On Interference Cancellation and Iterative Techniques

Ryuji Kohno
Yokohama National University

Robert H. Morelos-Zaragoza
Sony Computer Science Laboratories., Inc., robert.morelos-zaragoza@sjsu.edu

On Interference Cancellation and Iterative Techniques

Ryuji Kohno
Yokokohama National University
79-5 Tokiwadai, Hodogaya
Yokohama 240 JAPAN
kohno@kohnolab.dnj.ynu.ac.jp

Robert Morelos-Zaragoza
Sony Computer Science Labs., Inc.
3-14-13 Higashigotanda, Shinagawa, Tokyo
141-0022 JAPAN
morelos@csl.sony.co.jp

Abstract — **Recent research activities in the area of mobile radio communications have moved to third generation (3G) cellular systems to achieve higher quality with variable transmission rate of multimedia information. In this paper, an overview is presented of various interference cancellation and iterative detection techniques that are believed to be suitable for 3G wireless communications systems. Key concepts are space-time processing and space-division multiple access (or SDMA) techniques. SDMA techniques are possible with software antennas. Furthermore, to reduce receiver implementation complexity, iterative detection techniques are considered. A particularly attractive method uses tentative hard decisions, made on the received positions with the highest reliability, according to some criterion, and can potentially yield an important reduction in the computational requirements of an iterative receiver, with minimum penalty in error performance. A study of the tradeoffs between complexity and performance loss of iterative multiuser detection techniques is a good research topic.**

Introduction

Signal distortion affects the performance of wireless communications systems. This distortion can be broadly classified into two categories: (1) Inter-symbol interference (ISI), caused by delays of the signal in going through different paths; and (2) co-channel interference (CCI), which is due to multiple access and is also known as multi-access interference (MAI). There has been a great deal of work in measures for combating both types of signal distortion [1, 2]. Traditionally, an equalizer in the time domain is sufficient to handle short delay signals. However, as the delay time increases, the complexity of the required equalizer becomes too large for practical implementation.

Joint spatial and temporal signaling, equalization and channel coding offer drastic improvements in performance and capacity, as shown in [3]. These techniques provide practical countermeasures against multipath fading and multiuser interference in mobile radio communications systems. Most recently, significant gains in multiuser capacity have been shown to be achievable with iterative receivers using joint space-time processing techniques [4].

An array antenna (or a smart antenna) is a group of spatially distributed antennas. The output of an array antenna is obtained by proper combination of the outputs from each element. This combination makes it possible to extract the desired signal from the superposition of all received signals, even if all the frequency band is occupied. With array antennas, interference is reduced by making use of the arrival angles, or *direction of arrival* information. With spatial processing, even is the delay spread is large, the receiver complexity is not increased because interference can be reduced through antenna directivity.

Beam-steering techniques are used to form beams at the base stations, in order to maximize the power received from the desired user, while at the same time minimizing the contributions from other interference users, with the introduction of beam nulls in the array antenna radiation pattern. The combination of an array antenna and a traditional time-domain equalizer is expected to yield good performance. The adaptive algorithms used for deriving the optimal antenna weights can be though of as extensions of conventional adaptive digital filters [5].

This new joint space-time processing paradigm has become the technological break-through required for the successful implementation of 3G wireless communications systems.

Interference cancellation techniques

In essence, a multipath fading channel, such as a mobile radio channel, can be modeled with a transmitted signal arriving at the receiver's end with different angles and delays. An *adaptive tapped delay line (TDL) array antenna* can be used to provide spatial and temporal equalization. To reduce the ISI, several criteria have been introduced in the literature, such as zero-forcing (ZF), or decorrelating, and mean-square error (MSE), to update the adaptive array antenna weights and number of taps.

Since only a finite number of taps and multipliers are available in a practical system, there will be errors present in adaptive equalization based on time-domain updating algorithms. If a maximum permissible error is specified, then several combinations of number of taps and weight values may be possible. As a result, the number of antenna elements can be reduced by increasing the number of taps when the angular spread is large.

Temporal updating algorithms, such as LMS and Applebaum, form beams to track the desired signal and suppress interference by allocating nulls in the radiation pattern of the array antenna, so as to maximize the signal-to-noise ratio (SNR). The Applebaum array is also useful

0-7803-7119-4/01/$10.00 ©2001 IEEE

in situations where the angle of arrival is known in advance. On the other hand, an LMS array does not require knowledge of the angles of arrival. As long as a reference signal correlated with the desired signal is obtained, the array will adaptively beamform to maximize the SNR. Unfortunately, in time-varying channels, it is difficult to get a reliable reference signal.

Several algorithms have been proposed (see [3] and references therein) to control the antenna weights derived from the *spatial frequency spectrum* (SFS), by spatially sampling the received signals in the array elements. The angles of arrival can be estimated from the SFS, via DFT or MEM, from the samples. The MUSIC algorithm, which estimates the angles of arrival in noise subspace, has better estimation performance than MEM if the noise subspace is larger for uncorrelated signals than the signal subspace.

Optimal space-time processing at the receiver can be achieved by extending the combination of matched filter and an ML sequence estimator (MLSE) or Viterbi detector (VD) to the space-time domain. In this receiver structure, each antenna element receives the superposition of all the users signals, which are subsequently filtered by a *spatially and temporally whitened match filter* (ST-WMF), matched to the channel impulse response. Finally, the most likely sequence is estimated for the ST-WMF output with a VD and a channel estimator.

In direct-sequence CDMA (DS-CDMA) systems, the channel model includes both ISI, due to multipath, and CCI, due to the correlation between spreading sequences of simultaneous users. The optimum multiuser receiver for DC-CDMA detects every user data stream with MLSE, by interpreting the CCI as redundant information which is shared by multiple users. The concept of adaptive TDL array antenna makes it possible to design an optimum space-time multiuser receiver.

In addition to the techniques discussed so far, joint transmit diversity, or *space-time block coding* (STBC) [6], and equalization are currently being considered as a way to yield improvements in performance over frequency-selective multipath channels. The STBC technique was officially introduced in the 3G standardization process by the 3GPP [7], in January 1999.

ITERATIVE DETECTION TECHNIQUES

Iterative detection techniques can be applied to reduce complexity of implementation [8]. Iterative detectors utilize "soft" or extrinsic information to cancel multiuser interference and perform iterative channel decoding. Multiuser detection for frequency selective channels can be achieved by combining STBC, as well as other forms of space-time coding such as space-time trellis codes, and joint space-time equalization and interference cancellation techniques discussed in the previous section. Some results in this direction have been reported in [9].

The combination of space-time processing and error control coding for iterative detection, multiuser interference cancellation and equalization can result in a good trade-off between system capacity, error performance and implementation complexity. Basically, the idea is to combine a bank of single-user soft-output decoders with a soft multiuser interference canceller [10]-[12]. The inclusion of channel coding usually comes for free, since channel coding is already included in wireless communication systems (certainly in current 3G specifications) to provide coding gain and time diversity benefits.

Joint iterative multiuser interference cancellation and channel decoding techniques attempt to iteratively estimate the desired user, by combining the received signals with the soft-outputs feedback estimates from the previous iteration. As the number of iterations increases, the correlation between an estimate and the transmitted value increases, and thus better performance is achieved. It should be noted, however, that the residual multiuser interference is limited by the soft multiuser detector. Furthermore, the performance of a linear multiuser MMSE detector can be improved by introducing an array antenna at the receiver. Implementation complexity can be reduced through iterative techniques [13, 14].

For interference cancellers that utilize channel coding, we note that the complexity of the optimum receiver is exponential in the number of users and the number of trellis states (or an equivalent measure in the case of block channel codes). Several solutions to this problem have been studied. A maximum a-posteriori multiuser detector, providing soft-inputs to channel decoders, has been recently proposed [15]. Suboptimum soft-output multiuser detectors are introduced in [16] that can be used for multiuser detection and channel decoding.

A survey of other methods of reducing complexity in iterative detectors can be found in [8]. Among them, reduced-state via internal hard-decision feedback and external hard-decision feedback (EHDF) are worth investigating in the context of joint multiuser detection, space-time processing and channel coding. In particular, EHDF refers to the use of *tentative decisions* [17], made on the received positions with highest reliability, prior to the first iteration. The values of these positions are then fixed throughout the iterative decision process.

In addition to simply limiting (or fixing) the maximum number of iterations, the EHDF method can have different criteria for determining which symbols are decided early. We believe this is a good research topic. For example, tentative decisions can be based on either a reliability threshold or a predetermined number of positions. Moreover, the decisions could be changed dynamically during the iterative process. It is therefore of both practical and theoretical interest to study the complexity versus performance tradeoffs of iterative detection with tentative decisions.

References

[1] S. Verdu, *Multiuser Detection*, Cambridge University Press, 1998.

[2] U. Madhow, "Blind Adaptive Interference Suppression for Direct-Sequence CDMA," *Proc. IEEE*, vol. 86, no. 10, pp. 2049-2069, Oct. 1998.

[3] R. Kohno, "Spatial and Temporal Communication Theory Using Adaptive Antenna Array," *IEEE Personal Comm.*, vol. 5, no. 1, pp. 28-35, Feb. 1998.

[4] B. Lu and X. Wang, "Iterative Receivers for Multiuser Space-Time Coding Systems," *IEEE JSAC*, vol. 18, no. 11, pp. 2322-2335, Nov. 2000.

[5] S. Haykin, *Adaptive Filter Theory*, 3rd ed., Prentice Hall, 1996.

[6] S.M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," *IEEE JSAC*, vol. 16, pp. 1451-1458, Oct. 1998.

[7] `http://www.3gpp.org`.

[8] K. Clugg, A. Anastasopoulos and X. Chen, *Iterative Detection*, Kluwer Academic Publishers, 2001.

[9] J. Thomas and E. Geraniotis, "Soft-Decoder Feedback Aided Space-Time Processing in Multiuser Interference Suppression," *Proc. 1999 Wireless Comm. and Networking Conf. (WCNC'99)*, vol. 2, pp. 693-697.

[10] M. Moher, "An Iterative Multiuser Decoder for Near-Capacity Communications," *IEEE Trans. Comm.*, vol. 46, no. 7, pp. 870-880, July 1998.

[11] M.S. Akther, J. Asenstorfer, P.D. Alexander and M.C. Reed, "Performance of Multi-Carrier CDMA with Iterative Detection," *Proc. 1998 IEEE Inter. Conf. on Universal Personal Comm. (ICUPC'98)*, vol. 1, pp. 131-135.

[12] M.C. Reed, C.B. Schlegel, P.D. Alexander and J.A. Asenstorfer, "Iterative Multiuser Detection for CDMA with FEC: Near-Single-User Performance," *IEEE Trans. Comm.*, vol. 46, no. 12, pp. 1693-1699, Dec. 1998.

[13] X. Wang and H.V. Poor, "Space-Time Processing in Multiple-Access Systems," *Proc. 2000 IEEE ISSSTA*, vol. 2, pp. 343-347.

[14] M. Navarro and A. Grant, "Iterative Implementations of Linear Receivers for Spatial Diversity Channels," *Proc. IEEE VTC Fall 2000*, vol. 5, pp. 2503-2509.

[15] B.R. Vojcic and Y. Shama, "Optimum Soft Output Detector for Coded Multiuser Communications," *Proc. 1997 IEEE Inter. Symp. Info. Theory (ISIT'97)*, p. 229.

[16] Y. Shama, B.R. Vojcic and B. Vucetic, "Suboptimum Soft-Output Detection Algorithms for Coded Multiuser Systems," *IEEE Trans. Comm.*, vol. 48, no. 10, pp. 1622-1625, Oct. 2000.

[17] B.J. Frey and F.R. Kschischang, "Early Detection and Trellis Splicing: Reduced-Complexity Iterative Decoding," *IEEE JSAC*, vol. 16, no. 2, pp. 153-159, Feb. 1998.