NATIONAL TECHNICAL RESEARCH ORGANISATION (NTRO)

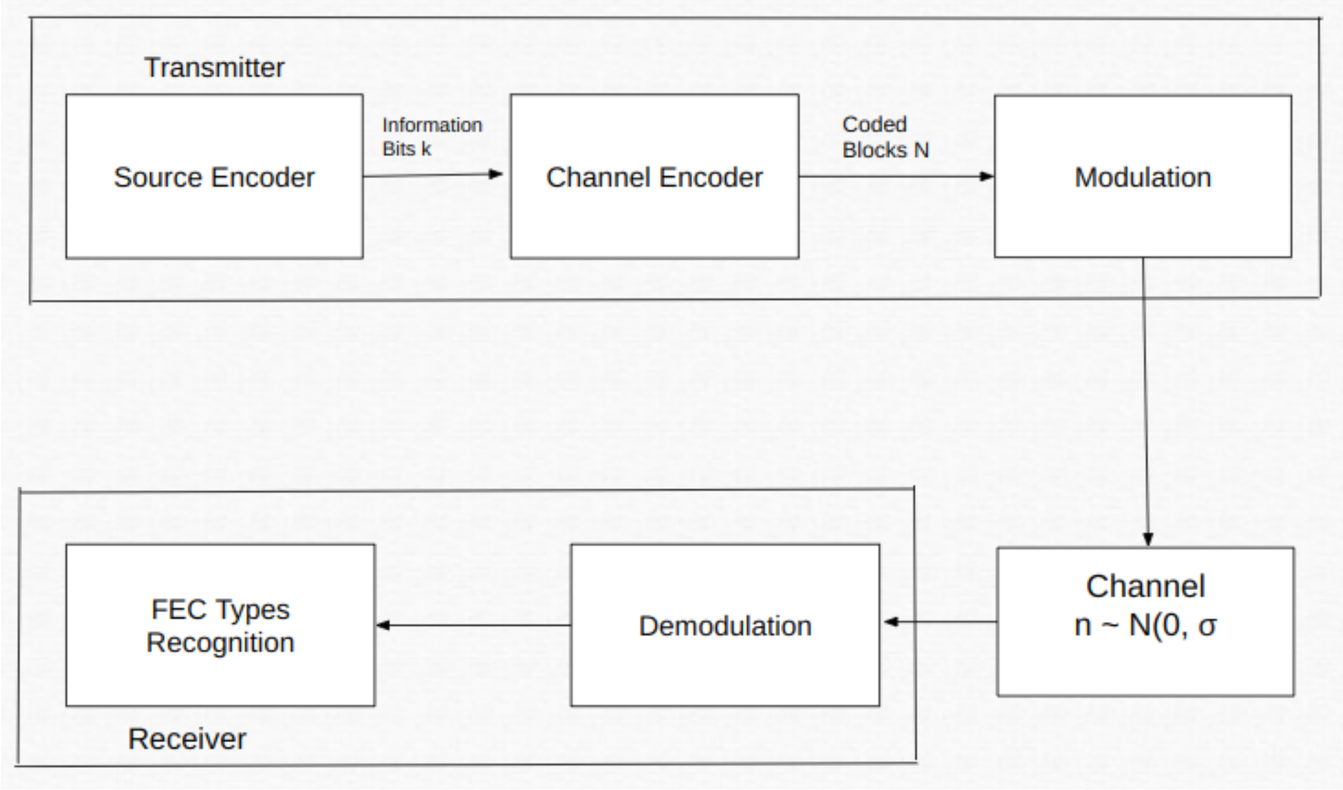
DAEMONS

SMART INDIA HACKATHON 2023

SIH1447: IDENTIFICATION AND EXTRACTION OF FORWARD ERROR CORRECTION (FEC) SCHEMES OF UNKNOWN DEMODULATED SIGNALS.

OBJECTIVE

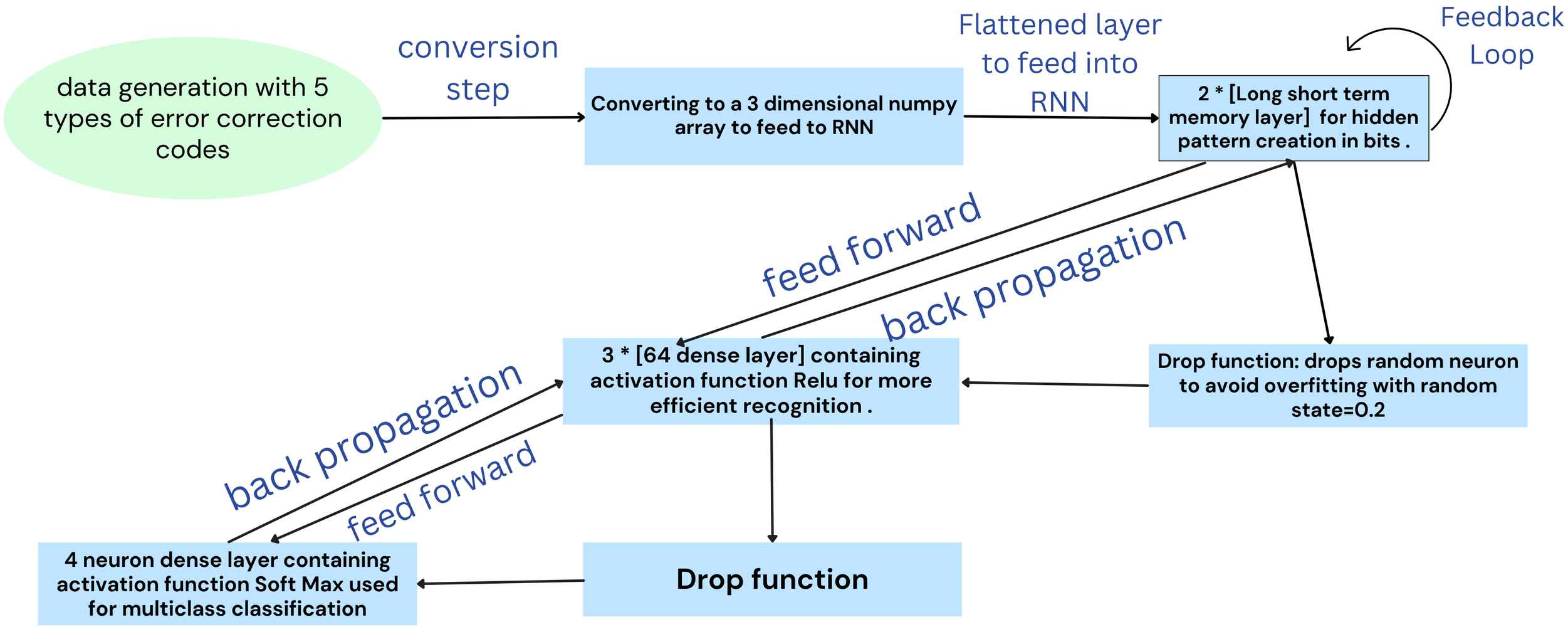
IDENTIFICATION AND EXTRACTION OF FORWARD ERROR CORRECTION (FEC) SCHEMES OF UNKNOWN DEMODULATED SIGNALS.



OUR APPROACH

- Generating surplus amount of satellite training data with different Forward error correction encoding using Python and Matlab.
- Training the Improved Recurrent Neural Network using the generated data.
- Testing on real-life satellite signals verifying our accuracy.
- Finding an ample way to implement it in satellite receivers.

EXPLANATION



DATA GENERATION STEPS

- Generating random bit strings of different sizes .
- Encoding with five different types of forward error correction schemes with varied code rates.
- Modulating encoded data using different modulation schemes.
- Adding additive white gaussian noise
- Demodulating noisy signals.

Encoding Techniques

- *The **Turbo-Product codes** consists of code rate R = 3/4 at variable block length.*
- ***BCH code** used is BCH(63, 56) as per TC Standard of Satcom.*
- ***LDPC codes** consists of variable block length at code rate R = 1/2, 1/3, 2/3 and 3/4.*
- ***Convolutional codes** uses Code Rates 3/4, n=4 and k=3 at variable block length.*
- ***Turbo Code** consists of code rate R = 1/2, 1/3 at variable block length.*

Consultative committee for space data systems (CCSDS) standard

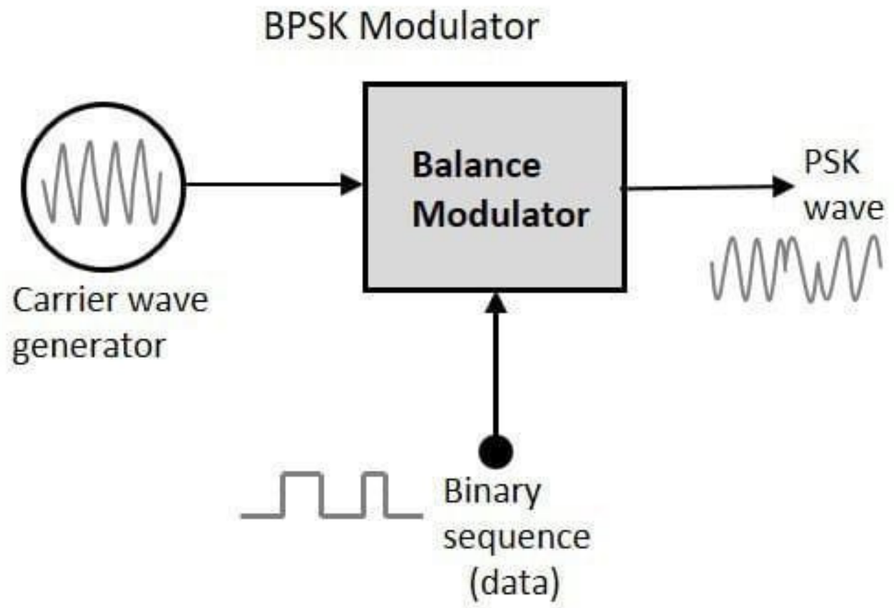
Modulation Techniques

- Binary Phase-shift keying (**B**PSK)
- 8 Phase-Shift Keying (**8-**PSK)
- 4 Phase-Shift Keying (**4**-PSK)

Binary Phase-shift keying (BPSK)

- The carrier undergoes two phase reversal 0 and 180. In PSK, the digital bit sequence is converted to NRZ bipolar signal which modulates the carrier wave.

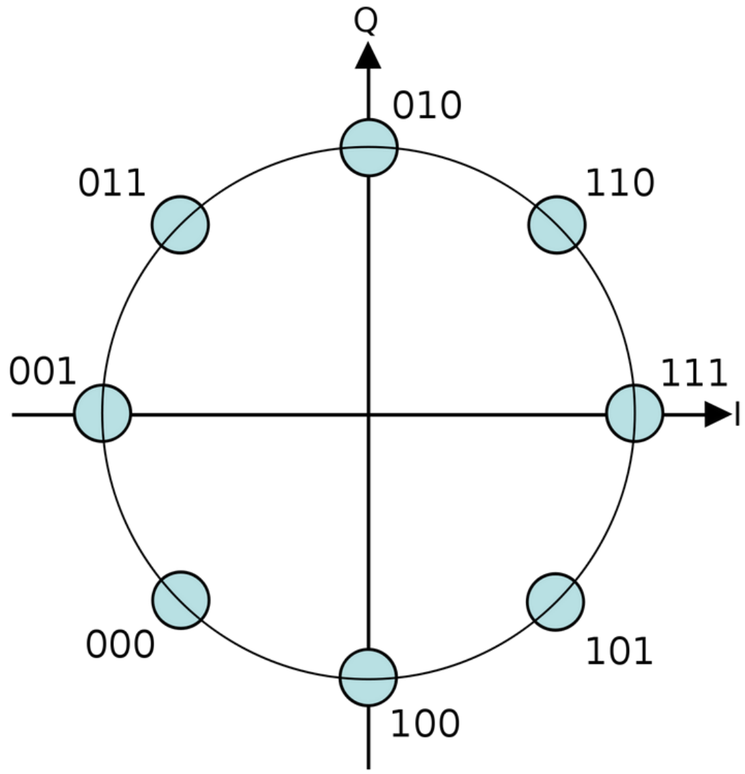
- BPSK holds significance in communication system like Wi-Fi, Bluetooth and satellite communication.



8 Phase-shift keying (8PSK)

- 8-Phase Shift Keying (8-PSK) optimizes data transmission by using eight phases to represent three bits per shift, resulting in higher throughput compared to binary PSK's one-bit-per-shift approach.

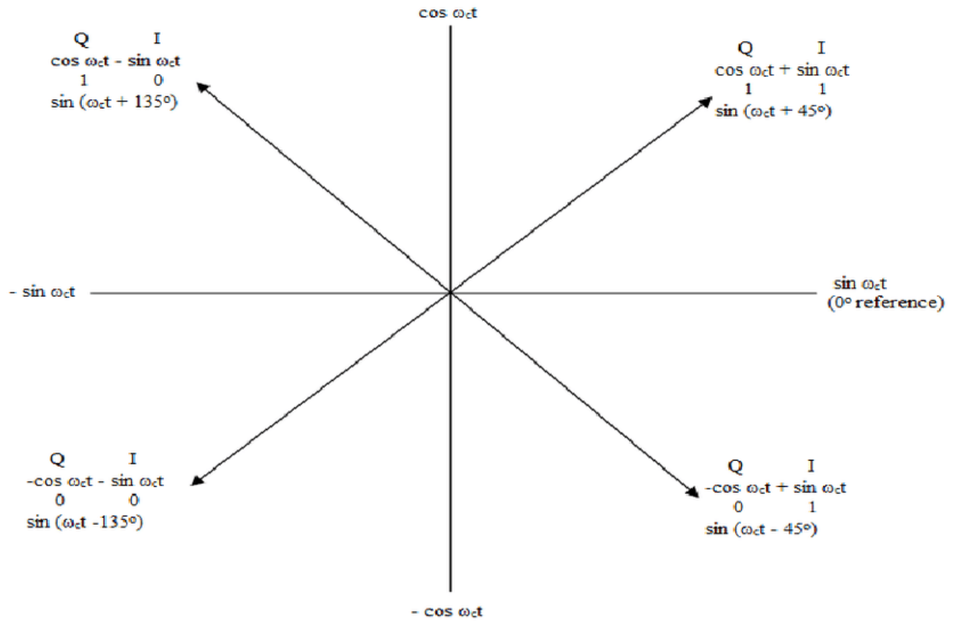
- 8-Phase Shift Keying (8-PSK) is vital for Wi-Fi, Bluetooth, and satellite communication, ensuring reliable data transmission in various applications.



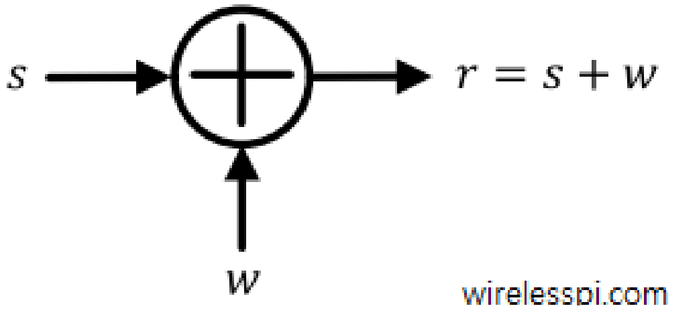
4 Phase-shift keying (4PSK)

- Quadrature Phase Shift Keying (QPSK) modulates two bits simultaneously, choosing from four carrier phase shifts (0, 90, 180, or 270 degrees). This enables the transmission of twice the information in the same bandwidth as ordinary PSK.

- QPSK finds application in satellite transmission of MPEG2 video, cable modems, videoconferencing, cellular phone systems, and various digital communication forms over an RF carrier.



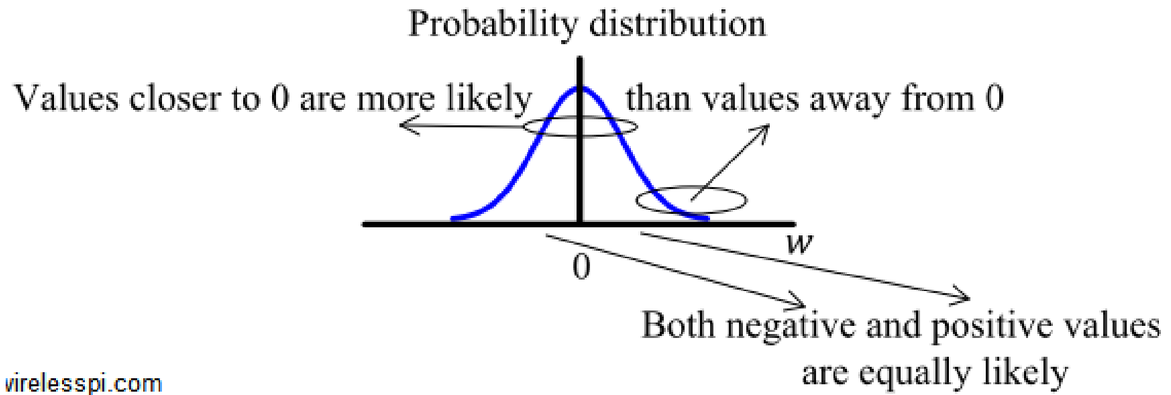
Additive White Gaussian Noise(AWGN)



- [Additive] The noise is additive, meaning the received signal equals the transmitted signal plus noise. This equation is fundamental in communication systems: \(r(t) = s(t) + w(t) \).

- [White] Similar to white light composed of all visible frequencies, white noise exhibits uniform power across the entire frequency band.

- [Gaussian] The noise samples follow a Gaussian probability distribution with a zero mean. In the time domain, samples can take both positive and negative values, with values near zero having a higher likelihood of occurrence compared to values far from zero.



ARCHITECTURE

- Three Layered Architecture:
  - Long Short-Term Memory (128 nodes)
    -- Bidirectional(2*(128 nodes) layers back to back)
  - Dense Layer (64 nodes) -- Dense(3*(64 nodes) layers back to back)
    -- Activation function ReLu
  - Dense Layer (4 nodes) -- Output Layer.
    -- Activation function SoftMax

- Optimizer: Adam optimizer (lr = 0.002(variable WRT minima selection(using ReduceLROnPlateau))).
- Loss function - Sparse Categorical Cross-entropy.
- Batch Size = 200/133/120(variable batch size are used for best efficiency)
- EPOCH = 50

Sigmoid Function used in our RNN

$$a_h^t = \sum_{i=1}^{I} w_{ih} x_i^t + \sum_{i=1}^{I} w_{h'h} b_{h'}^{t-1}$$

$$b_h^t = \theta_h(a_h^t)$$

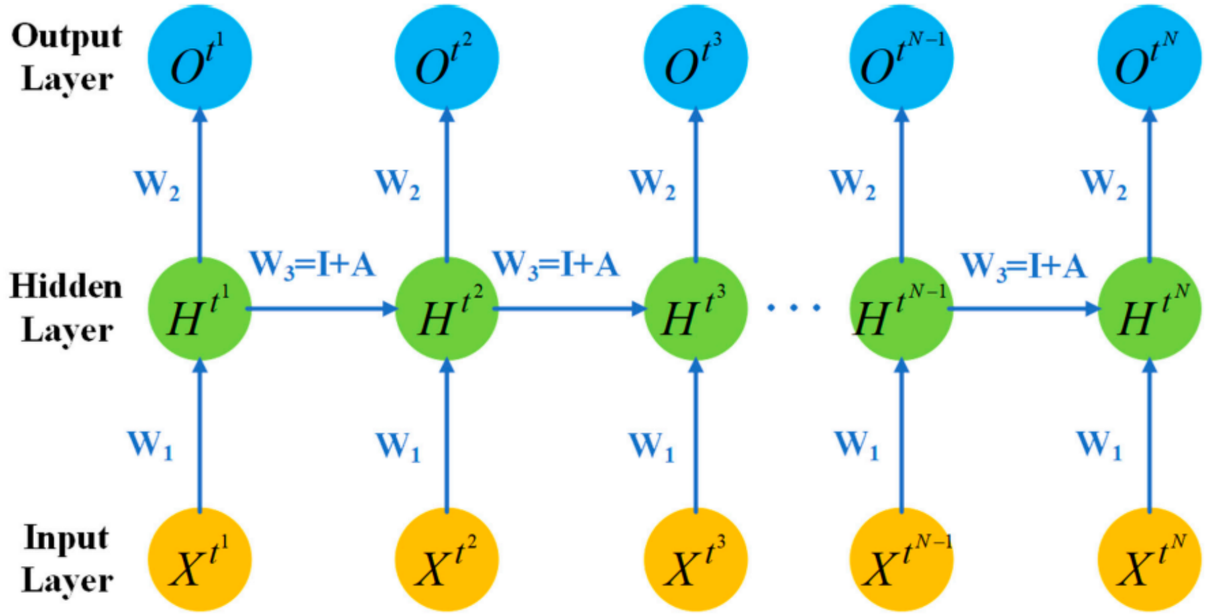
$$a_k^t = \sum_{i=1}^{H} w_{hk} b_h^t$$

- wi is forward forward-weighted parameter.
- wh is the feedback loop parameter.
- bh is the bias.

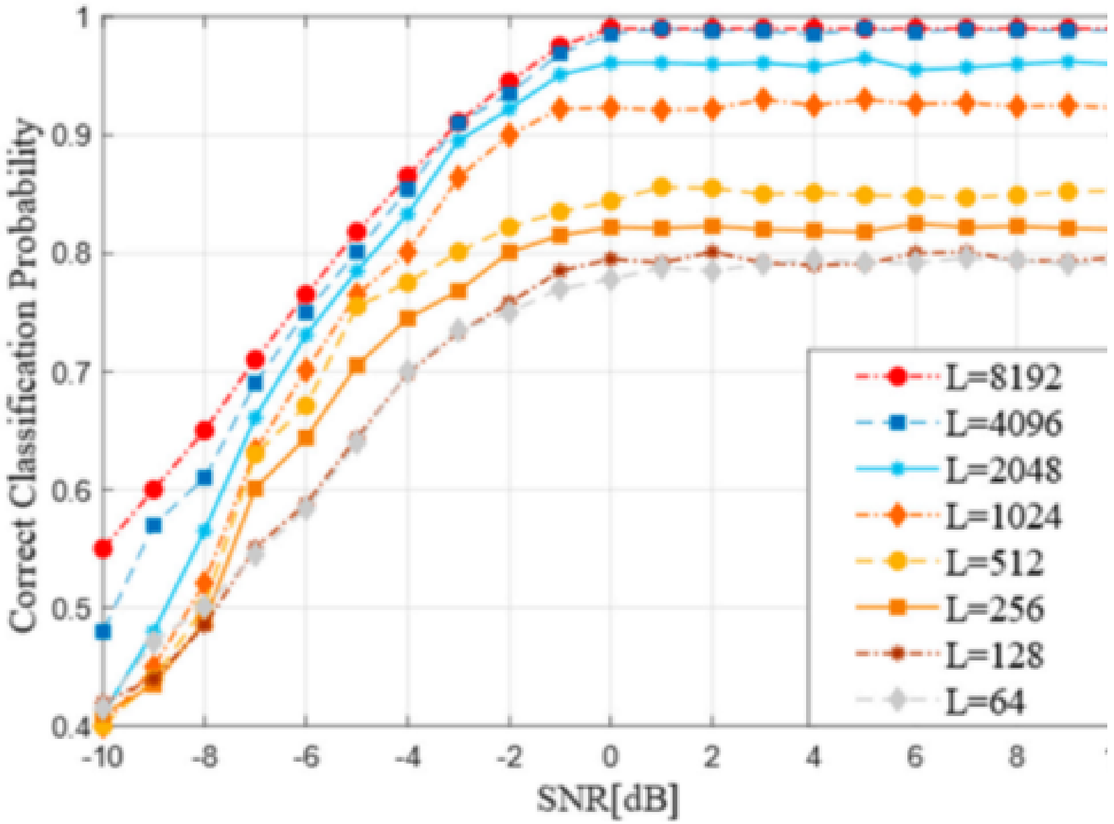
- X represents the input of Simple RNN at different time steps.

- H represents the state of the hidden layer at different time steps and O represents the state of the output layer of network at different timeline.

- For different time steps, the weight from the input layer to the hidden layer obtains W1 , the weight from the hidden layer to the output layer is always W2 and the weight of the self-connecting of the hidden layer is always W3.



- In low signal-to-noise conditions, recognition accuracy remains consistently low, irrespective of sample length, posing challenges for codeword recognition requirements.
- As signal-to-noise ratio (SNR) increases, network recognition accuracy significantly improves. With increasing input length, there is an approximately 4% boost in average accuracy.
- At sample lengths L = 4096, little difference in accuracy is observed, and the overall accuracy stabilizes at 0.99.



Differentiating points of our Approach

- Intelligent FEC detection scheme integration with
- We can detect the digital signals varying from length 64 bits.
- Can correct noise in bits
- Any kind of file can be sent
- Can be integrated with existing systems with nominal ov
- Highly scalable
- Training on different code rates.

PERKS

- 97+ percent accuracy(BPSK).
- 73+ percent accuracy(QPSK)
- 72+ percent accuracy(8PSK)

- Real-Time Recognition.
- Customizable backend.
- Optimized for embedded devices.
- Supports file as well as manual text input.
- Supports real time detection on stream of data.

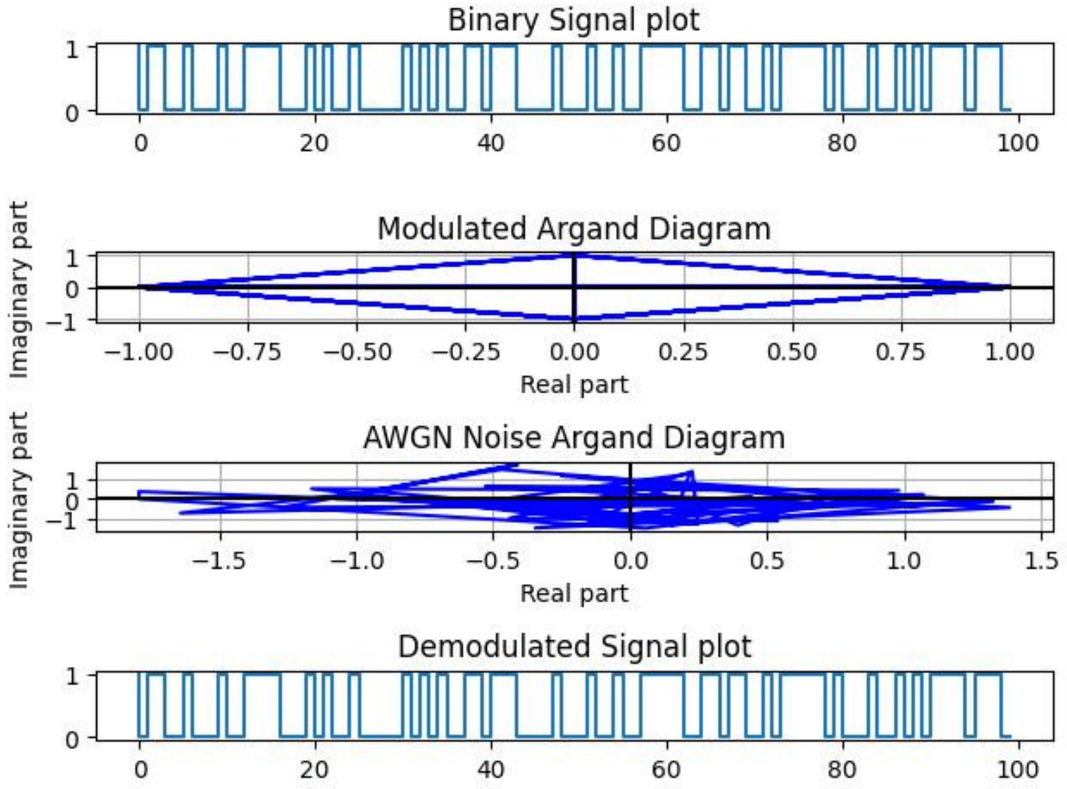
Open Source Signals

Applicable on:

- Audio
- Image
- Video

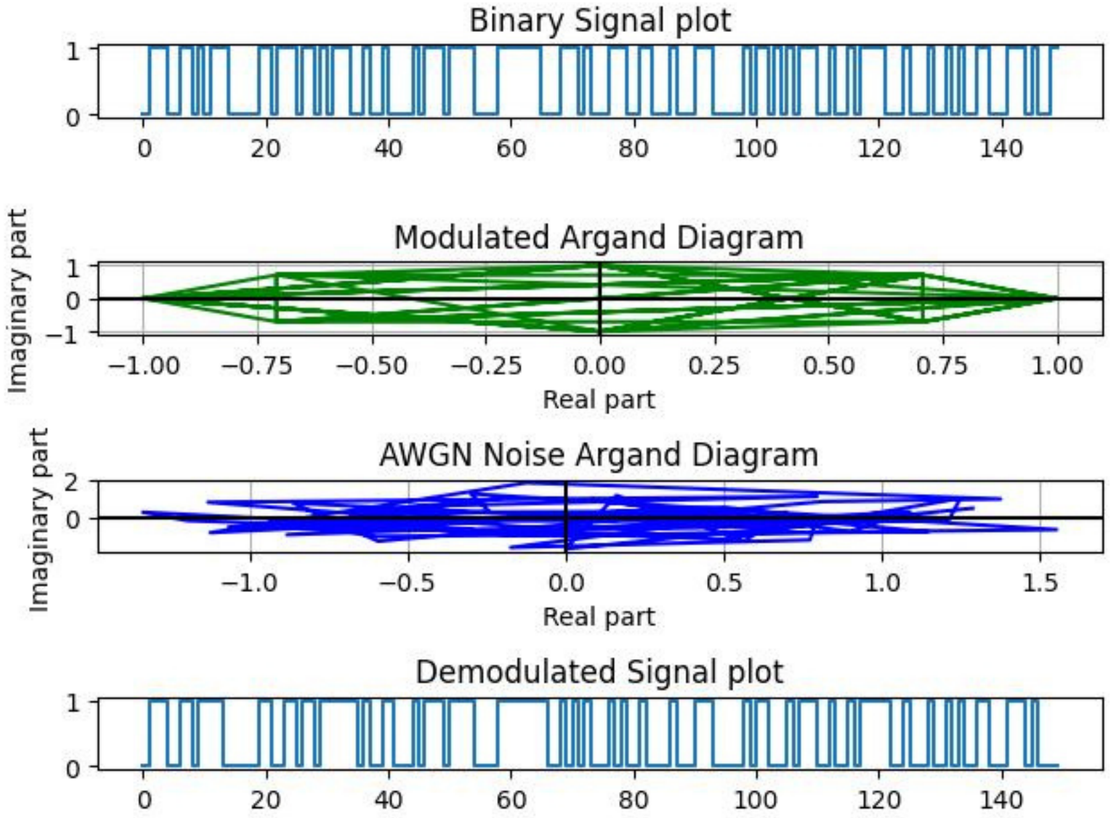
Visualisation

LDPC encoded string length 100, 4 PSK



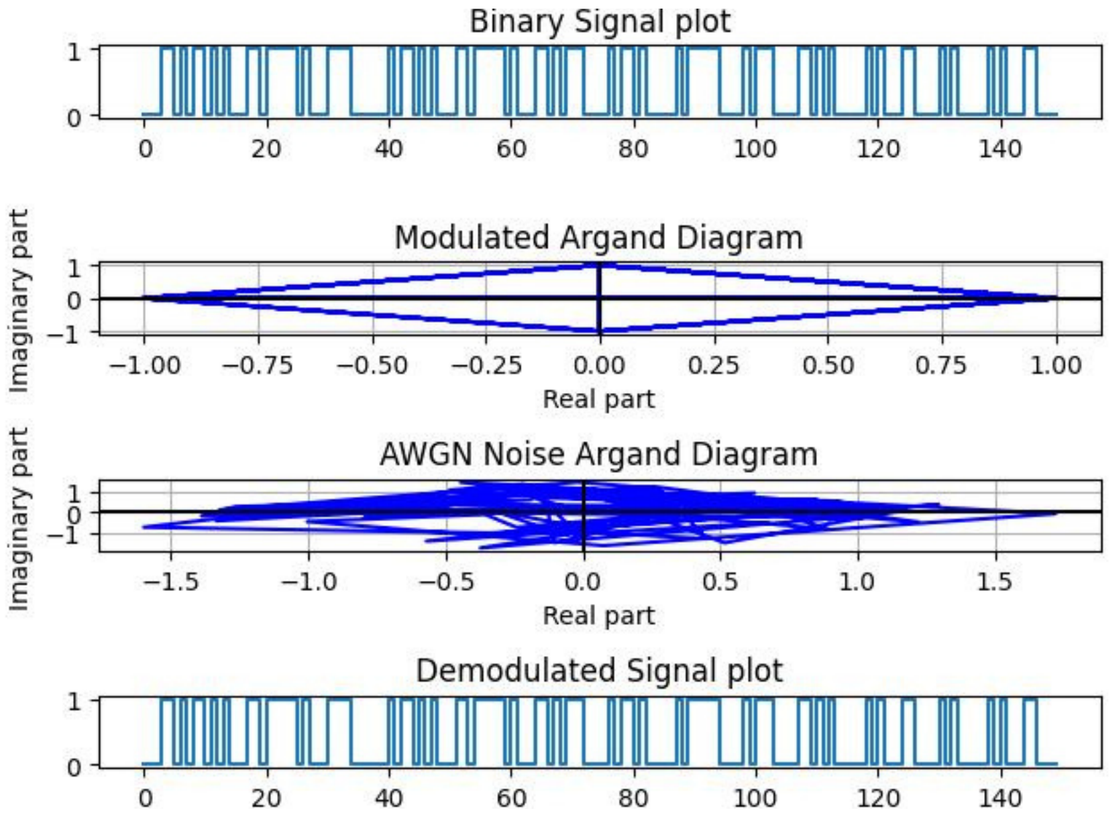
Visualisation

LDPC encoded string length 2048, 8 PSK



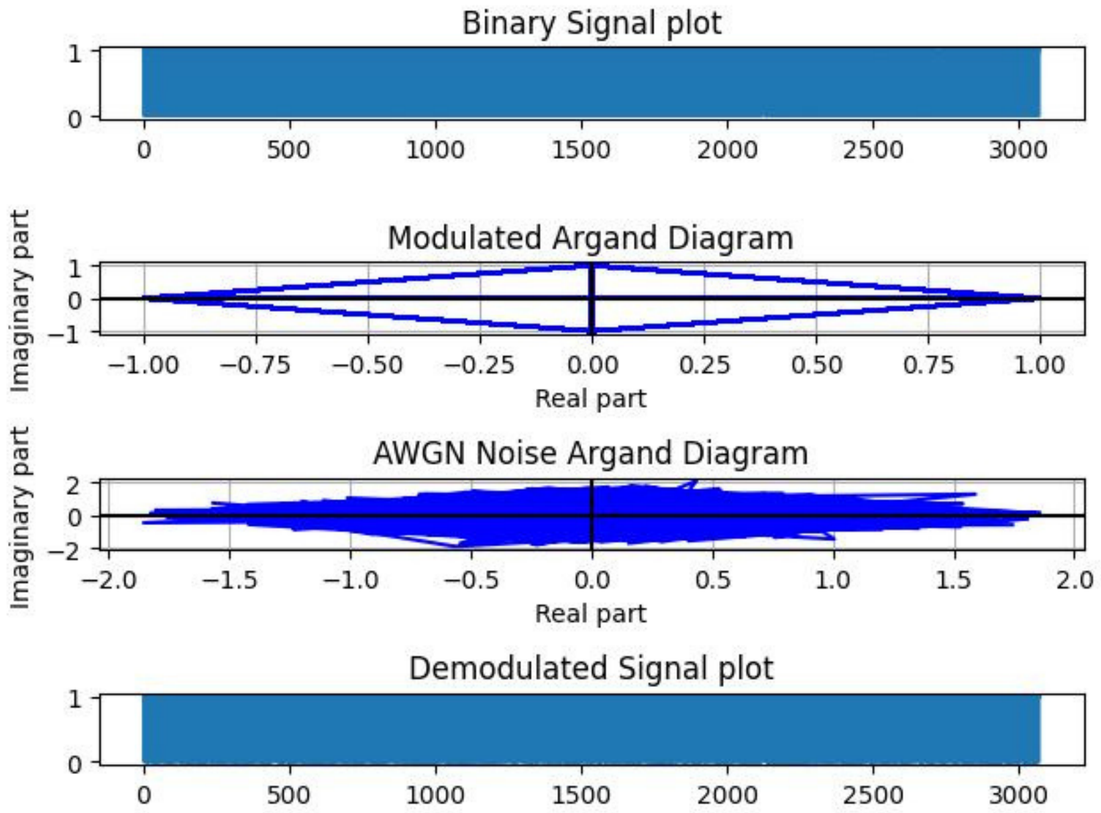
Visualisation

Turbo encoded string length 100, 4 PSK



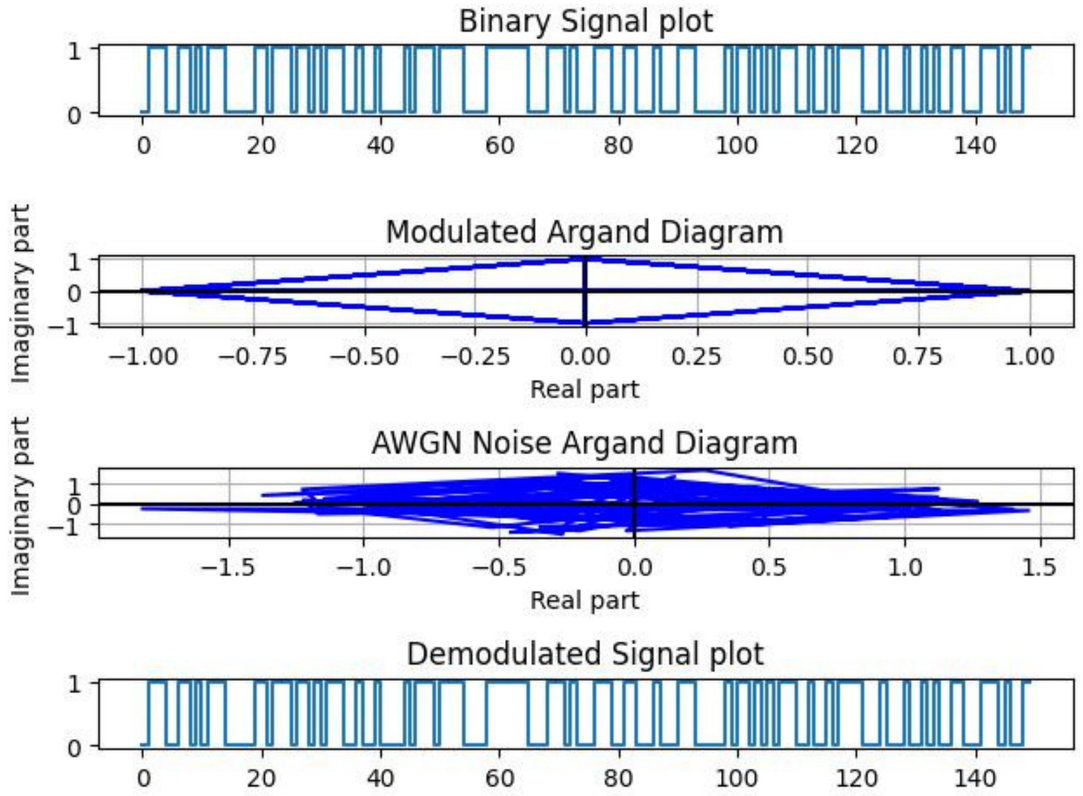
Visualisation

Turbo encoded string length 2048, 4 PSK



Visualisation

Convolutional encoded string length 2048, 4 PSK



GUI Implementation

REAL LIFE APPLICATIONS

- Signal Intelligence
- Satellite Communications
- Wireless Communication Monitoring

Future Scope

- SIGINT can be made portable by leveraging Software Defined Radios (SDRs) like LimeSDR and USRPs, with the added advantage of FPGA implementation for enhanced flexibility and portability.

Citations for Libraries

- Libraries used on Python: Sionna, scikit-commpy, galois, Numpy and Pandas

- Communication Toolbox on MATLAB

References

Mei F, Chen H, Lei Y. Blind Recognition of Forward Error Correction Codes Based on Recurrent Neural Network. Sensors (Basel). 2021 Jun 4;21(11):3884. doi: 10.3390/s21113884. PMID: 34199837; PMCID: PMC8200067.

Radu, F.; Cotfas, P.A.; Alexandru, M.; Bălan, T.C.; Popescu, V.; Cotfas, D.T. Signals Intelligence System with Software-Defined Radio. Appl. Sci. 2023, 13, 5199. https://doi.org/10.3390/app13085199

THANK YOU!