Filter-Based Low Complexity Turbo Equalizer for 2D ISI Channels

[01] Front matter

a. Date

April 27, 2011

b. Abstract

This proposal is concerned with low-complexity turbo equalizers that can handle severe intersymbol and inter-track interferences that plague all types of future recording systems including BPM. The goal is to develop a soft-in soft-out equalization algorithm that can achieve the performance close to that of the ideal matched filter using only the time-invariant FIR filter components. New extrinsic information formulation/processing strategies that provide immunity against error propagation will be developed. The idea of distributed equalization will be pursued which employs a number of weak low-complexity equalizers working together to collectively produce reliable soft decisions.

c. Proponent(s) and affiliation(s)

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a. Complete description of the research matter and its connection with ASTC stated goals

We consider turbo equalizer strategies that can handle both severe intersymbol interference (ISI) and severe intertrack interference (ITI). Concurrent ISI and ITI (or ISI in radial direction) would be the main issue for all types of future storage systems including BPM. Our key idea is to design a filter-based low-complexity equalizer that can give a matched filter performance (i.e., the effect of both ISI and ITI nearly eliminated but the complexity is way below that of trellis-based equalizers) when used in turbo-equalization setting. The proposed equalizer is likely to be a combination of simple linear equalizer, DFE and/or multi-directional DFE with new extrinsic information formulation/processing techniques that can provide immunity against error propagation. The proposed equalizer structure also will employ a creative soft information combining scheme that collects and processes soft outputs from various modules that may contain significant correlation. To speed up convergence and squeeze out the maximum performance the equalizer may also incorporate a self-iterating feature (i.e., soft information iterated within the equalizer). We have had some recent success on this type of approach on one-dimensional but very severe ISI [1][2]; We believe this can be extended to severe 2-D ISI (severe ISI+ITI). We will consider interference structures arising from recording systems characterized by a wide range of media grain distributions - from completely random distribution (i.e., PMR) to highly-ordered grains (i.e., BPM). We feel that turbo equalization must play a critical role in read channel design no matter what type of recording method is to be chosen, and there the most pressing issue (as well as fundamental challenge) is how to lower equalizer complexity while retaining the performance of the matched filter (MF). A number of researchers have discussed turbo equalizers for 2D-ISI in the past, but so far there appear to be no viable solutions that can provide the MF performance with low complexity.

b. Proposed research approaches

i. Soft-in soft-out (SISO) filter-based low-complexity equalizer structure

Powerful modern equalization methods are based on the turbo equalization principle wherein a SISO equalizer (or detector) and a SISO error correction decoder exchange soft information in an iterative fashion until the effect of interference is nearly eliminated and reliable decisions are generated. Trellis-based equalizers like the BCJR algorithm or the soft-output Viterbi algorithm often provide the matched filter performance (i.e., eliminates all or nearly all the effect of interference) when operating in turbo equalizer setting. The complexity of the trellis-based equalizers, however, gets very high in severe interference environments, especially
when the interference occurs along more than one dimension. We feel that a viable low complexity approach that can retain the performance of the trellis-based scheme is filter-based equalizers consisting of a number of finite-impulse response (FIR) filters. More specifically, we will consider a combination of linear equalizer (consisting of 1 FIR filter), DFE (consisting of 2 FIR filters connected in a feedback configuration), and multi-dimensional DFE (consisting of multiple DFEs running in different directions with appropriate soft-information combining strategy). With a carefully designed soft-output combining scheme that removes potential correlation among constituent equalizer outputs, we expect to approach the MF performance with overall complexity growing only linearly with the amount of total interference. For this, we will also have to focus on time-invariant FIR filter components as opposed to time-varying filters based on which existing filter-based SISO equalizers have been developed.

ii. Extrinsic information formulation geared to hard decision feedback

Handling inherent error propagation in DFE or any DFE-like method is a challenge but expanding the method we developed for severe ISI [1], we expect to be able to formulate extrinsic information in a way that provides significant immunity against error propagation. The basic idea is to foresee the effect of residual interference resulting from feeding incorrect hard decisions, but the key differentiating feature has been to design a highly simplified yet effective statistical model for the residual interference. We feel that a method along this direction can be equally effective in 2D interference environments.

iii. Self-iterating equalizer structure

We will investigate self-iterating equalizer algorithms that can run on a number of concatenated constituent equalizers that are individually weak. The idea is to iterate soft information among relatively simple equalizers in such a way that the shortcomings of individual equalizers may be compensated for via effective message passing. For example, the linear equalizer does not have the error propagation issue which the DFE suffers from, whereas the DFE often shows significantly better performance than the LE when feedback decisions are correct; and the multi-directional DFE provides solid performance even with time-invariant filters, although its complexity is a multiple of single DFE complexity. The “distributed” equalizer consisting of a number of equalizers helping one another is illustrated in Fig. 1.
The main challenge here is to handle a fair amount of correlation that naturally exists among constituent equalizer outputs due to the absence of interleaver. For one-dimensional interference case, a strategy has been devised to suppress correlation during message passing; the results indicated that this type of equalization scheme can provide considerably better overall performance in turbo equalizer setting than conventional single equalization schemes [2]. We will investigate and develop similar correlation-suppressing message-passing methods that can be applied to 2-D interference.


c. Likely outcome of research

- Mathematical and algorithmic description of the proposed equalizer (distributed equalizer structure with identification of appropriate component modules; optimized design with time-invariant filter constraint; extrinsic information formulation effective with hard-decision feedback equalizers; correlation-suppressing message-passing algorithm in self-iterating structure)

- Low complexity equalizer algorithm implemented in software
• Performance simulation and analysis results in the form of error rate simulation plots, EXIT chart plots and other means of characterizing convergence behavior

[03] Resources required to perform project
    a. Personnel, students, etc.
        PI partial salary support, RA stipend support, travel support
    b. Equipment, lab, etc.
    c. Computational

[04] Resources other than ASTC funding dedicated to perform project
    a. Grants: funding from the National Research Foundation of Korea (under grant no. 2010-0029205) can be used to support computing resources, travel expenses.
    b. Contracts
    c. Other

[05] Resources requested from ASTC and how they will be utilized
    a. Funding: $70,000 total
        i. Overhead: $10,000
        ii. Direct project cost: $60,000
        iii. Facility use fees: $0
        iv. Materials: $0
        v. Student stipends: $30,000
        vi. Travel: $10,000
    b. Expected technical cooperation with sponsor(s): materials to be provided by sponsor(s) (e.g., targets, devices, engineering support, etc.)
        Provision of channel model, real data sets
    c. Sponsors’ facility utilization
        None
d. Expected students’ internships: Highly encouraged

[06] Time line: 1 year

Distributed equalizer structure with identification of appropriate component modules: end of month 6

Optimized design with time-invariant filter constraint: end of month 6

Extrinsic information formulation effective with hard-decision feedback equalizers: end of month 12

Correlation-suppressing message-passing algorithm in self-iterating structure: end of month 12

[07] Not more than one page: Home institutions & resources

EE Department, KAIST, Daejeon, Korea

Ample computing resources, student tuition/fringe benefit support and partial travel support

[08] Not more than one-half page per contributor: contact information and biographical sketch of researcher:

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PI Jae Moon has a significant track record as well as 26-year experience in developing read channel ideas and algorithms. Among his inventions are fixed delay tree search, maximum transition run code, signal space detection and error-pattern-correcting code and equalization. Over the years, Jae Moon’s university research program has produced numerous engineers and scientists well-versed in storage signal processing who have played instrumental roles in the growth of HDD industry. Jae Moon also has a long history of collaboration with other researchers in the magnetic recording community. He had participated in various INSIC projects for the period of more than 20 years. He received the Technical Achievement Award from NSIC (which later became INSIC). He received the IBM Faculty Development Awards and the IBM Partnership Awards. He served as Program Chair for the 1997 TMRC Conference. He is also Past Chair of the Signal Processing for Storage Technical Committee of the IEEE Communications Society. He served as a guest Editor for the 2001 IEEE Journal of Selected Areas in Communication issue on Signal Processing for High Density Recording. He served as an Editor for IEEE Transactions on Magnetics in the area of signal processing and coding for 2001-2006. He worked as Chief Technology Officer at Link-A-Media Devices Corp., a read-channel start-up. He is an IEEE Fellow.