Turbo Receiver Design: From Theory to Practice

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Abstract

The turbo coding/decoding algorithm has made a huge impact on the performance of modern modem designs, ranging from deep space communications to 3G mobile communications. Likewise turbo receiver design based on the "Turbo Principle" is revolutionizing the way we design and develop modems for high capacity systems. Turbo receivers allow the minimization of interference, thereby allowing higher capacity systems which are more cost effective for both user and provider.

This tutorial covers algorithms that utilise the so-called "Turbo Principle". This course provides a detailed study of digital signal processing concepts applied to communication systems. Specifically, it studies the baseband signal processing technique for iterative receiver design, in the context of the turbo principle, better known as turbo receivers. Topics covered include detection criteria, decoding methods, transmitter configurations, wireless channel modelling, receiver design and analysis techniques.

By attending this course the participant will attain a fundamental understanding of how to design and analyse efficient receivers, how to use the turbo principle to mitigate interference and what the key design steps are. There will be practical system examples to reinforce the underlying principle and the application of this technique. By gaining an insight into these methods the participant will be able to apply the technique to a multitude of new real-world problems and system configurations, including systems that use antenna arrays, direct-sequence code-division multiple-access (DS/CDMA), continuous phase modulation (CPM), intersymbol interference (ISI) channels and much more.

Course Outline

- Introduction

  An introduction to the turbo receiver structure and some underlying reasons why reducing interference is important in modem design. A motivating example for a wireless system is provided in terms of system capacity and coverage improvement. Communication system block diagrams are compared for conventional communication systems, turbo coded systems and turbo receiver systems.

- Detection Criteria and Algorithms

  The detection criteria for channels with and without memory are discussed. The APP and MAP decision criteria as well as the ML criterion are detailed. Symbol-by-Symbol APP and MAP decision criterion are reviewed including the partitioning of channels with memory. Application of the detection criteria to the MAP algorithm is detailed with an overview of alternative techniques like soft-output Viterbi Algorithm (SOVA).

- Turbo Coding/Decoding Techniques

  Turbo coding and decoding is the fundamental cornerstone of the turbo principle. For this reason we describe turbo decoding for both the parallel and serial case. We show how the turbo receiver principle is based, primarily on the serial turbo encoder/decoder approach.

- The Turbo Principle

  This section details the turbo principle in a generalized sense. We detail a simple example and explain the technique with illustrations. We also show simplifications to the MAP detector which provide substantial complexity reductions.

- Turbo Receiver Applications

  Turbo receiver applications provide the participant with concrete examples of the application of the technique. Examples we cover include:-

  - Turbo Equalisation
  - Turbo CDMA (Iterative Multiuser Detection)
  - Turbo SDMA (Interference reduction for systems with Antenna Arrays)
  - Turbo CPM (Interference reduction for Continuous Phase Modulation)
  - Turbo MIMO (for multiple input and output antenna systems)
  - Space-Time Coding
  - OFDM and MC-CDMA
  - Turbo BLAST

- APP Detection Alternatives

  Turbo receivers typically contain MAP detection and MAP decoding elements. As the MAP detector has computation complexity that is exponential with the memory of the channel, this chapter looks at lower complexity alternatives to this block. The receiver techniques are compared and consist of interference cancelling, MMSE, and Bayesian statistical methods such as particle filtering or Gibbs sampling.

- Analysis of Turbo Receiver Techniques

  The analysis for turbo receivers is explored here. Two methods are proposed, one based on the utilisation of the noise/interference variance, and another based on the use of EXIT chart analysis. Further insight into analysis methods for non-linear non-Gaussian systems is discussed.

- Channel Estimation for Turbo Receivers

  The capacity of the system can be determined by the performance of channel estimation unit. This is especially important in a turbo receiver. The channel estimation function, includes signal timing acquisition, timing tracking, phase and amplitude estimation. This section discusses the utilisation of the turbo principle for channel estimation and shows large improvement in performance by using such methods. Close co-operation between the receiver and channel estimation units is needed to maximise the performance of the system.

Biography

Dr. Mark Reed received his B. Eng. (with honours), from the Royal Melbourne Institute of Technology, Melbourne in 1991. He then worked in industry for five years designing digital hardware, real-time software, and modems for the public switched telephone network. In 1998 he completed his Ph.D. at the University of South Australia, Adelaide, Australia, titled "Iterative Receiver Techniques for Coded Multiple Access Communication Systems". From 1998 to 2003 he was a Researcher in the research unit of Ascom AG, Switzerland, where he was involved in the research and development communication systems. He was part of a team that designed and developed a software radio Satellite-UMTS Modem European Space Agency. He also completed further work on multiuser detectors as technical lead in the highly successful European Commission project (IST-1999-10741), titled ASILUM (`www.nari.ee.ethz.ch/~asilum`) which investigated and validated advanced processing schemes for link improvement in UMTS. Since April 2003 Dr Reed is employed as a Senior Researcher National ICT Australia (`www.nicta.com.au,http://axiom.anu.edu.au/~mreed/`), Australian National University (`www.anu.edu.au`), Canberra, Australia, where he is involved in research, education, commercialisation, and linkages in the wireless signal processing program. He has over 30 international journal and conference papers and has been listed as inventor on four patent applications.