Spectral Sensing

April 30, 2024

Concepts: CR – SDR – SS

- *Cognitive Radio*: intelligent processing and flow controlling of wireless communication for effective use of radio resources, and to enable the coexistence between primary and secondary users (cognitive users).
- *Software Defined Radio* is "**a radio in which some or all of the physical-layer functions are software defined**". Therefore, SDR replaces traditional hardware components with software algorithms, providing enhanced flexibility and adaptability in radio systems.

  SDR allows to experiment and develop prototypes and solutions for CR implementation.
- *Spectrum Sensing* is the process of gaining an understanding of the state of channel occupancy and identifying the existence of spectrum holes in a geographical area before a transmission is initiated.

  Theoretically, the spectrum sensing problem is defined as a hypotheses test based on the presence of the primary user signal:
  - H_o: No primary user signal is present (absence)
  - H_1: primary user signal is present (presence)

Spectral Sensing

- ✓ Signal Detection
- ✓ Signal Classification
- ✓ Channel-State Estimation
- ✓ Decision Making
- ✓ Monitoring and System Management

Signal Detection

- Data Collection and Assembly:
  - Signal Reception Arrangement
  - Sampling and ADC Conversion
  - Data Storage
- Signal Conditioning
  - Data cleaning and anomaly detection
  - Narrowband Filtering and demodulation
  - Wideband Signal Decimation

→ Hardware Framework

- Energy calculation
  - Power Estimation and frequency scanning
  - Noise (SNR) Estimation
  - Thresholding

→ Machine-Learning Framework

Literature:

1. Spectrum Sensing Using Software Defined Radio for Cognitive Radio Networks: A Survey •
2. Spectrum sensing in cognitive radio: A deep learning based model •
3. A review of spectrum sensing in modern cognitive radio networks •

Data Collection and Assembly

- Enhanced signal reception
  - Diversity Antennas for reducing the impact of fading and shadowing: spatial diversity (using multiple antennas at different locations), polarization diversity (utilizing antennas with different polarization orientations), frequency diversity, and pattern diversity (employing antennas with different radiation patterns).

    multi-antenna receiver based on the maximum-likelihood (ML) criterion •

    Spectrum Sensing Scheme for a Multi-Antenna Receiver •
  - Enhanced Detection Sensitivity: By combining signals from multiple antennas, diversity combining techniques such as selection diversity, maximal ratio combining (MRC), or equal gain combining (EGC) can be employed to improve the detection sensitivity of spectrum sensing.
  - Multisensor Sensor Synchronization. Implementing diversity antennas adds complexity to the cognitive radio system, including hardware requirements and signal processing algorithms.

- Sampling and ADC conversion
  - Narrowband sampling:
    - Nyquist-based, wavelet-based,
    - Oversampling with enhanced resolution
  - Wideband sampling:
    - Compressive sampling (decimation), multicoset sampling
    - Data Compression and Undersampling to feed NN estimators: sigma-delta modulation

- Data Storage
  - Real-time analysis
  - Off-line training and validation
  - Data Retention Policies dictated by regulatory requirements, operational needs, or privacy considerations.
  - Data anonymization or encryption to protect sensitive information and ensure compliance with privacy regulations.
  - Data storage infrastructure for spectrum sensing applications may include local storage on cognitive radio devices, networked storage systems, or cloud-based storage solutions.

Signal Conditioning

- Narrow-band Filtering and demodulation
  - Narrow-band band pass and adaptive filtering to isolate specific signals or frequency bands of interest while suppressing noise and interference, improving the signal-to-noise ratio (SNR) of the desired signals.
  - Demodulation involves extracting the original information carried by modulated signals, such as voice, data, or multimedia content.
- Wideband Signal Decimation
  - Channelization, filter banks, and multichannel sensing
  - Software-defined filters: Filtering implementation on software-defined radio (SDR) platforms (processing power, flexibility, cost, and power consumption).

Energy Calculation

- Narrowband Estimation
  - Energy Detection (L_2-based estimation) and Entropy-based detection

    Energy detection-based spectrum sensing machine •
  - Shape signal Detection : correlation, cyclostationarity, covariance, waveform-based
  - Matched Filter (L_2-based filtering)
  - Matrix decomposition-based (eigenvalue detection)

    Maximizing Eigenvalue Using Machine Learning •

    FlashFFTConv •

    Energy detection under noise power •

    Multiscale Wavelet Transform Extremum Detection With the Spectrum Energy Detection •

    Exploring Deep Learning for Adaptive Energy Detection Threshold Determination: A Multistage Approach •
- Wideband Estimation
  - Nyquist-based. Wavelet-based,
  - Filter-bank, and Multiple narrow bands
- SDR implementation: Trade-offs between performance parameters (including cost, power consumption, and size) evaluated based on the specific requirements and constraints of the cognitive radio system.

  Practical Implementation of Adaptive Threshold Energy Detection using Software Defined Radio • Evaluating the practical performance of energy detector based spectrum sensing for cognitive radio • Deep Learning for Adaptive Energy Detection Threshold •

Hardware Framework

Narrowband Frequency Scanning

- spectrum-analyzer • •
- Simple AM and NFM scanner with multiple equally spaced channels •

  Frequency Monitoring Interface Design and System using HackRF •
- rtlsdr-scanner, software defined radio frequency scanner que utiliza un chip Realtek RTL2832u para convertir las señales de radio analógicas en señales digitales ✓ • • •
- Radio Frequency Detailed Scan from 240 to 960 MHz •
- Raspberry Radio Scanner •

Wideband Scanning

- Detailed Bluetooth LE Scanner with Python •
- IoT-Scan: Network Reconnaissance for the Internet of Things •

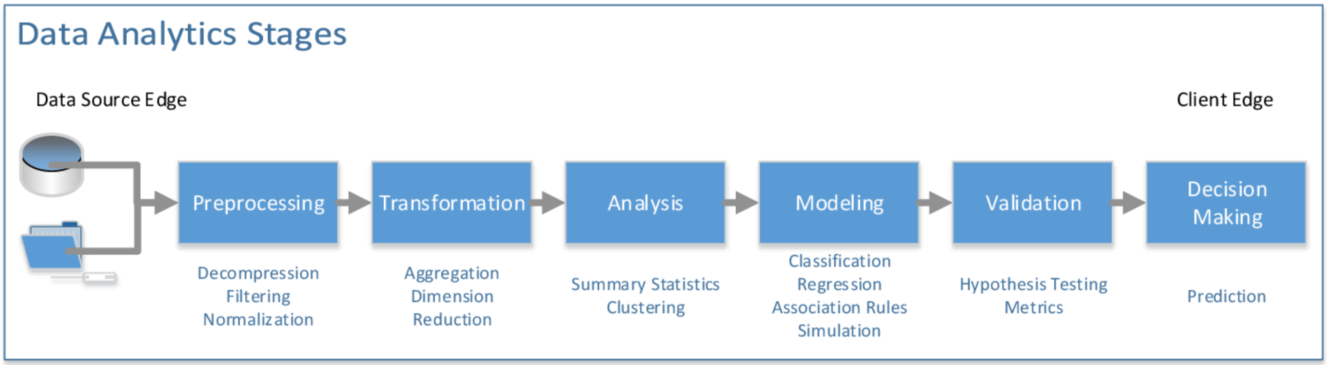
  Snout: A Middleware Platform for Software-Defined Radios •

  LoRadar: An Efficient LoRa Channel Occupancy Acquirer based on Cross-channel Scanning •
- PytonDAQ •
- Radio Frequency Density Sensor to count mobile devices within a range •

  For analyzing the transmission protocols •
- Real-time Decoding of Satellite Signals •
- identification of open and closed channels •
- Drone Detection and Defense Systems: Survey and a Software-Defined Radio-Based Solution •

Machine Learning Framework

The *Data Analytic Pipeline* automates machine learning workflows by processing and integrating data sets into a model to be evaluated and delivered, providing flexibility, efficiency, and better management in the framework implementation.



Main Architecture

- *Data Collection & Assembly*

  Acquisition, down/sampling, storage, and preparation of sample sets holding primary information about the inferring task under modeling.

- *Data Preprocessing*

  Inconsistent data is cleaning, transformed or encoded to be adequately parsed and fed into the compilation chain at a real computation burden.

- *Model Building / Training*

  Selection/design of an appropriate machine learning algorithm for model training that specifies how to infer patterns in data.

- *Model Evaluation*

  The models are trained and tested on sample data sets to make predictions and choose the best-performing model.

- *Model Deployment*

  The machine learning model is deployed to the production line to obtain predictions based on real-time data.

Data Preprocessing:

– Formatting and Cleaning Data

– Data Augmentation and Stratification

– Feature Engineering and Data Transformation:

[✓]*Formatting Data*

- Data Visualization●
- Anomaly Detection:
- Missing Values and Imputation
- Statistical test on data
- Data Augmentation and Stratification

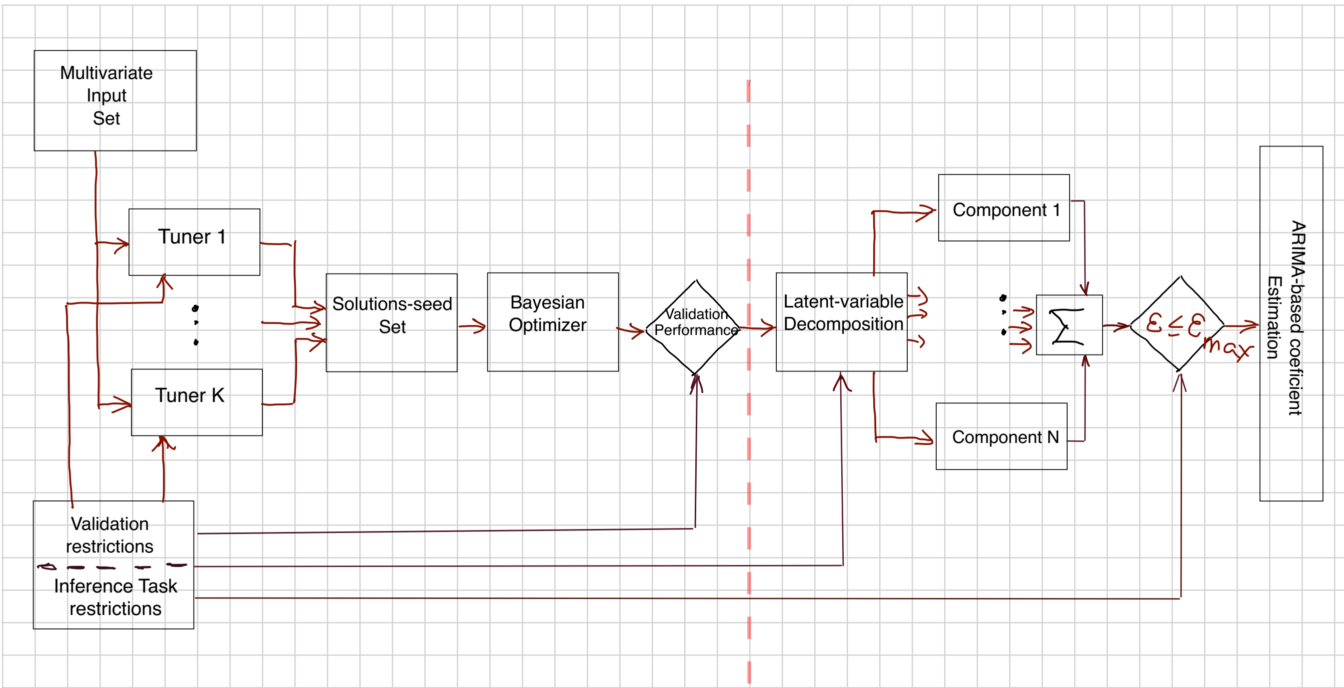
[✓]*Feature Engineering and Data Transformation*

- Time Series Transformation and Feature Selection:
- Latent Variable Decomposition

Model Building/Training:

[✓] *DL Model Design*

- *Task*: Scanning of VHF frequencies
- *Inference*: Prediction of power spectral density



DL Model Architecture

- *Multivariate Input Data*: raw time-series recordings captured after IF mixer sampled at 22 *Msps*
- *Validation requirements*:

  strategy

  sequencing
- *NN models*:

  MLP ?

  LSTM ?

  VAE ?
- *NN Model Optimization*:

  Time-series Dense Encoder ●●

  RandomSearch Optimizacion Space:

  ? Optimizacion Space:

  BayesianOpt Optimizacion Space: