A COMPLETE COMPLEXITY COMPETITIVE NARROW BAND ITERATIVE MULTI USER RECEIVER

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ABSTRACT

Software Defined Radio (SDR) enjoys the advantage of admitting the seamless implementation of complex signal processing algorithms that enhance communication system performance. A particular need in mobile satellite communications is the requirement to increase spot beam density and the number of co-channel users that can be supported without degradation of Quality of Service (QoS). An iterative multi-user receiver where the iterative process has been optimized is presented.

1. INTRODUCTION

In order to facilitate the development of mobile communication systems using spot-beams (as in the case of satellite communications) or terrestrial cellular systems the re-use of carrier frequency has been proposed as a means to overcome the problem of limited radio spectrum. Aggressive frequency re-use in narrow band systems introduces co-channel-interference (CCI) and special techniques must be used in the receiver to mitigate this interference [1]. In addition, multi-user techniques in conjunction with power control can be used to mitigate high interference between multiple users in a single spot beam.

Traditionally CCI has been approximated as a random additive white Gaussian noise process. However, with the advent of powerful signal processing techniques it is becoming feasible to at least partially remove the interfering signals. Interference Cancellation techniques along with multi user detection is well known in CDMA cellular applications [1,2,3,4]. The techniques are relatively novel in application to narrow band systems [5,6,7,8]. Any interference cancellation technique is dependent on the ability to identify and extract the desired signal from interfering signals.

Joint detection of the interfering co-channel signals is a powerful but exponentially complex technique that can be used in the narrow band scenario. However, due to complexity considerations an iterative non-linear method that iteratively reconstructs each of the transmitted waveforms is proposed in this work [4]. This method is based on using Soft Input Soft Output (SISO) single user decoders leading to stages of soft interference cancellation. Improved signal estimation, during each iteration, through demodulation (aided by accurate channel parameter estimation) and decoding (by employing powerful turbo codes in a complexity competitive manner) is of primary importance for the success of any practical iterative scheme.

This paper is divided into the following sections; A brief description of a satellite system model, a summary of a pseudo-analytic technique based on Extrinsic Information Transfer (EXIT) analysis techniques to evaluate advantages of iteration control, an overview of iteration control mechanisms employed within the multi user detector for mitigating these effects, simulation results and concluding remarks based on these results.

2. SYSTEM MODEL

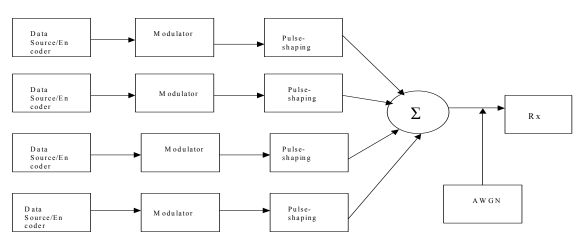

Figure 1 System Model

Figure 1 depicts the complex baseband model of the transmission system. This is the same system model used in [9]. The bit sequences in all transmitters, which correspond to desired and interfering signals are encoded, modulated and pulse shaped forming the transmit waveforms represented by

$$x_k(t) = \sum_n a_{k(n)} \delta(t - nT)$$

where $x_k(t)$ is the baseband signal; $a_k(n)$ is the symbol sequence for the k^{th} user and $\delta(t)$ is a root-raised-cosine pulse-shaping filter. A BPSK modulated known Unique Word (UW) sequence is inserted at the beginning and end of the packet, before over-sampling and pulse shaping.

The signal is then transmitted through a non-dispersive satellite channel to a ground station receiver. The received signal can be represented as

$$y(t) = c_d(t)x_d(t - \tau_d) + c_i(t)x_i(t - \tau_i) + w(t)$$

where, the subscripts 'd' and 'i' represent the desired and interfering signals, respectively and w(t) is a zero mean Additive White Gaussian Noise (AWGN) process. The received signal is then passed through a filter matched to the transmit pulse shaping filter giving rise to a Nyquist response. The co-channel signals have relative time offsets.

3. EXIT CHART ANALYSIS

Extrinsic Information Transfer Charts (EXIT) and were first presented in [10] as a method to visualise the convergence behaviour of iterative decoding. An EXIT chart is a plot of the transfer characteristic of all the constituent decoders. The transfer characteristic of a code is defined as the input mutual information versus output extrinsic mutual information with respect to the source. The input mutual information (IA) is obtained by finding the information content between the transmitted unmapped bits and the input prior values. Similarly the output mutual information (IB) is obtained by finding the information content between the transmitted unmapped bits and output extrinsic values. The output mutual information is determined using Monte Carlo simulation given a predetermined range of IA and fixed channel conditions. Posterior probabilities are calculated by

$$p_{Y|X}\left(y[i] \mid x\right) = \exp\left(-\frac{(y[i]-x)^2}{2\nu}\right)$$

Where x is the binary input data and y[i] is the observation at the channel output.

The mutual information between the output y and the information symbols x is calculated empirically, given the received sequence y[i] and input sequence x[i], by:

$$I\left(x;y\right) = \sum_j p_X(x_j) \sum_k q_j[k] \log_2\left(\frac{q_j[k]}{\sum_k p_X(x_k) q_j[k]}\right)$$

where, $q_j[]$ is the distribution of the observed log likelihood ratios conditioned on the input being x_j. The index k represents the bins of the empirical distributions.

An example of an EXIT chart is shown in figure 2, where the solid lines represent the mutual information characteristics of the turbo decoding (1-10 iterations) and the dashed line represents the mutual information characteristics of the iterative MUD cancellation process. This chart represents the trajectories of the respective processes, where each of the users has a Es/N_0 of 10 dB and Carrier-to-Interference (C/I) of 6 dB.

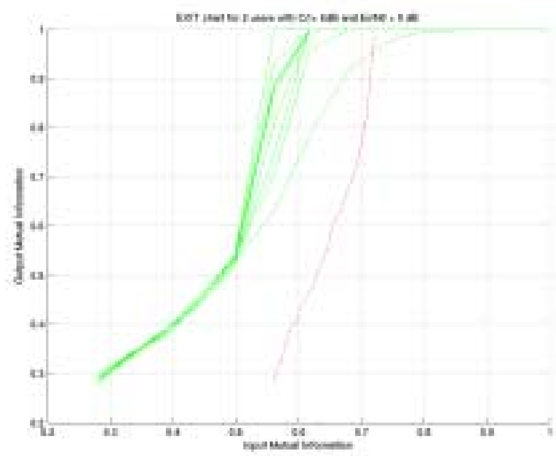

Figure 2 EXIT chart for a 2 user scenario where at Es/N_0 of 9 dB and mutual C/I of 6 dB

It can be seen that the receiver usually converges (EXIT charts consist of averaged metrics) when the final turbo decoding step is made up of more than six decoder iterations. However, below an output mutual information of 0.5 bits there is virtually no gain in performing more than one turbo iteration. Therefore, there is a strong suggestion that reducing the number of turbo iterations during the initial receiver iterations can reduce the complexity of the multi user detector without sacrificing performance.

4. ITERATION CONTROL

In a typical single user receiver with turbo decoding, each received packet is processed with a fixed number of iterations of the turbo decoder (turbo iterations). This concept has been extended to known multi user detector architectures too. However, as revealed by the EXIT chart analysis a fixed number of turbo iterations is not the most efficient strategy in a multi user scenario. Complexity is significantly reduced if the turbo iterations on each receiver cycle are controlled and terminated when sufficient convergence is achieved. Further more, the receiver iterations themselves could be controlled and terminated when convergence corresponding to the achievable frame error rate is achieved.

Methods based on stopping criteria for termination of turbo codes have been suggested in [11-17]. These methods have been investigated by the authors and others [18]. The advantages of using the Sign Change metric to terminate the decoder and receiver iterations vs. a receiver with a fixed number of iterations (10 turbo receiver iterations and 10 turbo iterations per receiver iteration) are shown in figures 3 and 4.

The Sign Change metric method is based on the Cross Entropy Criterion turbo termination method described in [13,14]. The number of sign changes in the soft estimate of the information bits is checked between iterations. If the number of sign changes per block length is below a pre-determined threshold the iterations can be terminated.

5.1. Simulation results

Figure 3 shows a profile of iterations for a single user in a two user scenario where Es/N0 per user is 9 dB and the mutual C/I = 6 dB. It is observed that the turbo iterations are a maximum on the second receiver iteration (after initial canceling) and the maximum number of turbo iterations available (pre defined as 10, are never used). The reduction in complexity is significant since the decoder is usually the most computation intensive component of the receiver. Also, most packets converge within five receiver iterations rather than the fixed maximum receiver iterations of ten.

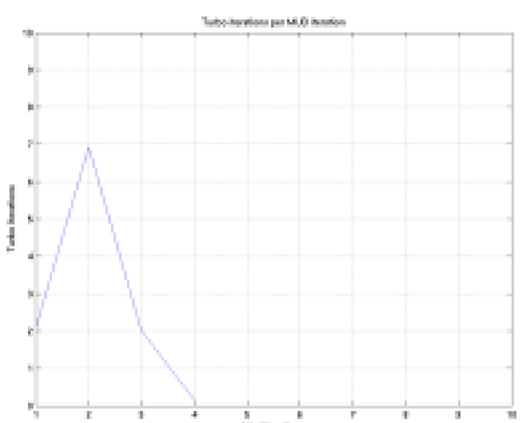

Figure 3 Turbo iterations per receiver iteration.

Figure 4, which shows error in the estimation of the residual frequency offset in the receiver after the initial cancellations further confirms the improvement in the quality of the signal after the initial receiver iteration. Therefore, this result provides verification the iteration controller performed efficiently in employing the full power of the turbo decoder only when it could have the most impact (on a cleaner signal). It should be noted that on the first iteration, where the pre-cancelled signal is distorted only the minimum number of turbo iterations were performed, thereby, ensuring complexity savings and reducing the possibility of convergence to an incorrect point.

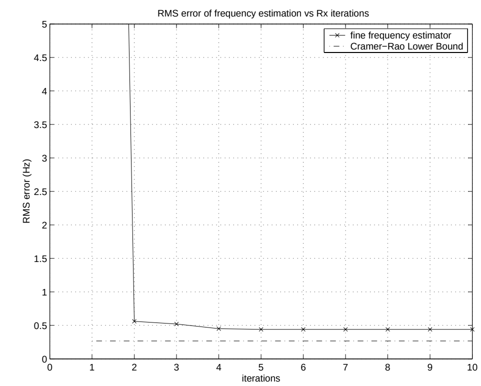

Figure 4 Performance of Fine Frequency Estimator over ten Receiver Iterations

Figures 5 shows frame error rate Vs Es/N_0 for 2 users at a mutual C/I of 6dB in an AWGN channel, indicating that the target frame error rate of 10^{-3} is achievable with the use of iteration control.

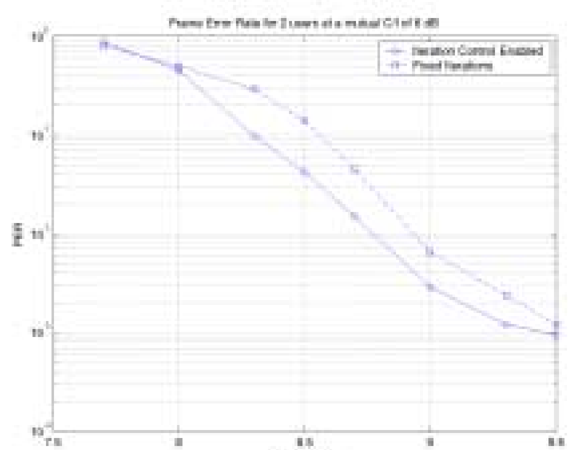

Figure 5 Frame Error Rate with respect to Es/N_0

Figure 5 also shows that for this particular scenario there is a slight performance gain of approximately 0.2 dB at a frame error rate of $10^{-2}$when using iteration control. This is attributed to the fact that in the case of the fixed iteration configuration of the receiver, the decoder may be forced into converging to an incorrect point by using the full 10 turbo iterations on an interference dominated signal during the initial receiver iterations.

5. CONCLUSION

This paper has shown that the interplay between the powerful turbo decoding system and the cancellation process in the multi user receiver can be exploited to significantly reduce complexity in the receiver. The complexity benefits are obtained firstly, by the reduction of the number of turbo iterations from a fixed 10 iterations on every receiver iteration to an average of 3 on all but one or two receiver iterations without sacrificing performance. Secondly, the number of receiver iterations is reduced eliminating unnecessary processing. It is believed that this mechanism to reduce complexity will accelerate the deployment of multi user techniques in narrow band communication systems to mitigate co-channel interference and increase capacity

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