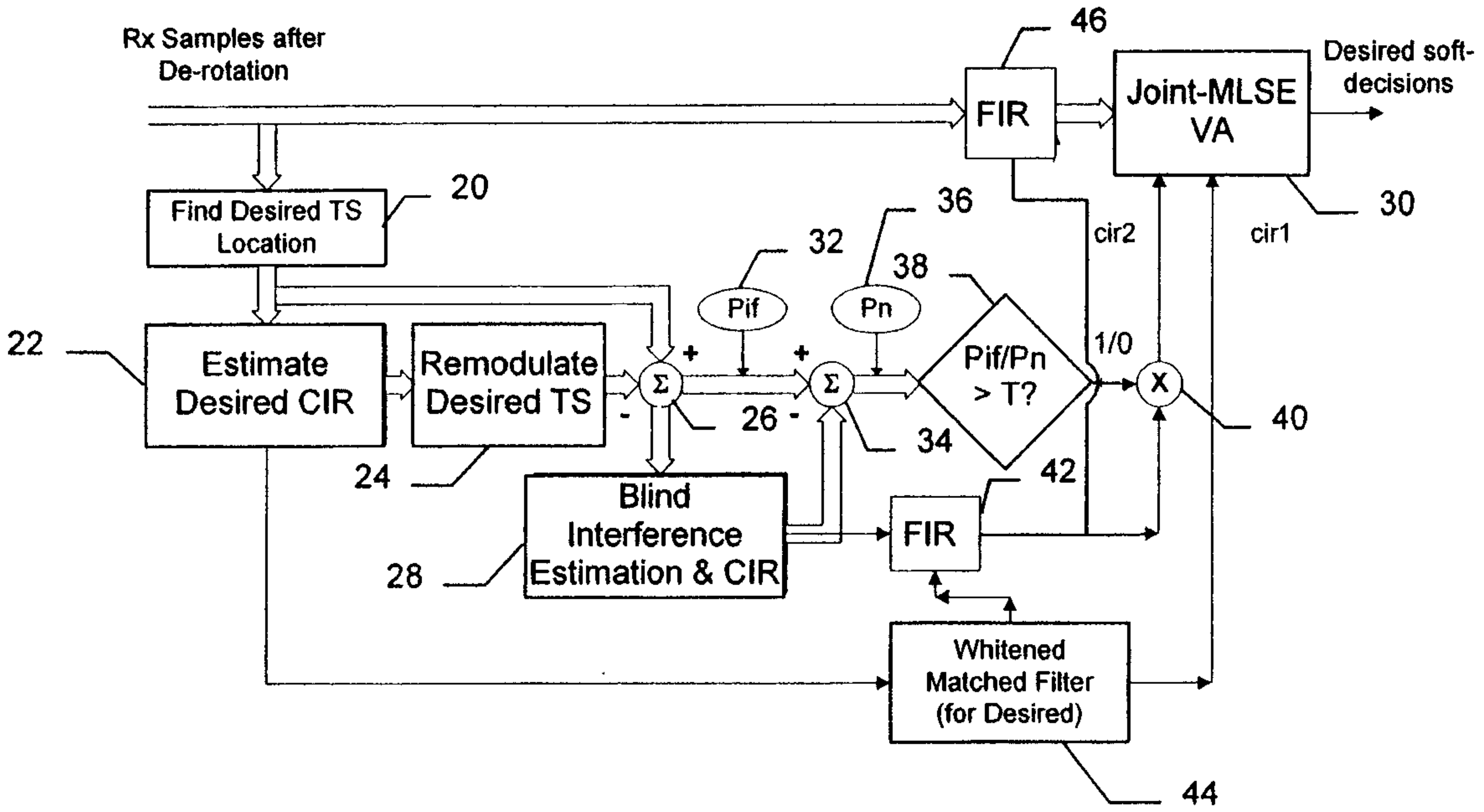
Rx Samples after
De-rotation
46
FIR
Joint-MLSE
VA
Desired soft-
decisions
20
Find Desired TS
Location
36
32
38
30
cir2
cir1
22
Estimate
Desired CIR
Remodulate
Desired TS
Σ
+
-
26
Pif
Pn
Σ
+
-
34
Pif/Pn
> T?
1/0
X
40
24
42
Blind
Interference
Estimation & CIR
28
FIR
Whitened
Matched Filter
(for Desired)
44

FIG. 1

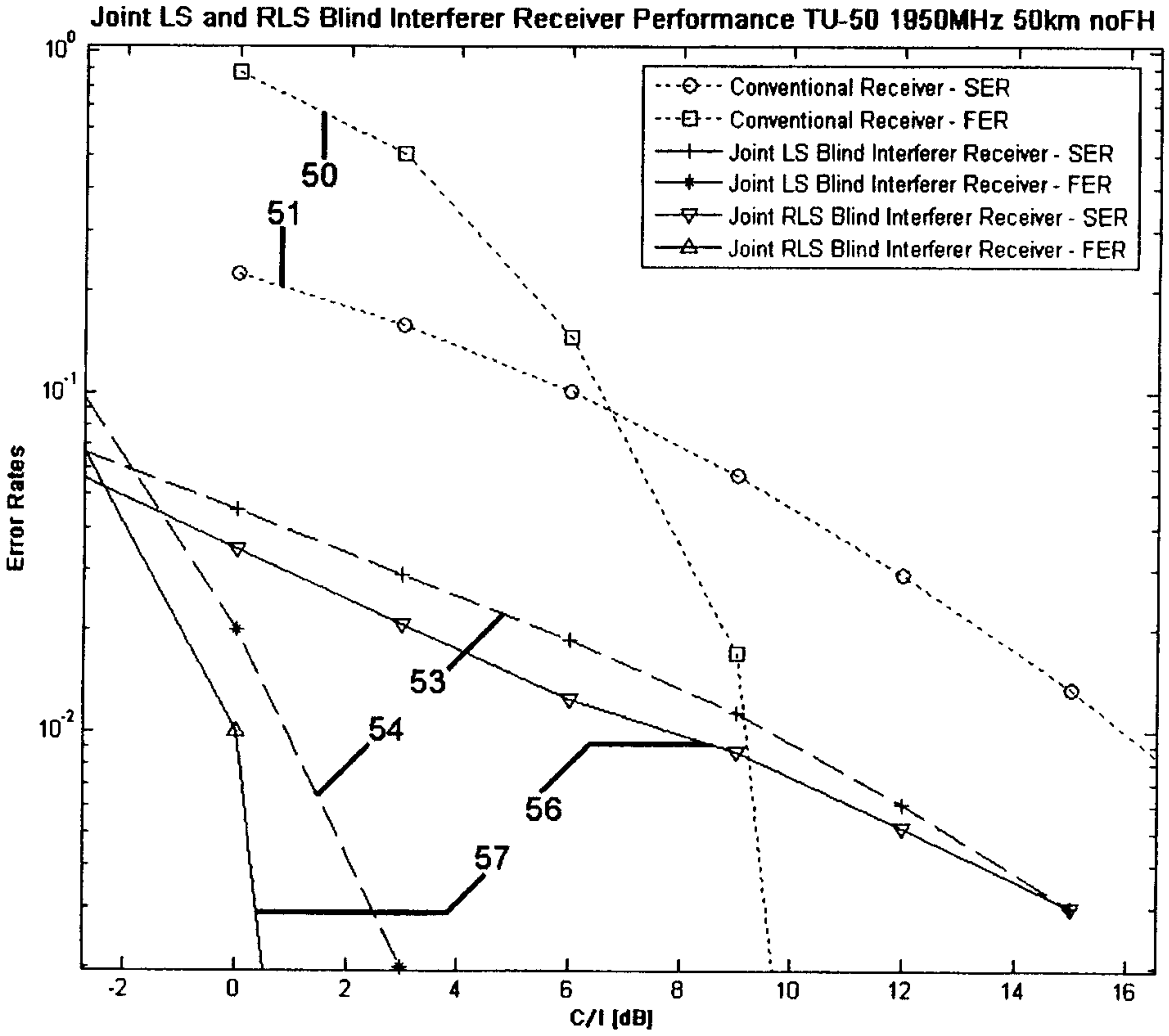
Joint LS and RLS Blind Interferer Receiver Performance TU-50 1950MHz 50km noFH
Error Rates
10^0
10^{-1}
10^{-2}
C/I [dB]
-2
0
2
4
6
8
10
12
14
16
Conventional Receiver - SER
Conventional Receiver - FER
Joint LS Blind Interferer Receiver - SER
Joint LS Blind Interferer Receiver - FER
Joint RLS Blind Interferer Receiver - SER
Joint RLS Blind Interferer Receiver - FER
50
51
53
54
56
57

FIG. 2


Rx Samples after De-rotation
46
FIR
Joint-MLSE VA
Desired soft-decisions
20
Find Desired TS Location
30
36
32
cir2
cir1
38
Pif
Pn
22
Estimate Desired CIR
Remodulate Desired TS
+
+
Pif/Pn > T?
1/0
Σ
Σ
X
-
26
-
34
40
24
42
Blind Interference Estimation & CIR
FIR
28
Whitened Matched Filter (for Desired)
44