Chapter 1

INTRODUCTION

Equalization refers to signal processing that attempts to restore pulse shapes affected by intersymbol interference (ISI). The effect of ISI is equivalent to a linear convolution performed on the transmitted data stream by the baseband channel. This channel is called ISI channel and is often modeled as a finite impulse response (FIR) filter. Dispersion of a signal over successive symbol intervals results in a reduced peak of it at the sampling instant at the matched filter output. This reduces the noise margin and the problem can not be taken care of by increasing the transmitter power. Hence, the receiver needs to carry out suitable signal processing operation in order to combat the effects of ISI. Equalization is performed either in the adaptive or following the iterative approach (turbo) for achieving impressive gains over moderate to severe ISI channels which are considered to be hard-to-equalize even with zero forcing (ZF) and/ or minimum mean square error (MMSE) techniques.

Turbo equalization reduces the effect of interference iteratively in a single carrier, point to point communication link under non line of sight (NLOS) channel conditions. The NLOS condition is a common feature in many applications especially for high bit rate transmission. Turbo equalization combines the tasks of equalization and channel decoding in an iterative manner by incorporating feedback. Generation of soft outputs in the form of reliability of a given symbol by each signal processing module is crucial to the operation of the turbo equalizer (TEQ). The soft output of a bit is defined in terms of its log likelihood ratio (LLR). The absolute value of the LLR is also defined in many cases as reliability. The theoretical 3 dB power gain of soft output processing over conventional hard processing is well established. The processing of soft outputs in the turbo manner promises even bigger gains. It promises a close proximity to the matched filter bound (MFB) even over severe ISI channels which is not possible with conventional means of equalization and hard decoding.

Significant research has been carried out over the last one decade on turbo equalization. The research has evolved mostly in two distinct directions. In one of the approaches reduced complexity structures are investigated. The second approach hinges around finding applicability of turbo technique in different channel conditions. These channel conditions include cancellation of interference encountered in a variety of environments. Some analytical results have been derived; however, most of them consider filter based TEQ structures. However, there remains a need to attempt a unified analytical treatment on the issue of combined equalization and decoding for data communication with forward error correction (FEC) technique over ISI channel. Appropriate statistical models to understand the behavior of the TEQs are also required.

Performance gain in terms of average bit error rate (BER) along with size and power consumption of typical hand held devices need development of signal processing algorithms that require less number of computations. The requirement to keep the number of floating point operations, storage of all variables involved in the algorithm and latency in making a decision make it important to develop turbo equalization algorithms that require an acceptable complexity while maintaining the desired performance. Complexity is defined here as number of floating point operations per processor cycle. This thesis considers some aspects of low complexity TEQs.

The trend shown by analytical result is verified by simulation experiments. Two new TEQ schemes have been proposed in Chapter 3. These achieve performances close to the analytical results derived here. The simulated and the analytical results show the ability of the TEQs to approach asymptotically near coded additive white Gaussian noise (AWGN) performance even for severe ISI channels. The optimum probabilistic detector is the maximum a posteriori probability (MAP) algorithm that minimizes symbol error.

This is used for equalization as well as for decoding. In Chapter 3 also, various permutations and combinations of MAP and maximum likelihood sequence estimation (MLSE) with the soft output Viterbi algorithm (SOVA) have been compared for their relative merits and demerits by simulation studies. It may be mentioned here that MAP-MAP and SOVA-SOVA TEQ performance exists in the literature. As the MAP algorithm is optimal in terms of symbol error minimization, the corresponding reliability can be considered optimal, in general. This is the driving factor behind considering MAP as the equalization algorithm. The motivation behind studying the MAP-SOVA based scheme follows from the fact that, for binary data transmission of small to moderate sized data packets over ISI channels described with a small length of sampled channel impulse response (CIR), a MAP equalizer may not be difficult to implement on silicon. This is due to its inherent capability to produce soft outputs. Therefore, in next portion of Chapter 3, MAP is considered for equalization. The SOVA is known as an alternative to MAP algorithm for turbo decoding application (3G and DVB-RCS) with marginally poor performance. The decoder used in the turbo equalization scheme is actually a parallel structure of multiple identical modules (as soft output is to be generated for all the coded bits). Hence, the SOVA algorithm has been preferred to the MAP in the decoding module in order to realize an overall low complexity TEQ. The key factor is to generate high reliability information for all bits in the equalizer while maintaining acceptable complexity in the decoder. This helps to reduce the number of iterations required to come close to the coded AWGN performance. However, the MAP most often used in literature needs storage of entire observation before any processing takes place.

In Chapter 3, the effect of segmenting the received block into fixed size subblocks on the equalizer performance has been studied. The resultant structure gives a flavor of windowed MAP (WMAP) architecture. The computational complexity has been analytically compared with respect to block/sub block size. Three versions of the WMAP algorithm have been proposed and their relative merits and demerits with respect to the optimum scheme have been studied. Equalizers considered in Chapter 3 are computationally inferior to filter based equalization scheme.

Most of the MMSE equalizers use transversal filters in a linear, decision feedback and or combinations thereof. Recently, soft output based transversal filters in cascade with FEC decoders in turbo manner have also been discussed in literature. In Chapter 4, such equalizers have been explored for their step by step convergence to optimum performance by deriving expressions for statistical parameters. In Chapter 4, a new high performance Wiener filter based TEQ is proposed. In this case, the equalizer algorithm is forced with latency delay, however with a gain in repeated matrix inversion operation. The matrix inversion is done per iteration only once instead of sample-by-sample matrix operation which is done as usual. The convergence behavior of the TEQ is determined by the eigen spread of the channel.

Chapter 5 is concerned with detailed analysis and modified structures for soft interference cancellation (SIC) based TEQs. Here two schemes are proposed and supported with analysis results for their performance gain. The SIC and the soft decision feedback equalization (SDFE) as discussed here converge to lower BER value.

In Chapter 6, an attempt has been made to explore the behavior of the TEQ for asymptotic conditions. The signal to noise ratio (SNR) amplification model as discussed for classical turbo decoder performance modeling in literature has been used to derive results for the equalizer. In addition, the discrimination factor (DF) enhancement model for explaining the observed phenomena has been studied. A novel model for LLR enhancement has been introduced for the equalizer. It is to be noted here that the results of this LLR enhancement model are valid for trellis based and MMSE based TEQ schemes. All of these models exhibit identical structures under asymptotic conditions.

Major observations and insights drawn from previous chapters, are summarized in Chapter 7. Indications for need of further research are also provided in this last chapter.