Mobile Wireless Channel Dispersion State Model

Enabling Cognitive Processing Situational Awareness

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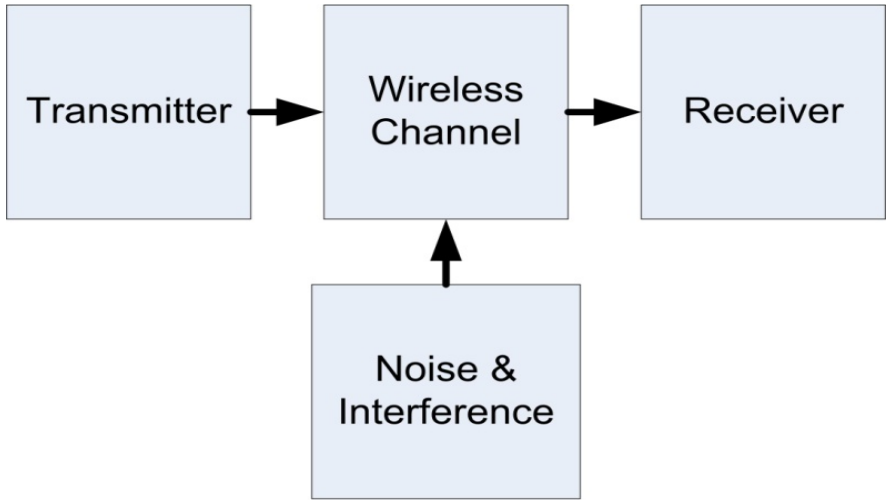
System Modeling Background

- System engineering models
  - Behavioral (mathematical, logical, flow, state, others)
  - Structural (physical, architecture, interface, others)
- Hidden Markov models
  - Dual statistical model, hidden random sequences, observable random sequences
  - Initial, transition, output probabilities
  - Training, generative, evaluation, decoding modes
  - Applications: automatic speech, image, facial, writing, gait, biological, and network traffic recognition.
- Published multistate mobile wireless channel models

•Binary nonfading/fading FSMM,
•Amplitude quantized FSMM,
•Error rate FSMM
•N-state SNR FSMM
•N-state pdf FSMM
•Variable length Markov chain
•Average dwell time FSMC
•High order FSMM
•Statistical distribution FSMM
•State variable models

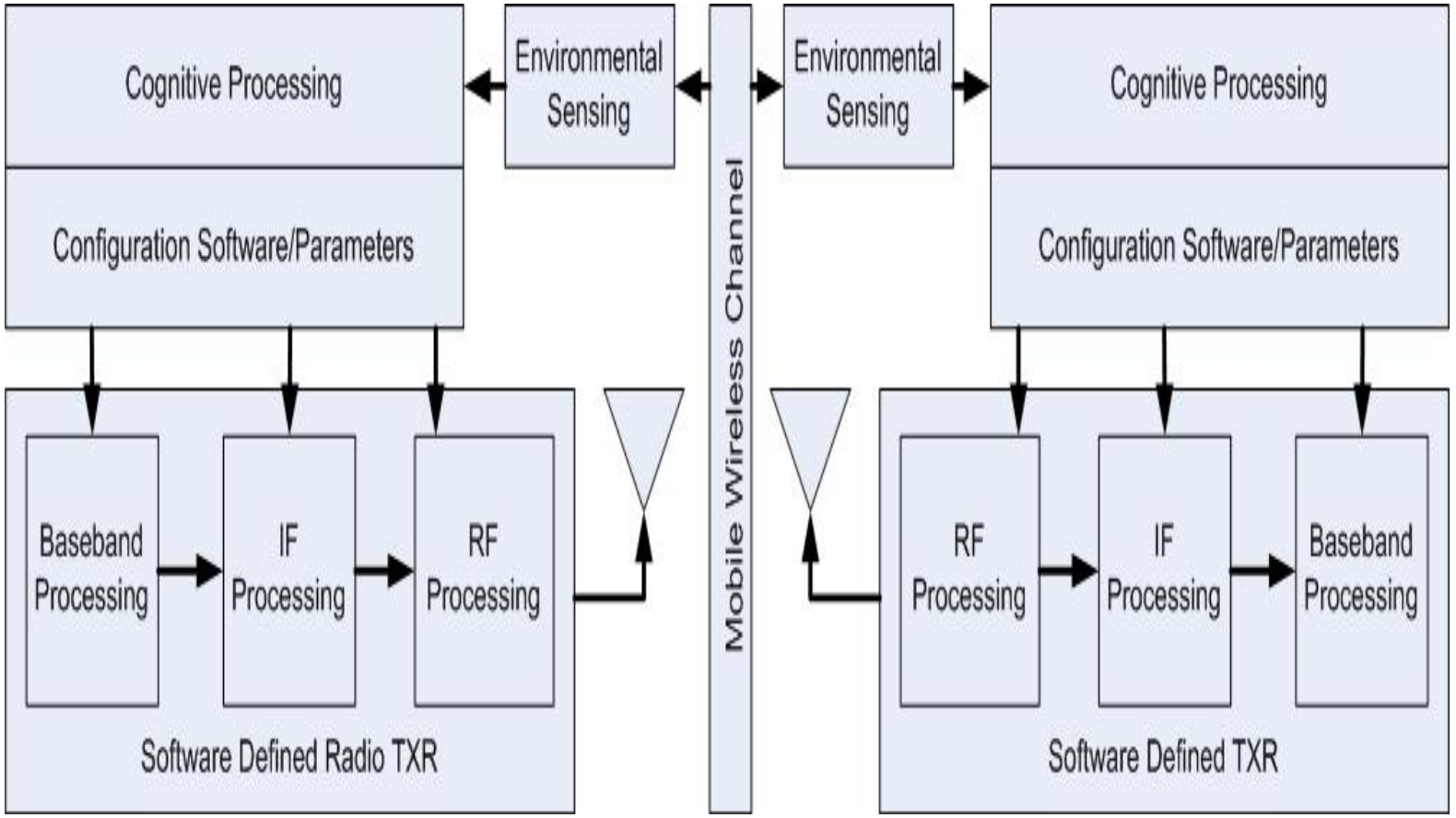
Mobile Wireless Channel Architectural Model

- Mobile wireless channel architecture
  - TX, mobile channel, RX
- Cognitive radio CSR architecture
  - Software defined processing
  - Cognitive processing
  - Environmental sensing
  - Mobile wireless channel



Mobile Wireless Channel System Model

Mobile Wireless Channel Architectural Model



Cognitive Radio CSR Architecture

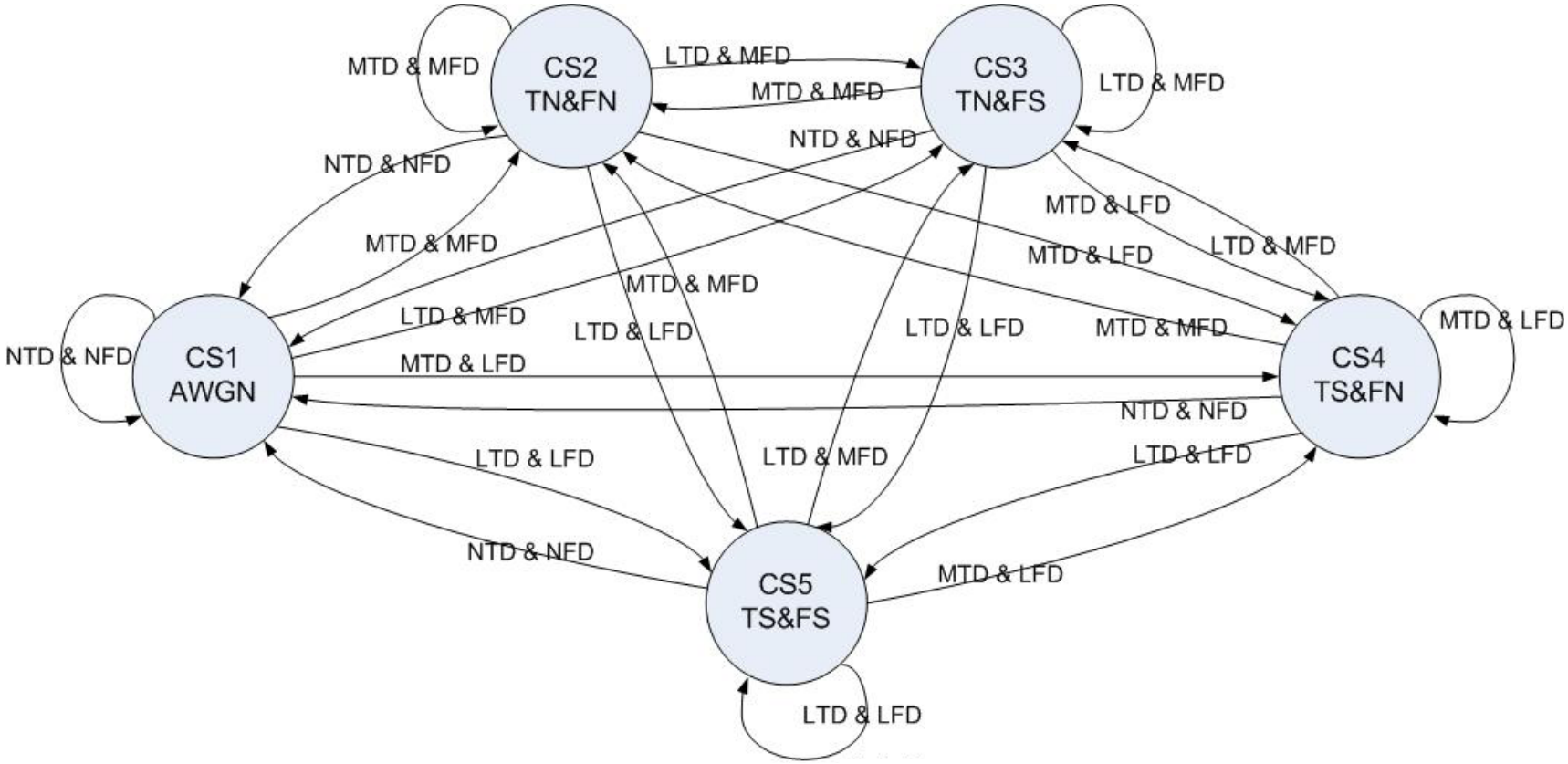
MWC Dispersion State Model

Mobile Wireless Channel DSM

- MWC dispersion state space
  - Non dispersive, single time, single frequency, dual time/frequency dispersion
  - Non fading, flat frequency, frequency selective, time selective
- DSM state transitions
  - Symbol period
  - Symbol rate

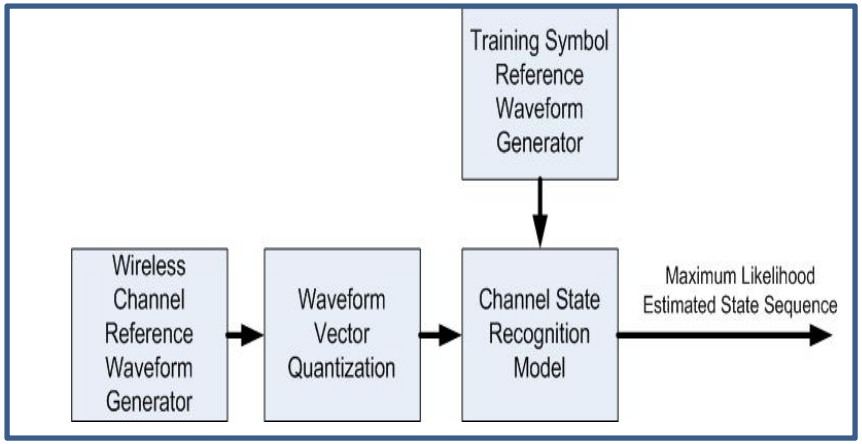
NTD&NFD	No Time Dispersion and No Frequency Dispersion
MTD & MFD	Minimal Time Dispersion and Minimal Frequency Dispersion
LTD & MFD	Large Time Dispersion and Minimal Frequency Dispersion
MTD & LFD	Minimal Time Dispersion and Large Frequency Dispersion
LTD & LFD	Large Time Dispersion and Large Frequency Dispersion

MWC Dispersion State Model

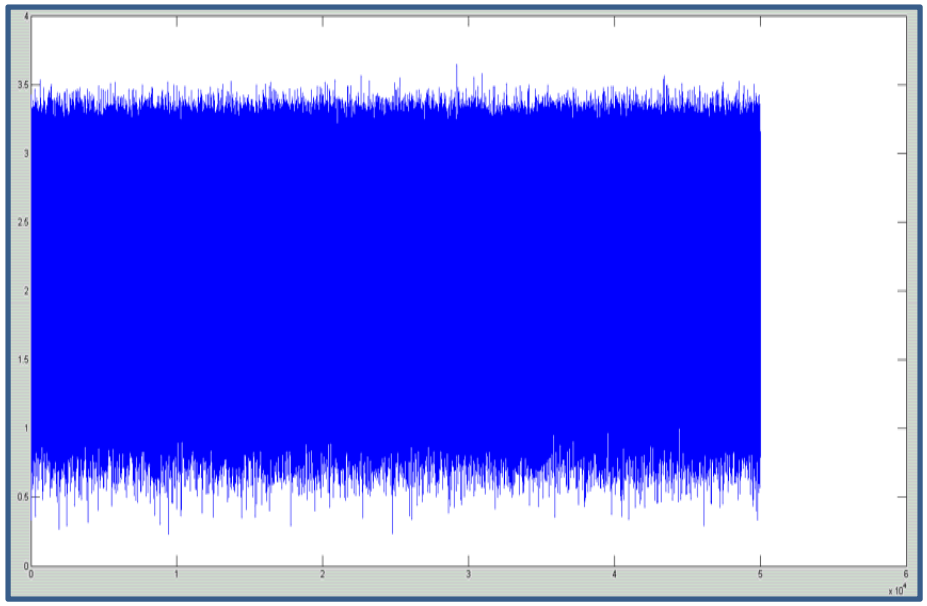


CSR Test System

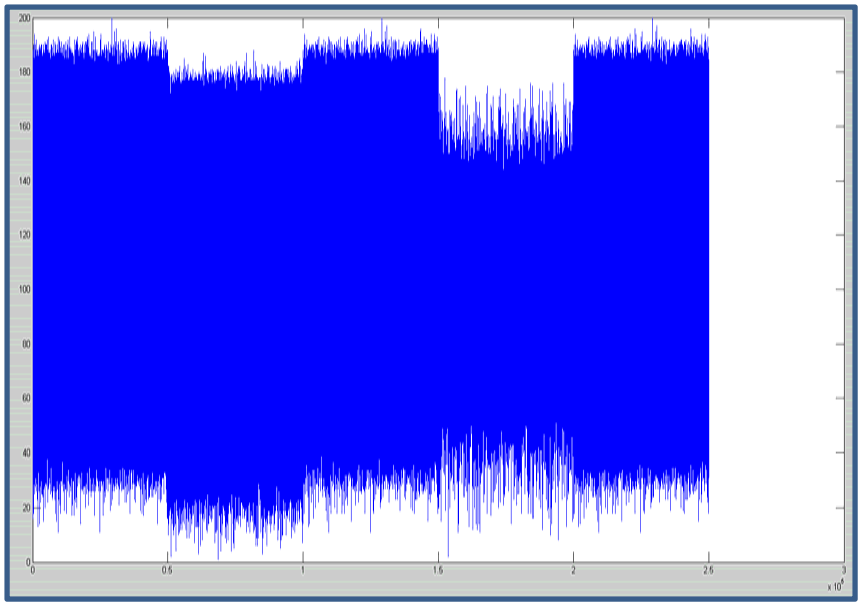
CSR Test System
- Reference waveform generator
  - Simulink data, TX, channel, RX models
- Statistical quantizer
  - Amplitude histogram bin index
- CSR training RWG
- DSM FSMM embedded in CSR HMM
- Operational sequence decoding



CSR Test System



Reference Waveform Generator Output

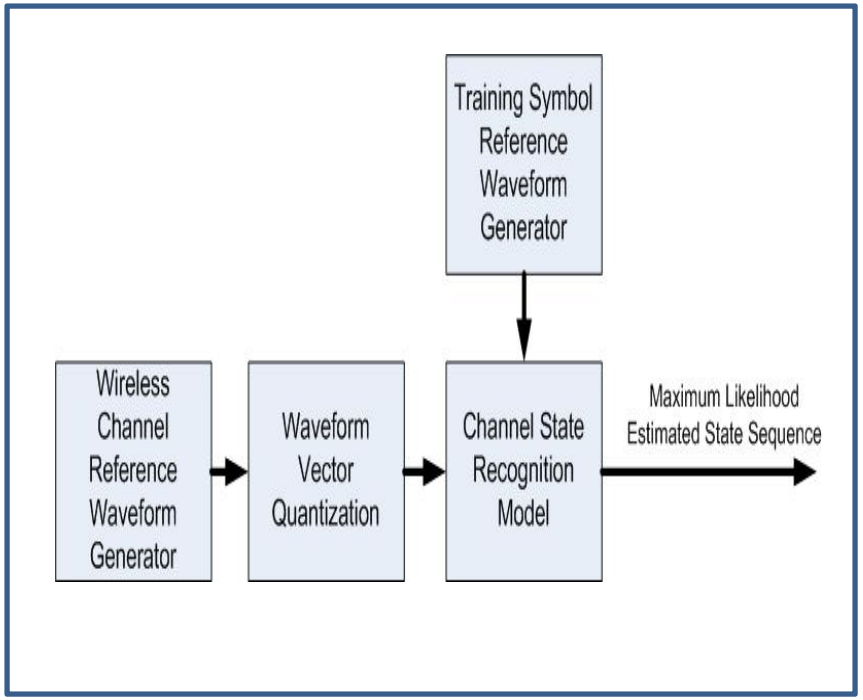


Waveform Quantizer Output

DSM Validation

Accuracy Validation Approach

- CSR Test System
  - Generate calibrated reference waveforms,
  - Apply training hidden state sequences to estimate HMM parameters,
  - Train 5 HMMs with varying combinations of hidden state sequences,
  - Apply a single calibrated operational reference waveform
  - Statistical quantization
  - Decode operational waveform hidden state sequences
- Post processing
  - Enumerate decoded states
  - Quantify statistical sensitivity
  - Quantify statistical specificity



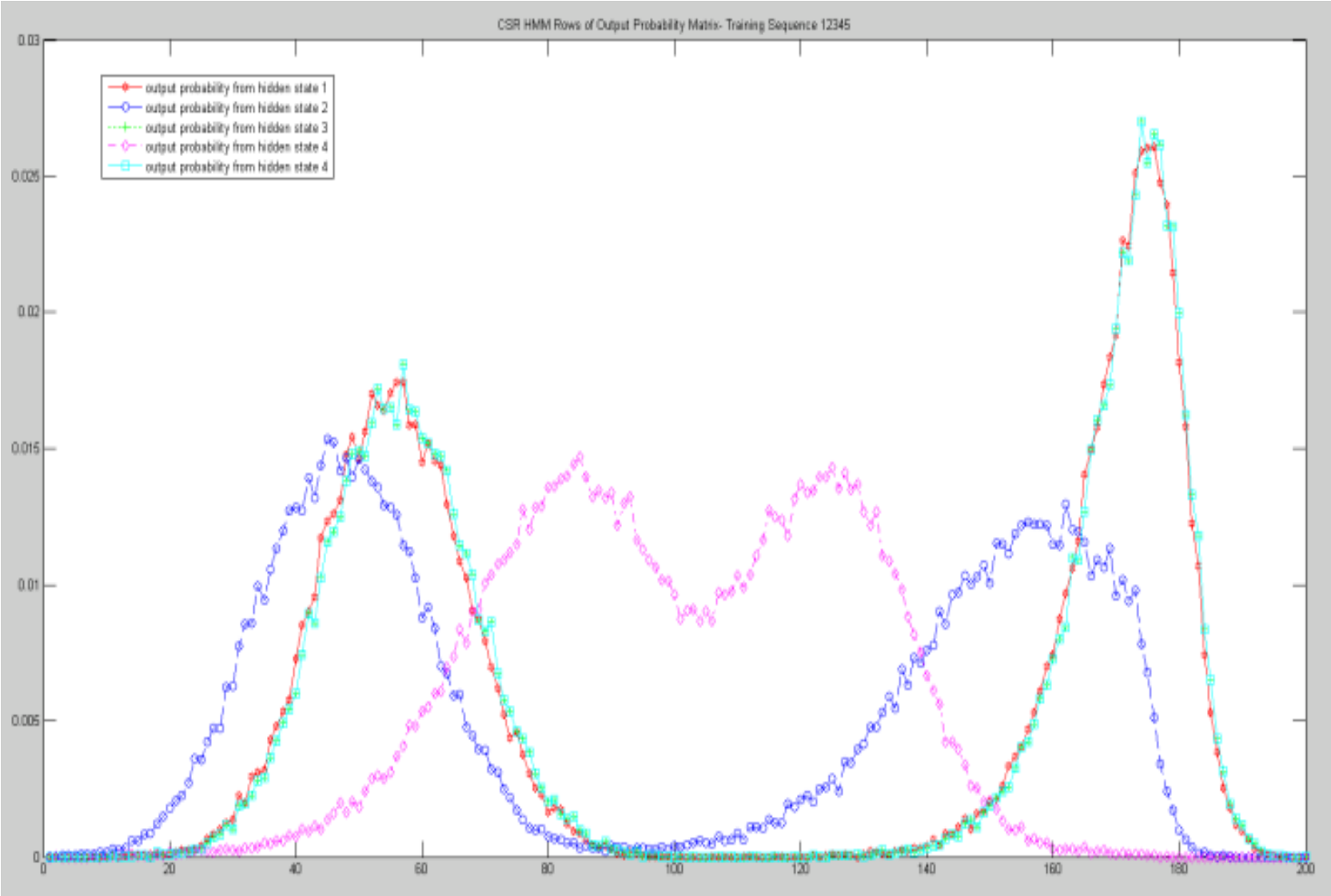
CSR Test System

Channel State Recognition HMM Training

- Viterbi parameter estimation
- Baum-Welch parameter estimation
  - Initial state probability
  - State transition probability
  - Output probabilities

0.999920006399	1.9998400127e-05	1.9998400127e-05	1.9998400127e-05	1.9998400127e-05
1.9998400127e-05	0.999920006399	1.9998400127e-05	1.9998400127e-05	1.9998400127e-05
1.9998400127e-05	1.9998400127e-05	0.999920006399	1.9998400127e-05	1.9998400127e-05
1.9998400127e-05	1.9998400127e-05	1.9998400127e-05	0.999920006399	1.9998400127e-05
1.9998400127e-05	1.9998400127e-05	1.9998400127e-05	1.9998400127e-05	0.999920006399

Channel State Recognition HMM Training



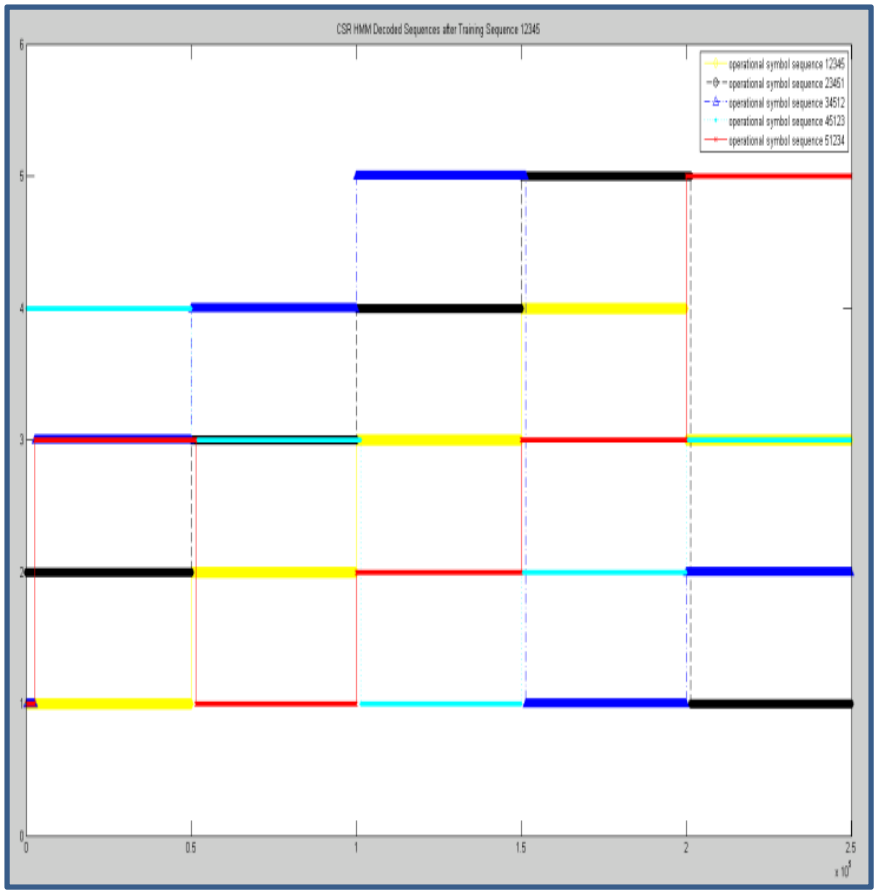
CSR Operational Sequence Decoding

Hidden Sequence Decoding

- Maximum likelihood
- Viterbi algorithm
- Response to operational sequences
  - 12345
  - 23451
  - 34521
  - 45123
  - 51234

$$\pi^* = \max_{\pi} P(x, \pi)$$

$$v_l(i) = e_l(x_i) \max_k (v_k(i) a_{kl})$$

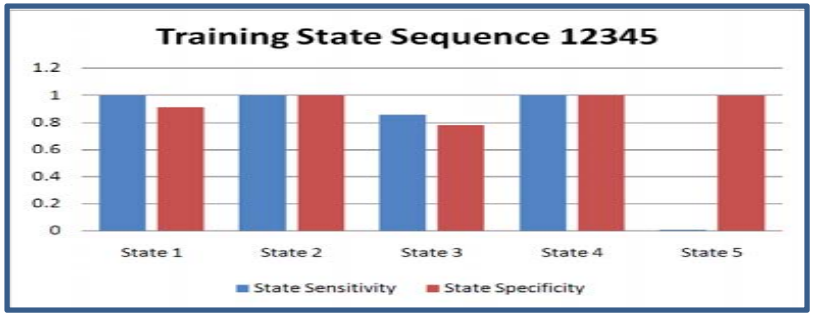


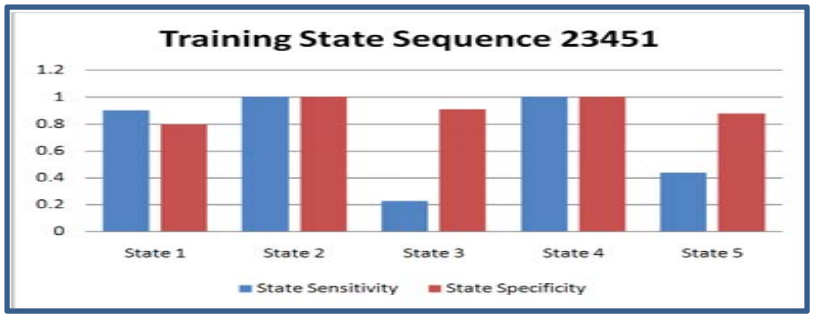
DSM CSR Accuracy Results

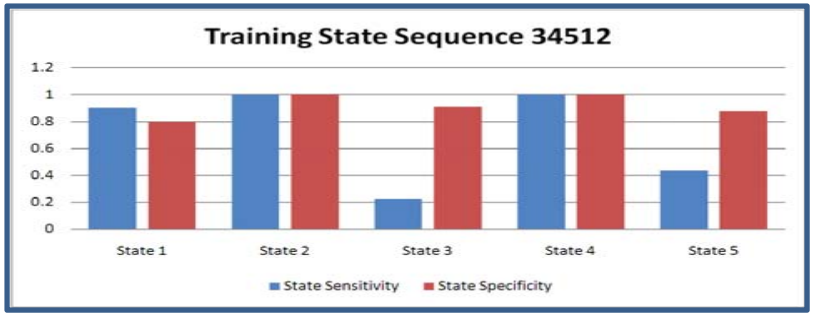
Statistical Accuracy

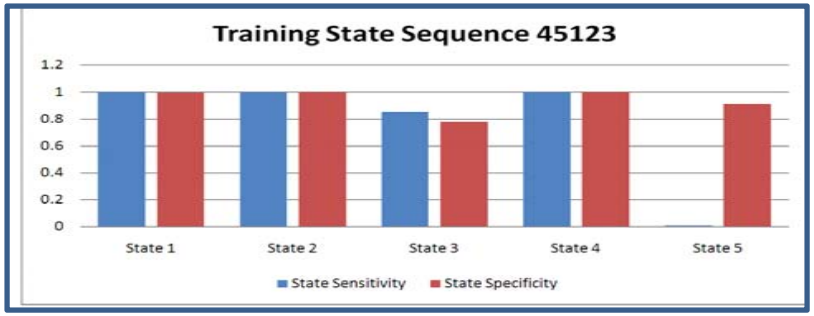
- Decoded hidden state sequences
- Statistical accuracy results
  - Sensitivity
  - Specificity

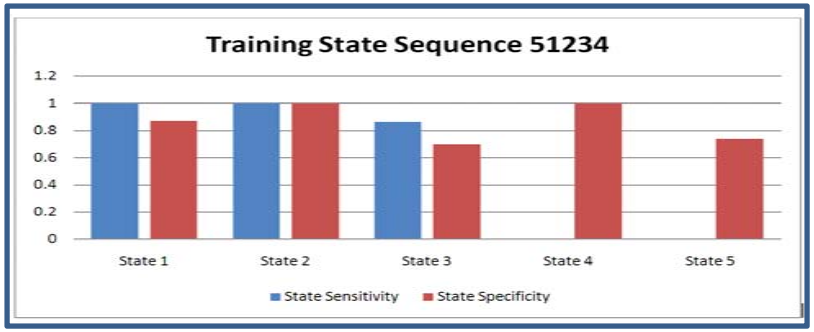
$$Sensitivity = \frac{TP}{TP + FN} \qquad Specificity = \frac{TN}{TN + FP}$$











CSR Accuracy Conclusions

- None of the HMMs discriminated dual dispersive state 5 from the frequency selective state 3. More effective training required. Output probabilities are similar.
- All HMMs recognized the absence of dual dispersive state 5.
- All HMMs recognize the presence of nonfading state 1 with >85% accuracy and the absence of state 1 with > 80% accuracy.
- Two of the HMMs would recognize the presence of frequency selective state 3 with > 80% accuracy while all HMMs would recognize the absence of state 3 with > 70% accuracy.
- Accuracy improvements will be topic of future CSR research.

CSR Accuracy Conclusions

- If the HMMs were logically combined, states 1,2, and 4 could be recognized with 100% accuracy and state 3 would be recognized with > 90% accuracy. A subject for further CSR research.
- The results suggest that CSR is insensitive to waveform parameters such as modulation or symbol period. Topic for further CSR research.
- Convergence is delayed for some state transitions and will be a topic for further CSR research.
- State sensitivity and specificity performance are less than 100% and will be a topic for further CSR research.