Utilizing EXIT Charts for Turbo-processing of M-ASK Modulations in 6G Communications

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Introduction

The upcoming 6G wireless networks are ready to introduce a new era of unmatched level of connectivity, demanding innovative approaches to modulation and coding for optimized spectral efficiency. In this research, we propose a framework that integrates the extrinsic information transfer (EXIT) charts and iterative decoding while continuously monitoring and analyzing the channel state information. The soft-in soft-out (SISO) decoders are used to accept and provide soft estimates for the transmitted symbols. Based on the exchange of information between SISO decoders, we gain the ability to refine the code parameters and realize improved error-correction performance. Figure 1 shows a serially concatenated convolutional coding and M-ASK modulation with controllable parameters.

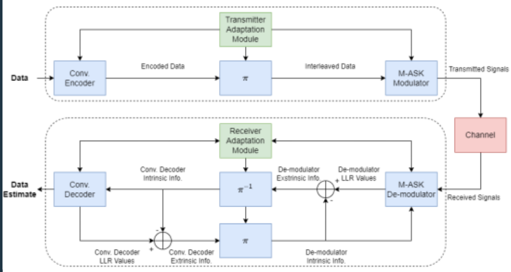

Figure.1 Serially concatenated coder and M-ASK modulator.

Controllable M-ASK Modulation

In fact, two M-ASK modulations can be seen as one M-QAM modulations, except for modulations like M-PSK. The use of 2 parallel M-ASK modulations, one for the in-phase and the other for the quadrature-phase, simplifies strongly processing, especially at the receiver. The encoded data are interleaved before modulation to gain immunity against burst errors. The modulator is initialized with a controllable value of M which gives the rate as $\log_2 M$. The demodulator has the behavior of an inner decoder and can be viewed as a SISO decoder. Figure.2 shows the BER performance for different M-ASK modulations. The trade off here is that lower M values means lower bits per symbol which is directly related to the data rate. Hence, it is desirable to have a controllable M-ASK modulation to accommodate maximum reliable data rate.

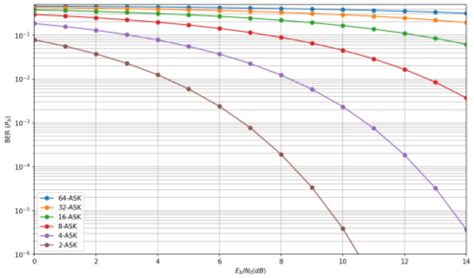

Figure.2 BER comparison for different M-ASK modulations.

Controllable Channel Coding

Any realistic channel model have the potential to introduce many types of noise and interference such as multi-path fading, Doppler shifts, atmospheric absorption, interference from other signals, and phase noise. Data are encoded to have bit error detection and correction capabilities to increase the communication reliability. However, coding data means adding parity bits either systematically or non-systematically which reduces the bit rate. Therefore, a compromise between reliability and rate is imposed, and the choice can be made based on the available channel state information. The BCJR algorithm is used to decode the received symbols according to the following a posteriori probabilities (APP) equations

$$\lambda_k(m_i) = \alpha_k(m_i)\beta_k(m_i) \quad (1)$$

$$\sigma_k(m_i,m_j) = \alpha_{k-1}(m_j)\gamma_k(m_i,m_j)\beta_k(m\_i) \quad (2)$$

Where:

- Forward Probability : $\alpha_k(m_i) = \sum_{m_j} \alpha_{k-1}(m_j)\ \gamma_k(m_i,m_j)$ (3)
- Backward Probability : $\beta_k(m_i) = \sum_{m_j} \beta_{k+1}(m_j)\ \gamma_{k+1}(m_i,m_j)$ (4)
- Joint Probability : $\gamma_k(m_i,m_j) = \sum_{S[k]} p_k(m_i \mid m_j)\ q_k(S[k] \mid m_i,m_j)\ f_{R|S}(R[k] \mid S[k])$ (5)

$p_k(m_i \mid m_j)$	$q_k(S[k] \mid m_i,m_j)$	$f_{R\mid S}(R[k] \mid S[k])$
Transition	Output Probability	Channel PDF

Turbo-equalized Concatenation

In the context of iterative decoding, the demodulator makes soft estimates for the transmitted symbols based on the received signals and channel state information. We estimate the symbols one by one and output the log likelihood ratio (LLR) to indicate the reliabilities for the given estimates according to the following equation

$$LLR_k = log\left(\frac{\Pr\{S[k]=1\}}{\Pr\{S[k]=0\}}\right) \quad (6)$$

The LLR is unitless and its behavior as a function of probability is shown in Figure.3. The logarithmic scaling is clear especially for probabilities at the extreme points i.e., near zero or one.

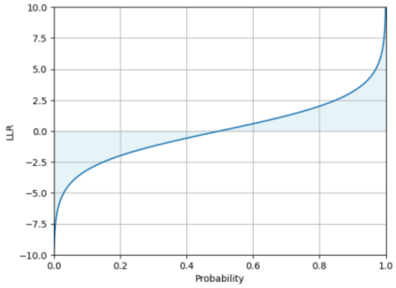

Figure.3 LLR as a function of probability.

To make the computations more efficient, we work in the Log MAP domain to avoid overflow operations since it is sufficient to work with the exponents in this case. Moreover, multiplications and normalization divisions will be additions and subtractions that consume considerably less FLOPs.

EXIT Chart Adaptation Module

Assuming that the channel is AWGN i.e., $N(0,\sigma_n^2)$, the intrinsic LLR values for a SISO decoder will be normally distributed $N(\mu_{In},\sigma_{In}^2)$. The mean and variance of the intrinsic LLR values are related by

$$\mu_{In} = \frac{\sigma_{In}^2}{2} \quad (7)$$

The extrinsic LLR values are also assumed to be normally distributed according to $N(\mu_{Ex},\sigma_{Ex}^2)$. The following steps are used to generate the EXIT chart

1. Set the noise to a given SNR value
2. Transmit and receive the symbols using the channel
3. Generate random samples of input LLR values for a given variance
4. Feed the decoder with the generated input LLR values
5. Estimate the mean and variance of the extrinsic LLR values
6. Compute the mutual information at the input and output of the decoder
7. Iterate from step 3 to step 6 for a given range of input LLR variance values

Figure.4 presents the EXIT chart for (5,7) convolutional decoder followed by the 4-ASK demodulator both acting as SISO decoders.

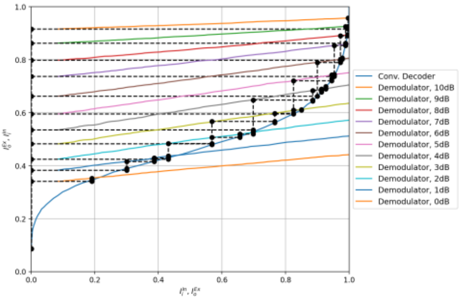

Figure.4 EXIT chart for the proposed system.

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