Neural Networks for Communication Data Equalization & Demodulation

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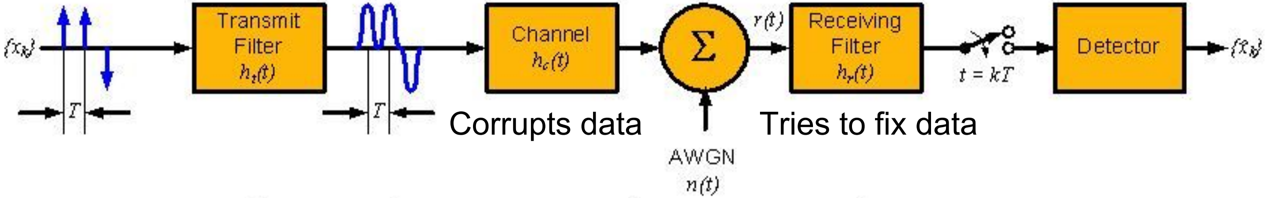
Classical Comms approach

Introduction



- Systems with equalization are best viewed as communications links where each block filters the signal.
- The signal at the receiver input is:

$$r(t) = x(t) * h_t(t) * h_c(t) + n(t)$$

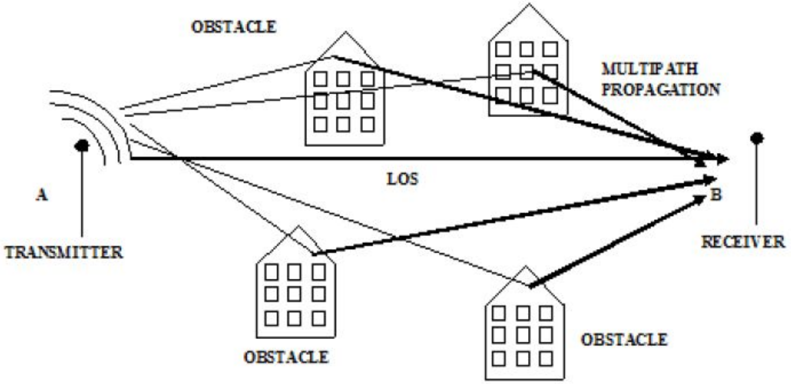
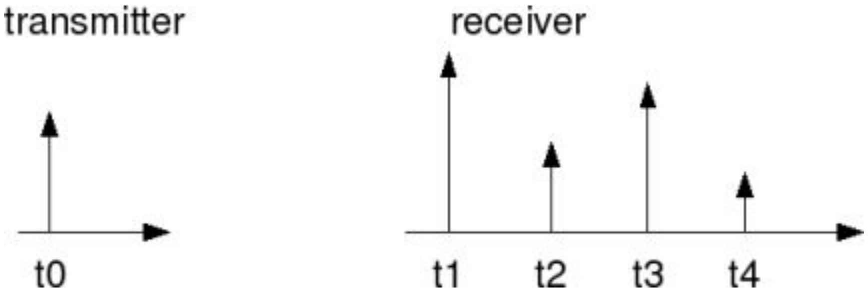
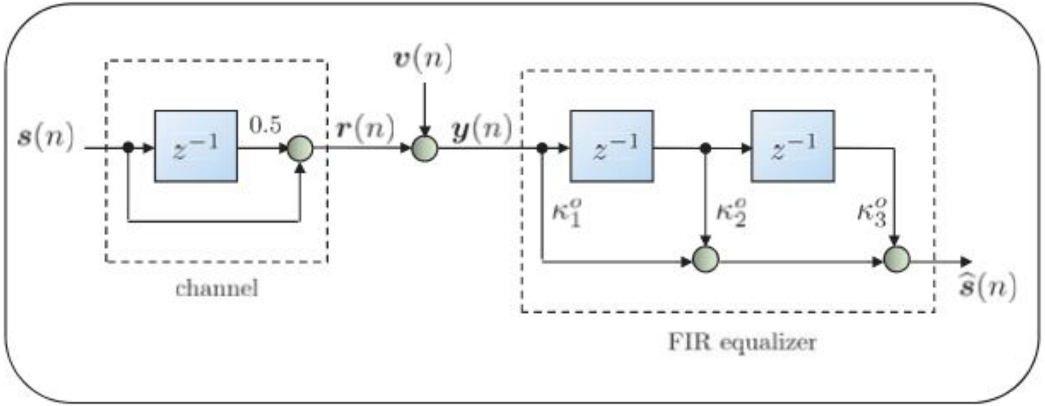


Fig.1 Mobile user in the presence of multipath and interference



Classical Channel Equalization: LMS



$$w^o = \mathrm{col}\{\kappa_1^o, \kappa_2^o, \kappa_3^o\}$$

Cost Function

$$C[n] = E\{|e[n]|^2\} = \sum_{n=1}^{N} (\hat{s}[n] - s[n])^2$$

Calculate error

$$e[n] = s[n] - w^{\circ H} y[n]$$

Gradient Descent Step

$$\hat{w}[n+1] = \hat{w}[n] + \mu e^H[n] y[n]$$

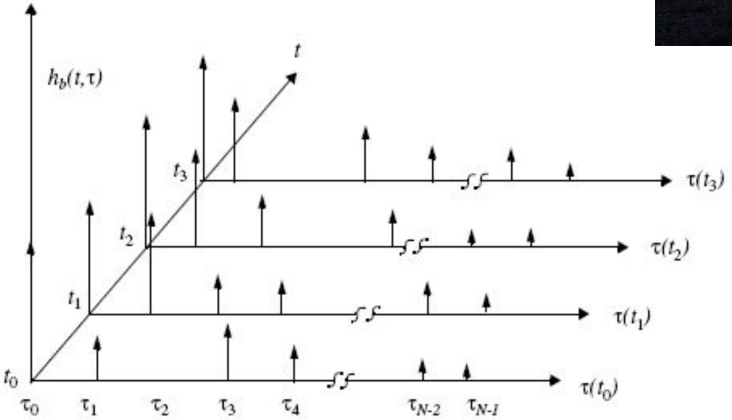
Addressed Problems

- Additive noise
- Multi-tap channel distortion
- Implicitly decreases Symbol Error

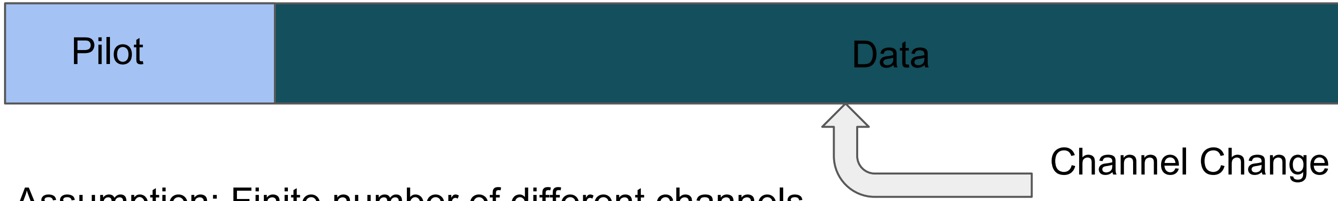
Complications

- Adaptive to time variant channels

Why Time Variance?

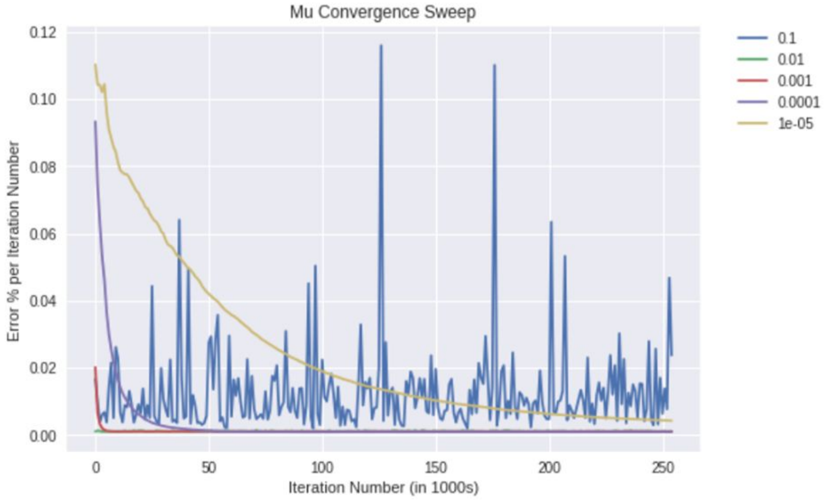


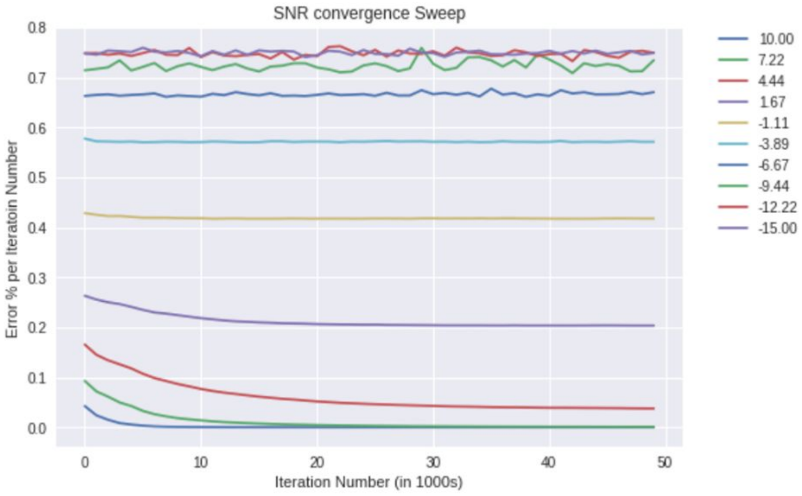
LMS Solutions for Time Variant Channels: Pilot



- Assumption: Finite number of different channels.
- Estimate Channel via header pilot symbols in front of each data packet
  - Pilots known on sender and receiver
- LMS + Pilots
  - Train
    - Add pilot headers before each message
    - Train different classifiers on time invariant channels for each channel using LMS gradient descent
  - Test
    - Decode each header and pick the best performing classifier
    - Then, decode the following message with the chosen classifier
    - Use those weights to decode the next x messages
- Cons
  - Reduces the rate of transmission
  - If the channel changes in the middle of a message, we will misclassify until the next header

Results of LMS: Time Invariant Channel





Experiment Parameters:

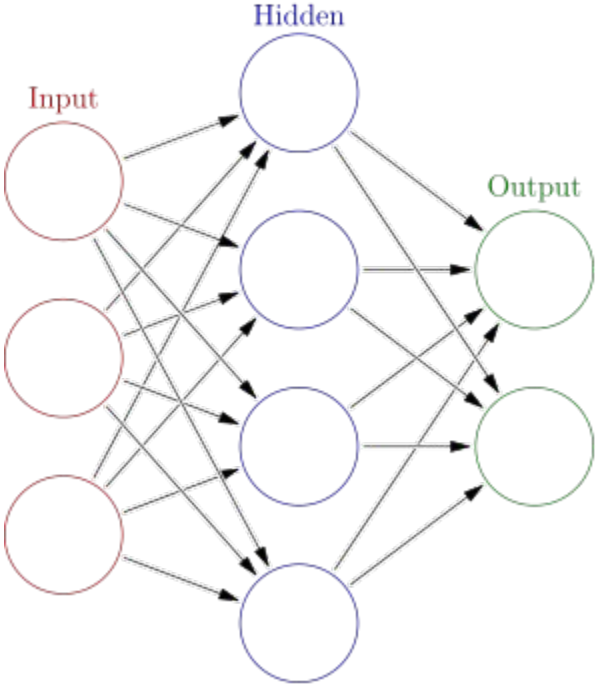
- 3-tap Time Invariant Channel

Key Observations:

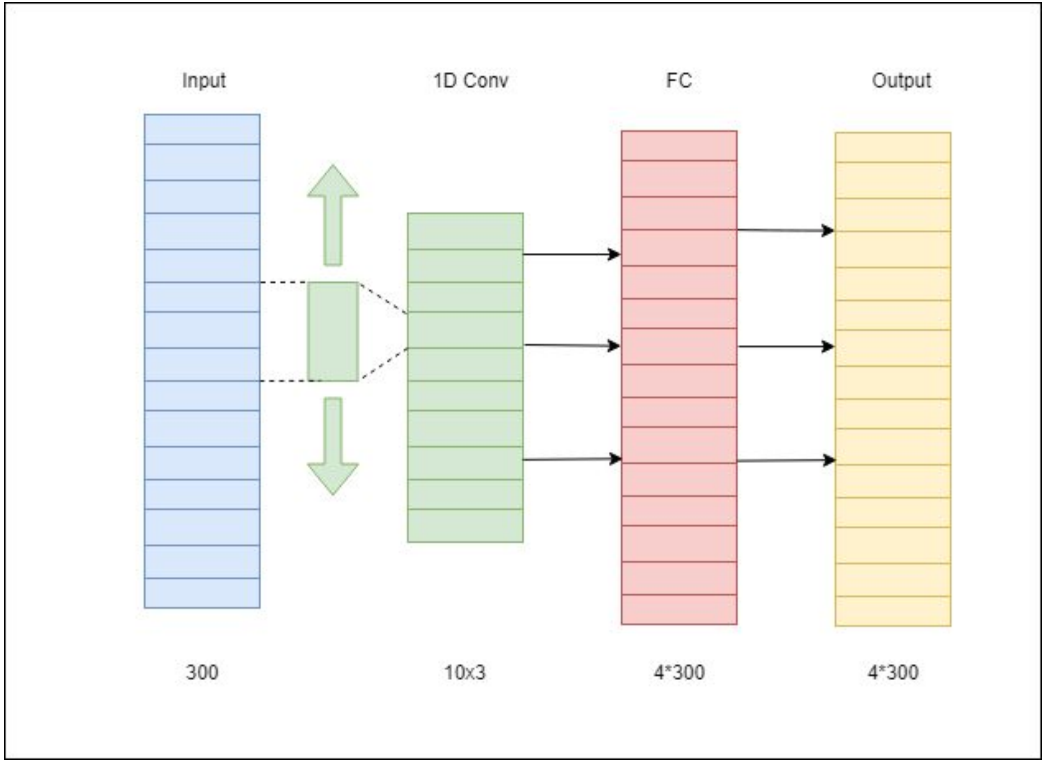
- Converges to 99+% accuracy for SNR > 7
- Converges to 80% accuracy for SNR = 1.67

Channel Equalization through Neural Network

- Computational graph abstraction
- Allows for higher complexity models
- Straightforward Optimization
- Allows for automatic detection of channel variation
    - Eliminates the need for a Header thereby increasing Channel Rate.
    - Can detect channel change as soon as it happens and automatically changes decodes
- Directly optimizes Symbol Error Rate

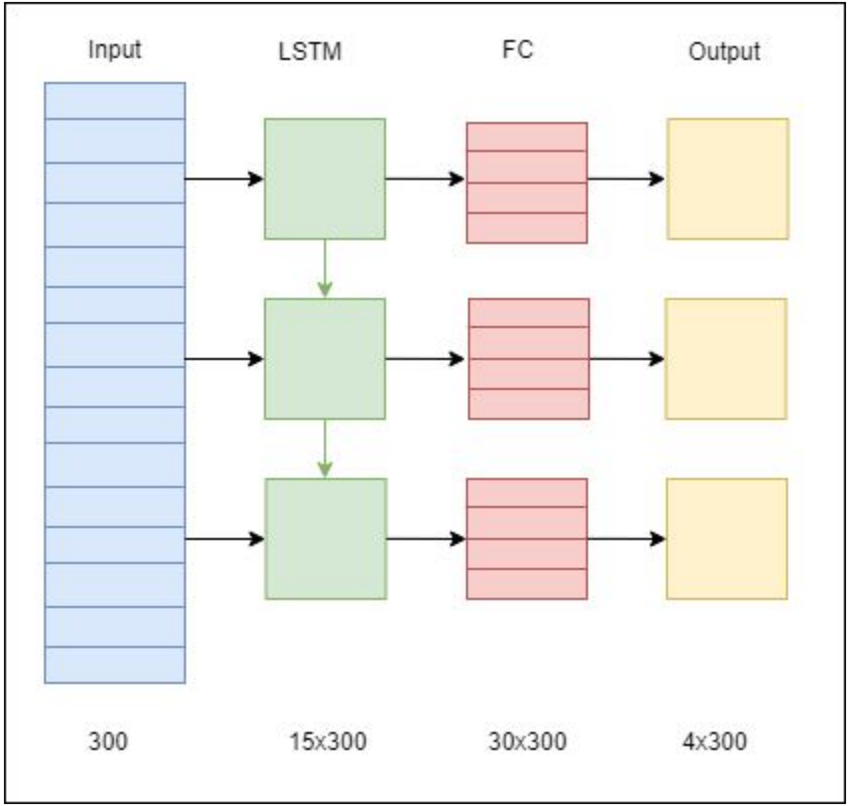


Convolutional Neural Network Architecture



- Model
  - 1D Conv
    - Extracts Features
    - Linear activation function
  - Fully Connected(FC)
    - Takes output of LSTM and applies a linear transformation
  - Output
    - Softmax Layer to get prediction for Symbols

Recurrent Neural Network: LSTM



- Model
  - Input:
    - Can be either a single feature vector or a window of feature vectors
  - LSTM
    - Extracts Features
  - Fully Connected(FC)
    - Takes output of LSTM and applies a linear transformation
  - Output
    - Softmax Layer to get prediction for Symbols

Note: LSTM has 100 times less parameters then the Convolution Network.

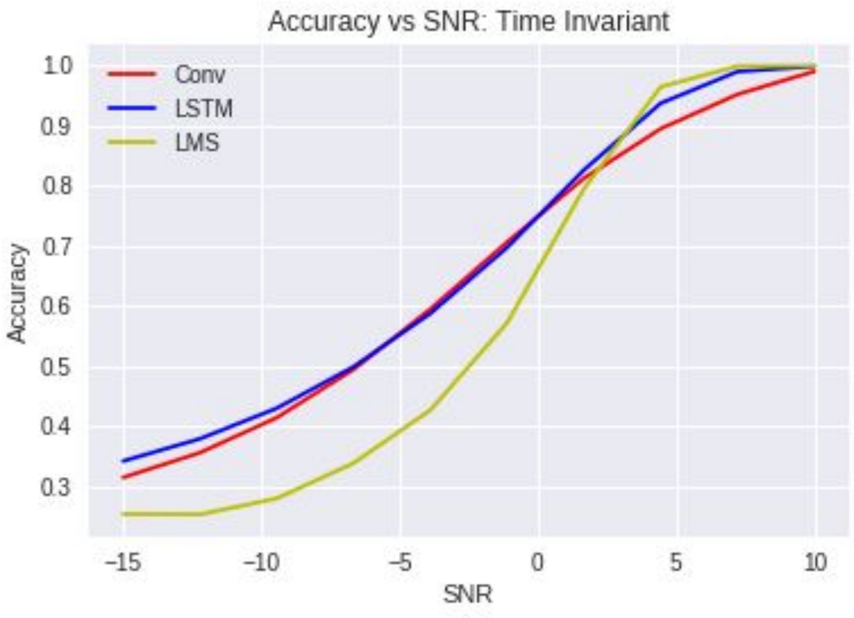
Experimental Results: Time Invariant Channel

Experimental Parameters:

- 3-tap channel with parameters [1,0.5,-0.3]

Key Observation:

- Equalizers perform similarly at high SNR
- Neural Networks outperform LMS at low SNR.

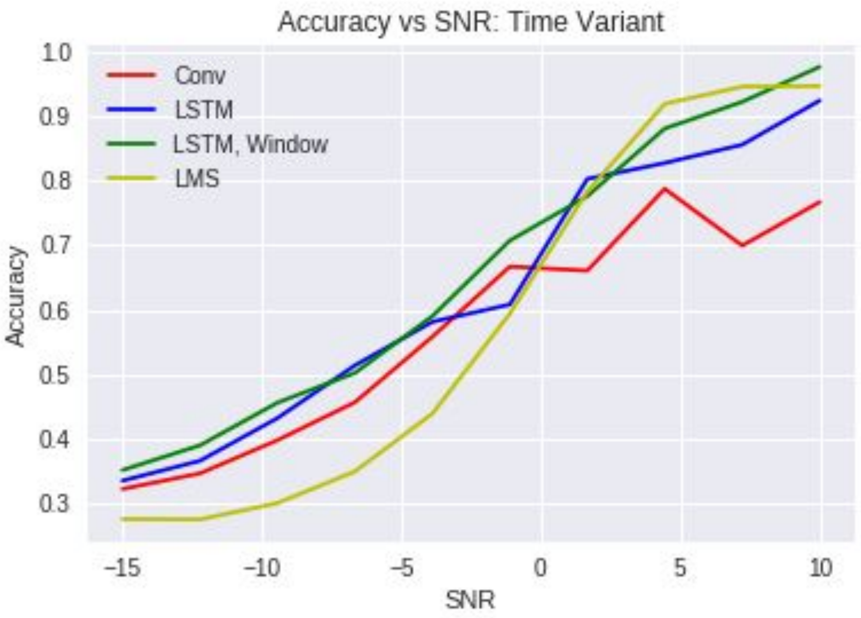


Experimental Results: Time Variant Channel

Experimental Parameters:
- Time Varying Channel with 3 different channel configurations
- All configurations are 3 tap channels

Noiseless Accuracy:
- LMS: 95.06%
- LSTM, No Window: 99.1%
- LSTM, Window: 99.9%
- Conv: 97.7%

Key Observation:
- LMS and LSTM+Window are comparable at high SNR.
- Neural Networks outperform LMS at low SNR.
- Windowed LSTM performs the best out of the all the Neural Network



Possible Improvements

- 2nd Reverse LSTM
    - Improve upon the Windowing idea by using future samples to help decode samples in the past
- Windowed LSTM+Conv
    - Using Windowed LSTM and Convolutional Network together
    - Apply Convolution on the Windowed Sample to get temporal dependencies

Conclusion

- The neural network approaches have comparable accuracy to the LMS
- LSTM is comparable to LMS across all SNR with a drastic difference at low SNR
- Can now remove pilot symbols are increase the rate