Phase Tracking for Turbo Codes: 
An Approach Based on Adaptive SISOs

Communication Theory Workshop 
Aptos, CA 
May 1999

Achilleas Anastasopoulos and Keith M. Chugg

Communication Sciences Institute 
Electrical Engineering Department - Systems 
University of Southern California 
Los Angeles, CA, USA 90089-2565 
e-mail: achillea@zeus.usc.edu, chugg@usc.edu

This research has been funded in part by the National Science Foundation (CCR-9726391)
Talk Overview

- Motivation
- Summary of adaptive SISO theoretical framework (linear observations)
- Application to phase tracking in SCCC and PCCC
The need for adaptive processing (Cont.)

![Graph showing BER vs Eb/No for different conditions: Perfect CSI, PSP, CA-MLSD.](image-url)
Enabling iterative detection: Example

![Graph showing the performance of different codes with BER vs Eb/No](image-url)
MLSD with Random/Unknown Channel

- Optimal MLSD receiver for random channel: Estimator/Correlator (Kail61)
Practical Adaptive MLSD Algorithms

- Tree search $\iff$ exponential complexity growth
- Practical adaptive MLSD algorithms can be viewed as suboptimal tree search procedures
- e.g. Per Survivor Processing (PSP): tree is force-folded to a trellis

[Diagram of CA-MLSD (e.g. Unge74) and PSP (e.g. RaPoTz95)]
Definition of Soft Metrics

- Two types of soft metrics can be defined (e.g. for the input symbol $x_k$)

\[ \text{Fixed Interval (FI)} \]
\[ \text{Fixed Lag (FL)} \]

\[ \text{APP}(x_k) \sim P(x_k|z_0^n) \sim \sum_{x_0^n:x_k} P(z_0^n, x_0^n) \]
\[ \text{MSM}(x_k) \sim -\log[\max_{x_0^n:x_k} P(x_0^n|z_0^n)] \sim -\log[\max_{x_0^n:x_k} P(z_0^n, x_0^n)] \]
Background Summary

Type of Decisions

<table>
<thead>
<tr>
<th>Channel Knowledge</th>
<th>Perfect CSI</th>
<th>Imperfect CSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Soft</td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>
Definitions of Soft Metrics with Parametric Uncertainty

- What is a meaningful Soft information in the presence of parametric uncertainty $\Theta$?
  
  - For random $\Theta$ averaging is possible:
    
    $$\text{APP}_p(x_k) \sim P(x_k|z_0^n) \sim \sum_{x_0^n:x_k} E_\Theta\{P(z_0^n, x_0^n|\Theta)\}$$
    $$\text{MSM}_p(x_k) \sim -\log[\max_{x_0^n:x_k} P(x_0^n|z_0^n)] \sim -\log[\max_{x_0^n:x_k} E_\Theta\{P(z_0^n, x_0^n|\Theta)\}]$$
  
  - For deterministic $\Theta$ maximize (Generalized Likelihood):
    
    $$\text{APP}_d(x_k) \sim \sum_{x_0^n:x_k} \max_{\Theta} P(z_0^n, x_0^n|\Theta)$$
    $$\text{MSM}_d(x_k) \sim -\log[\max_{x_0^n:x_k} \max_{\Theta} P(z_0^n, x_0^n|\Theta)]$$

* All soft metrics are derived from $P(z_0^n, x_0^n|\Theta)$
Options for the exact evaluation of soft metrics

- 6 options: $E_{\Theta}$, $\max_{\Theta}$, $\Sigma_{x_0^n:x_k}$, $\max_{x_0^n:x_k}$, order of operation on $P(\hat{z}_0^n, x_0^n | \Theta)$
Parameter-first Combining (GM channel)

- A forward and backward tree may seem redundant but this structure decouples complexity with smoothing depth
- Entire complexity is due to the tree structure
• Design options: number of estimators, parameter estimation technique, binding term
SCCC with Carrier-Phase Tracking

![Diagram of SCCC with Carrier-Phase Tracking](image)
SCCC with Phase Tracking (Continued)

- 4-state 1/2 outer RSC, $N = 16K$ interleaver, 4-state 2/3 inner RSC, 8PSK mapping in AWGN with no phase dynamics

![Graph showing BER vs. Beq for different Eb/No values]

- Eb/No = 1 dB
- Eb/No = 1.5 dB
- Eb/No = 2.0 dB

- (32,256) training
- No Training
SCCC with Phase Tracking (Continued)

- 4-state 1/2 outer RSC, $N = 16K$ interleaver, 4-state 2/3 inner RSC, 8PSK mapping, (16,256) pilot symbols, in AWGN with phase dynamics
PCCC with Carrier-Phase Tracking

\[ y_k(1) \rightarrow Puncture and Modulate \rightarrow m_k \rightarrow z_k \]

\[ y_k(2) \rightarrow \]

\[ \theta \rightarrow e^{j\theta} w_k \rightarrow z_k \]

Decision Directed PLL

External PLL

[LuWi98]
PCCC with Carrier-Phase Tracking

Adaptive Iterative Detection

Example Forward Recursion

Decision Directed PLL
PCCC with Carrier-Phase Tracking (Continued)

- 4-state 1/2 RSCs, $N = 16K$ interleaver, QPSK mapping, (16,256) pilot symbols, in AWGN with phase dynamics

- Conclusions very similar with the SCCC case