Machine-learning-based spectrum sensing enhancement for software-defined radio applications

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Who we are

- Capgemini engineering: 270,000 experts worldwide A strong international presence in nearly 50 countries
- 8 research programs in France:

Future of mobility

Future of energy

Future of healthcare

Applied AI

Future of industry

Future of engineering

Future of networks & compute

Future of People@Work

Our activities

- Aeronautical Cognitive Transceiver (**ACT**) is a project attached to **Future of networks & compute program.**
- The ACT project aims to find the best digital radio architectures for optimal use of frequency bands.
    - 2 R&D lead engineers:

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Main concepts:

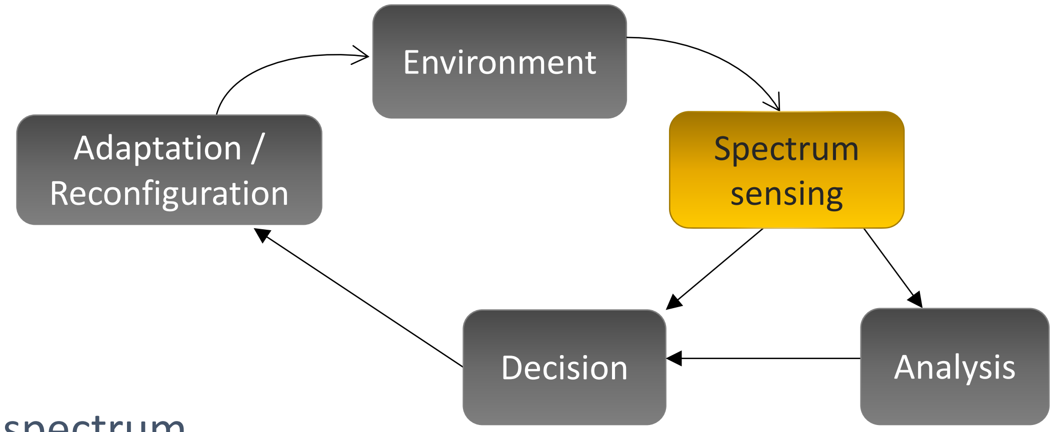
- **Software-Defined Radio (SDR):**

Complex analog system design has been replaced by simpler software and signal processing algorithms.
SDR propose: lightweight, compact, multipurpose & flexible wireless systems.

- **Cognitive Radio (CR):**

Thanks to the flexibility of SDR systems, CR technology enables intelligent wireless communication systems.
CR is capable of:

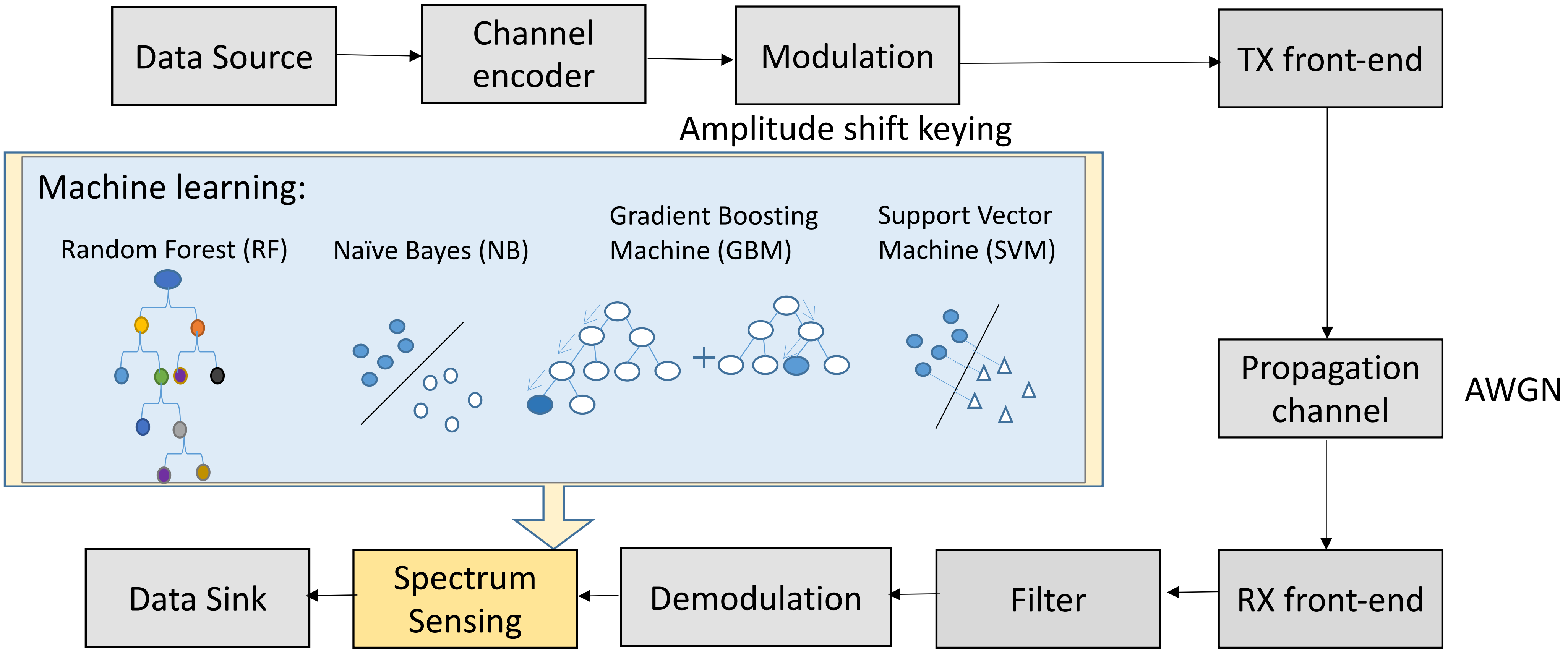
  - monitoring its environment
  - analyzing what it senses
  - deciding on the information obtained
  - adapting the system to its environment



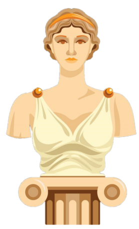
- **Spectrum Sensing (SS)**

The CR purpose in our case is to manage the frequency spectrum.
The first step is to sense the available spectrum.

Machine Learning algorithms:



How to model a system with SS?



- An environment with several primary users (PU) is considered,
- Only one secondary user (SU) is in this environment,
- The PUs randomly walk in the environment,
- The SU observes the environment to detect the absence of a PU to occupy the available spectrum,
- The SU must not disturb the PUs.
- Two hypotheses should be considered in this case:

$$\mathcal{H}_0: x[n] = w[n]$$ PU not detected

$$\mathcal{H}_1: x[n] = s[n] + w[n]$$ PU detected

PU signal

additive white Gaussian noise (AWGN) with the distribution N(0,σ^2).

How to evaluate the system performance?

Two model system hypotheses lead us to 4 different possibilities:

We could not detect any signal because it is not there!

True Negative (TN)

We could not detect any signal, however it is there!

False Negative (FN)

We detect a signal because there is a signal here!

True Positive (TP)

We detect a signal but there is a problem!

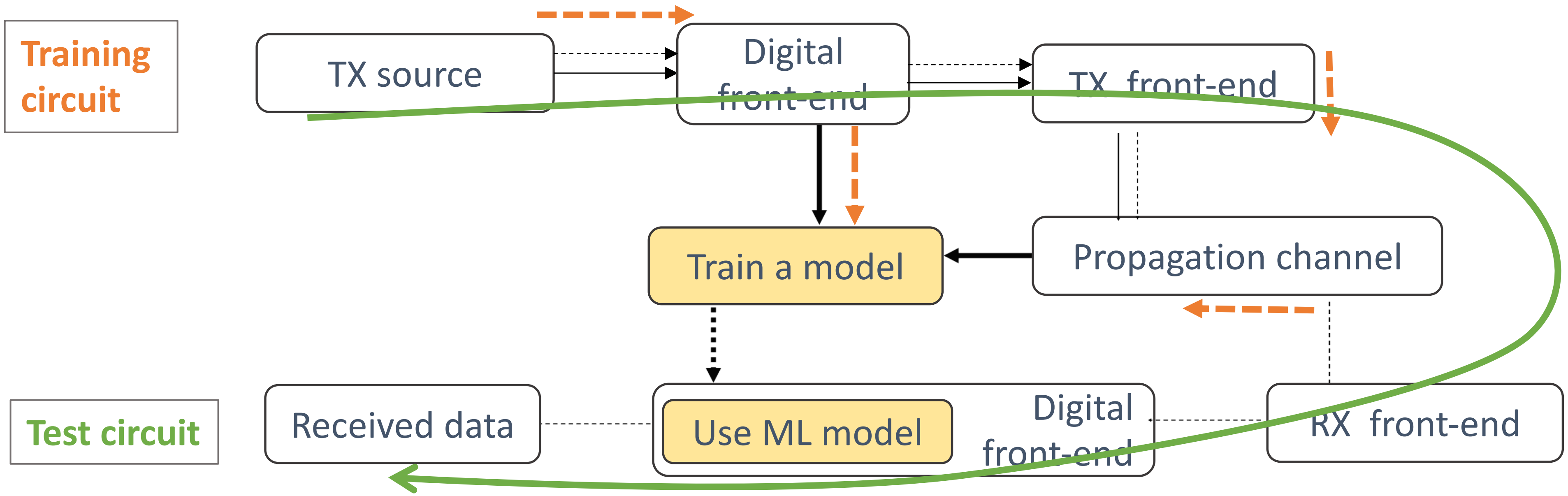
False Positive (FP)

Evaluation metric for binary classification problems:

- Receiver Operating Characteristic (ROC) curve: TP vs FP
- Area under ROC curve (AUC)

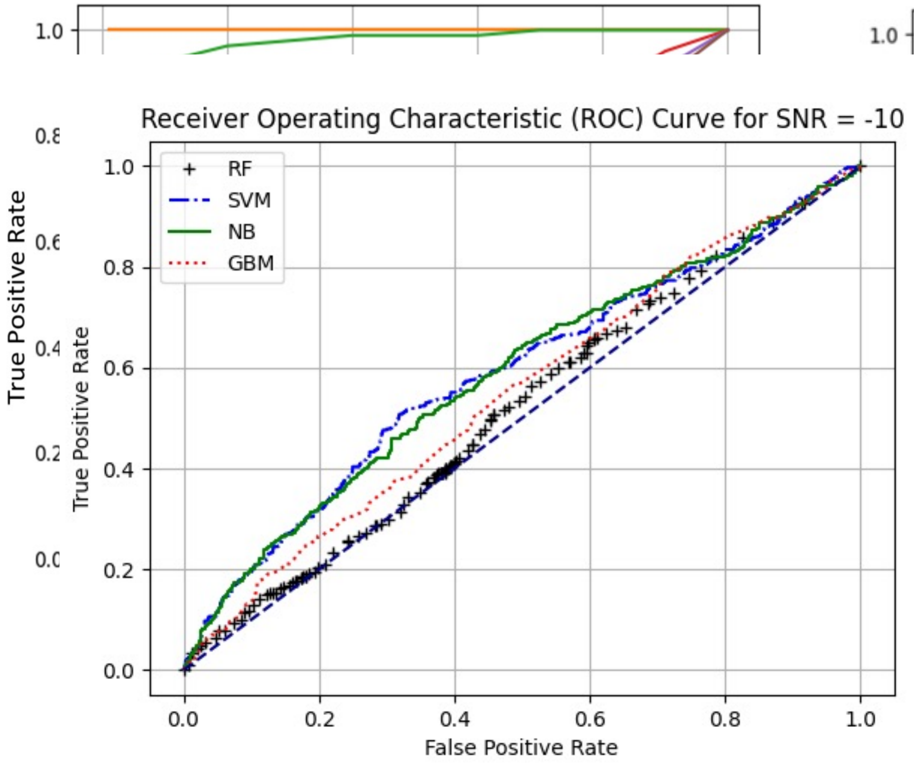
Proposed framework:

- Use the entire transmission chain to train the ML algorithms,
- The ML algorithms are trained to sense the available spectrum,
- Use the trained ML algorithms for new data test,
- The proposed system is able to remove the channel effect.

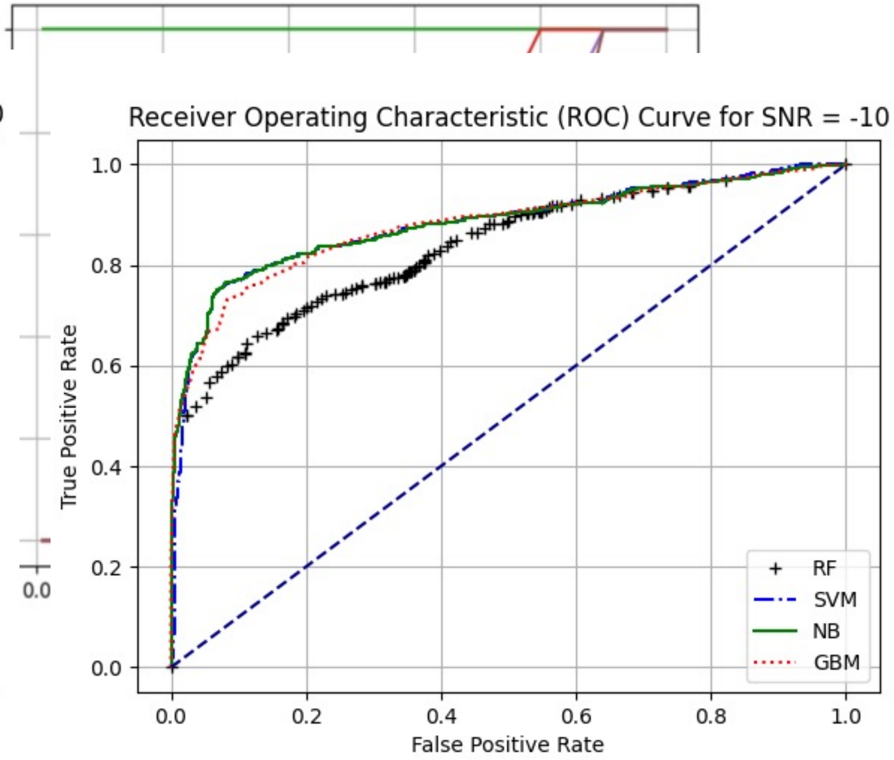


Simulation results:

- Classic criterion: Neyman-Pearson detector
- ML algorithms



Without filtering



With filtering

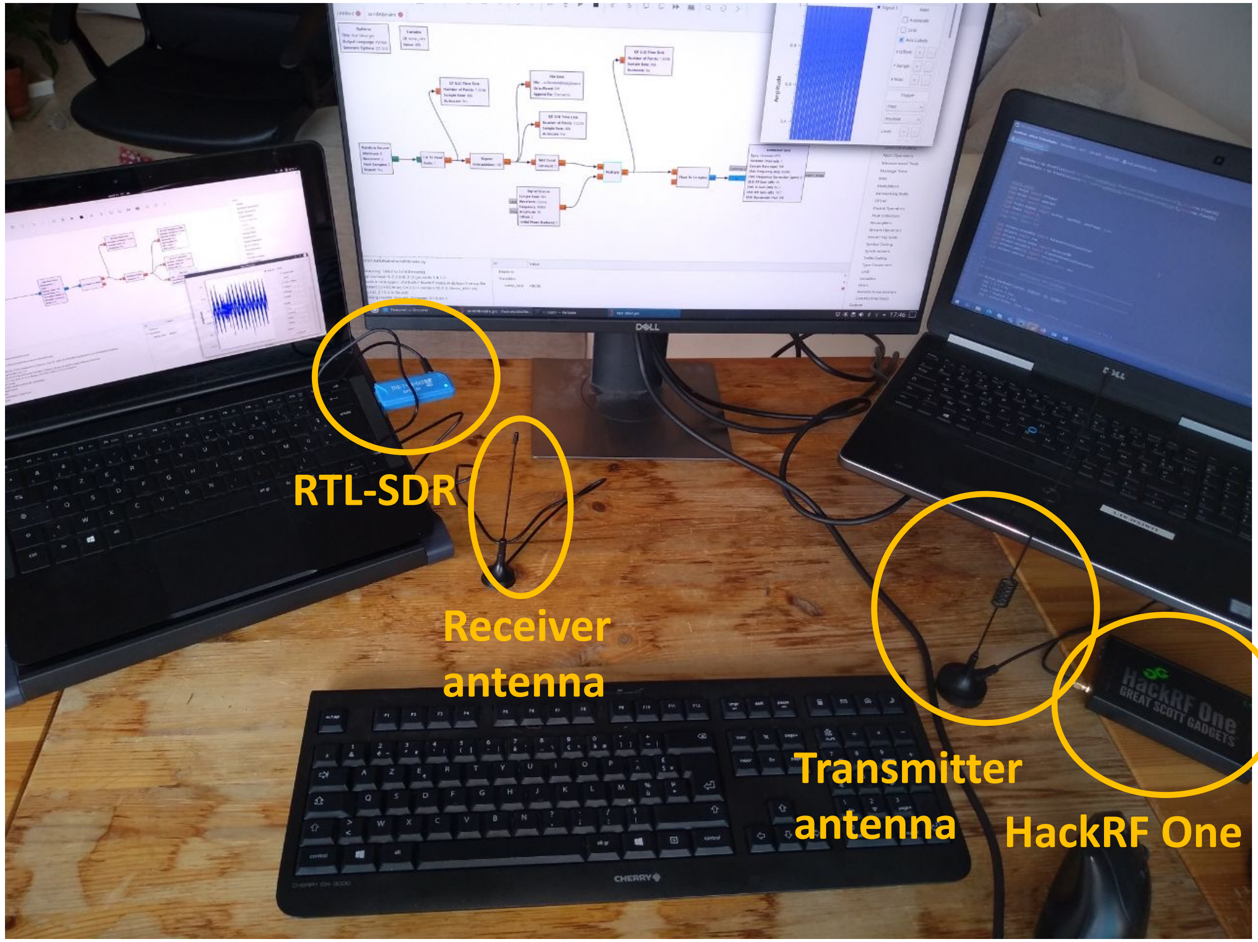
Simulation results:

AUC for simulation results:

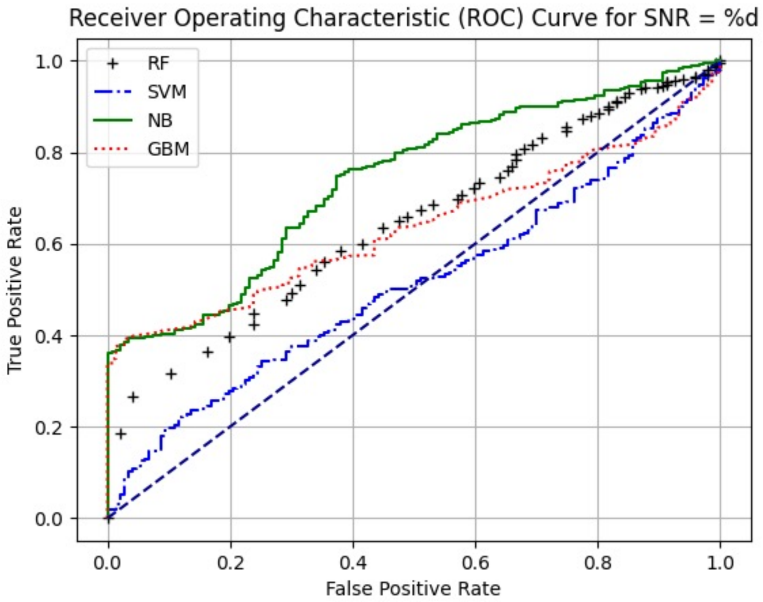
0.5 → no discrimination
0.7 to 0.8 → acceptable
0.8 to 0.9 → excellent
more than 0.9 → outstanding

		Before filtering					After filtering				
	SNR (dB)	-20	-10	0	10	15	-20	-10	0	10	15
Machine learning algorithm	Random forest classifier	0.48	0.51	0.70	0.89	0.87	0.46	0.80	0.88	0.93	0.93
	Naïve Bayes	0.49	0.56	0.74	0.92	0.93	0.72	0.89	0.91	0.96	0.97
	Support vector machine	0.50	0.64	0.75	0.93	0.93	0.71	0.89	0.91	0.96	0.97
	Gradient boosting machine	0.49	0.51	0.73	0.91	0.89	0.69	0.86	0.90	0.95	0.94

Practical results:



ROC curve:



Area under ROC curve:

Random forest classifier	Naïve Bayes	Support vector machine	Gradient boosting machine
0.64	0.74	0.51	0.64

Conclusions / Perspectives

- From the simulation results: all the algorithms have a better performance than the Neyman-Pearson classic detection method.
- The ML algorithms are able to consider the filter and channel effects in spectrum sensing.
- Naïve Bayes and SVM obtained more accurate results than GBM and random forest.
- In practice naïve Bayes is identified as the most suitable algorithm between the four studied ML algorithms.
- More complicated system combinations should be evaluated by the ML algorithms.
- More precise results can be obtained by expanding the scope of research to the cooperative signal detection.

Thanks for your attention!