Iterative Receiver Algorithms

Tutorial

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Any digital receiver comprises of two major parts: an *inner* and an *outer* receiver. The task of the inner receiver is to generate a “good channel” for the decoder (the outer receiver) by estimating the channel parameters from the received signal. In conventional receivers for packet transmission these parameters are estimated from pilot symbols inserted into the information stream. In this case the flow of information is unidirectional from the inner to the outer receiver. Since the channel parameters are estimated solely based on the pilot symbols these receivers discard information contained in the coded information sequence. This information can be utilized by iteratively exchanging information between the decoder and the channel estimator (the inner receiver). Such an information exchange is commonly called the “*turbo principle*”, a term introduced earlier in the context of coding theory.

During the last years a huge variety of receiver structures have been reported characterized by their “different type of information exchange” in a signal flow graph. Many of these heuristically derived algorithms are special cases or approximations of the maximum- likelihood (ML) optimization criterion.

In this tutorial we follow a systematic approach introduced recently (Walsh, Schmitt, Meyr). We link the turbo principle to an *unconstrained ML sequence detection and joint parameter estimation problem*. We develop a framework that allows to systematically derive complete and implementable receiver structures for static as well as dynamic channels with memory in a unified way.

First, we demonstrate how the *turbo decoder* can be systematically derived from the ML sequence detection criterion. We show that a method to solve the ML sequence detection problem is to iteratively solve the corresponding *critical point equations* of the *equivalent estimation* problem (for the continuous valued log-likelihood ratios) by means of *fixed point iterations*. The turbo decoding algorithm is obtained by reasonable approximations of the overall a-posteriori probabilities such that the fixed point iterations become feasible and the optimum ML solution is still a solution of the corresponding approximate critical point equations. *Extrinsic information* appears naturally as a consequence of applying block-iterative solution methods (e.g. Gauss-Seidel) to solve the fixed point equations. The equivalence of the detection problem to an estimation problem allows to elegantly include channel estimation. The task of estimating the channel parameters and decoding the transmitted data is then identified as a joint estimation problem for which a set of joint critical point equations can be derived. The input-output characteristic of the set of fixed point equations uniquely defines the information exchange between the various parts of the receiver, hence defines the *structure of the receiver.*

The iterative solution of the fixed point equations requires the definition of an initialization of the unknown parameters, and, an iteration schedule. The choice of the *iteration schedule* in nested loops is of key importance for the receiver performance (acquisition time, variance etc). We demonstrate how *soft symbols* naturally appear as a consequence of performing the fixed point iterations. Examples for fading and static channels are discussed.

We also discuss the potential performance gain of iterative receivers compared to conventional receivers. For this purpose we use recently developed bounds on the achievable rate for noncoherent fading channels. On the basis of a comparison of these bounds with bounds on the achievable rate for traditional non-iterative receivers with a solely pilot based channel estimation we upper bound the possible gain of iteratively enhancing the channel estimation by using reliability information given by the channel decoder (iterative code-aided channel estimation).