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# On the Application of Machine Learning/Deep Learning in Spectrum Sharing

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# Spectrum Sharing

The spectrum sharing paradigm has been proposed to improve the efficiency in spectrum utilization.

Spectrum sharing is an approach where the radio resources can be re-used by multiple users/technologies/applications to optimize the trade-off between limited spectrum resources and traffic demands.

Spectrum mobility

Spectrum sensing

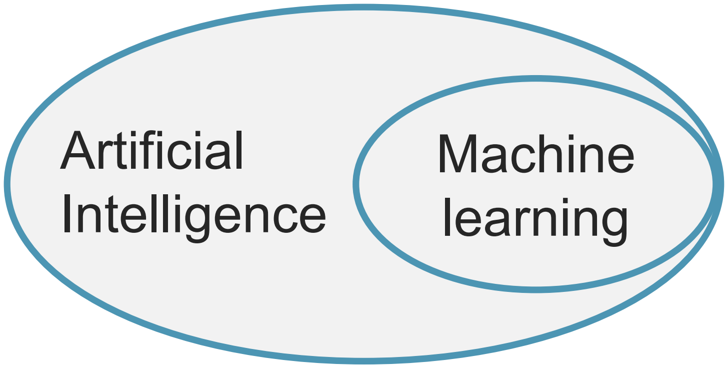
Spectrum sharing functions

Spectrum management

Spectrum decision

# Artificial Intelligence (AI) and Machine Learning (ML)

- AI strengths:
  - Efficient processing of large amount of data
  - Dynamic processing
  - Automatic detection of data correlation
  - No need for tailored programming
- Machine learning:
  - A type of AI that can learn dynamically from data without being specifically programmed



# AI / ML for Spectrum Sharing

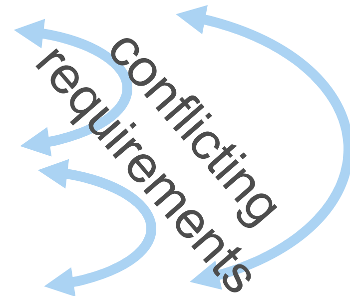
Managing the spectrum sharing process in a dynamic and efficient manner while maintaining different regulatory and performance constraints is a challenging task.
For example: the technical difficulty to manage the complexity of a real propagation environment or the complexity of the interaction among different communication systems

AI/ML can play a major role in facilitating the dynamic sharing of the spectrum efficiently by:

- Processing and analysing a large amount of data from RF spectrum environment.
- Manage the complexity of spectrum sharing in an automated way.
- Support or enable the implementation of spectrum sharing functions

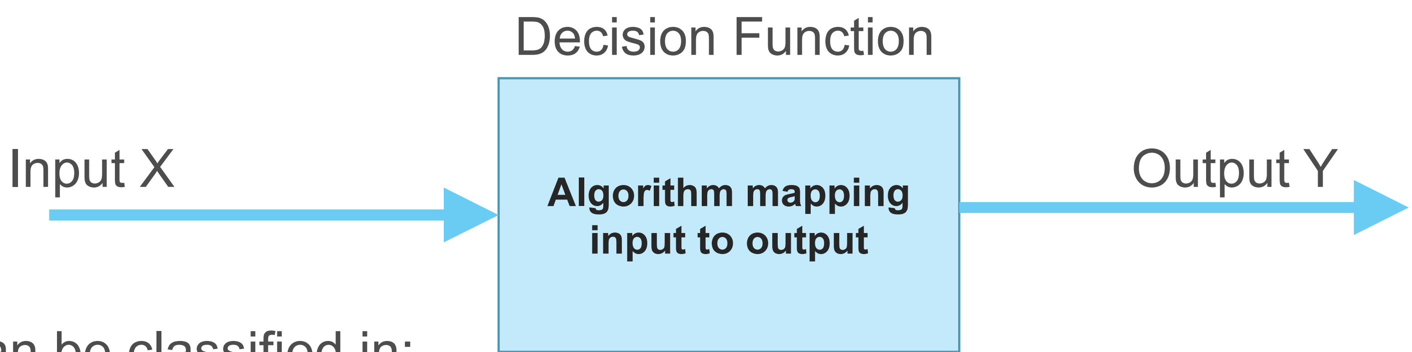
# High level requirements

- AI/ML learning and convergence should be:
  - Rapid → handover issue
  - Accurate → proper assessment of interference
  - Efficient → battery lifetime and HW limitations




- Use realistic scenarios for testing and collecting data for training:
  - AI/ML/DL performance depends on data
- AI should be trustworthy (lawful, ethical and robust from technical and social point)

# ML Algorithms for Spectrum sharing

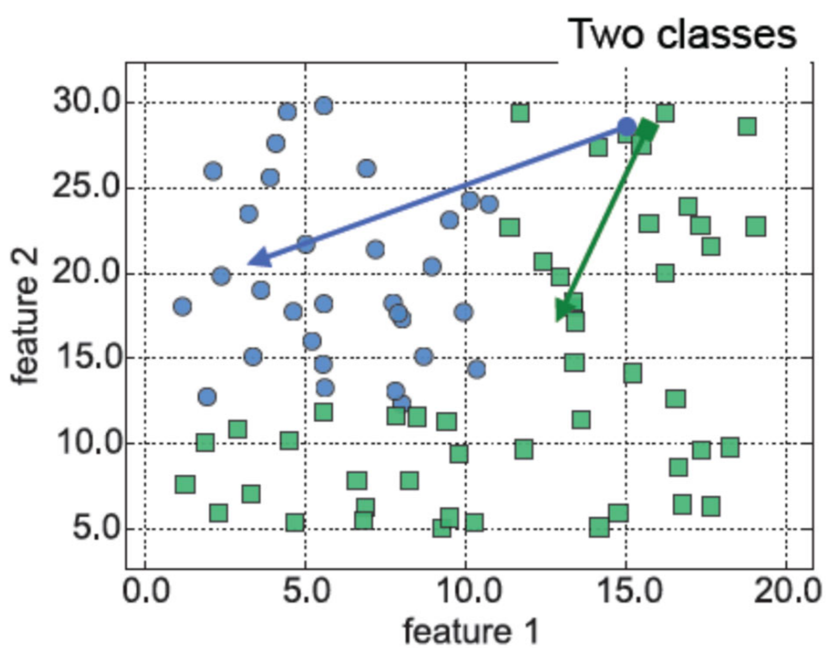



ML/DL can be classified in:

- Supervised: trained with a labelled set of data. Both the inputs and outputs are available (x,y). Optimal scenario for research but not always practical.
- Unsupervised: learning from unlabelled data. Only the inputs are available (x). Most of the cases in the real world.
- Reinforcement learning: agents learn while maximizing a reward function. No direct access to the «correct» output. Useful for dynamic and changing environments.

# ML Algorithms for Spectrum sharing (supervised)

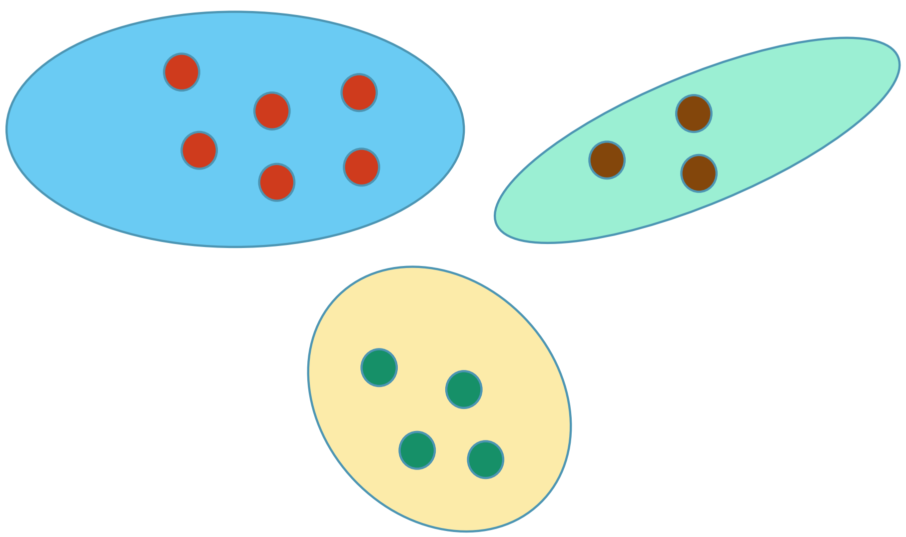
- Useful to test an approach or algorithm on a set of labelled data.
- Lack of public high quality labelled data sets in spectrum sharing is a problem.
- Some algorithms: Support Vector Machine, K-Nearest Neighbour, Decision Tree, Random Forest…



# ML Algorithms for Spectrum sharing (unsupervised)

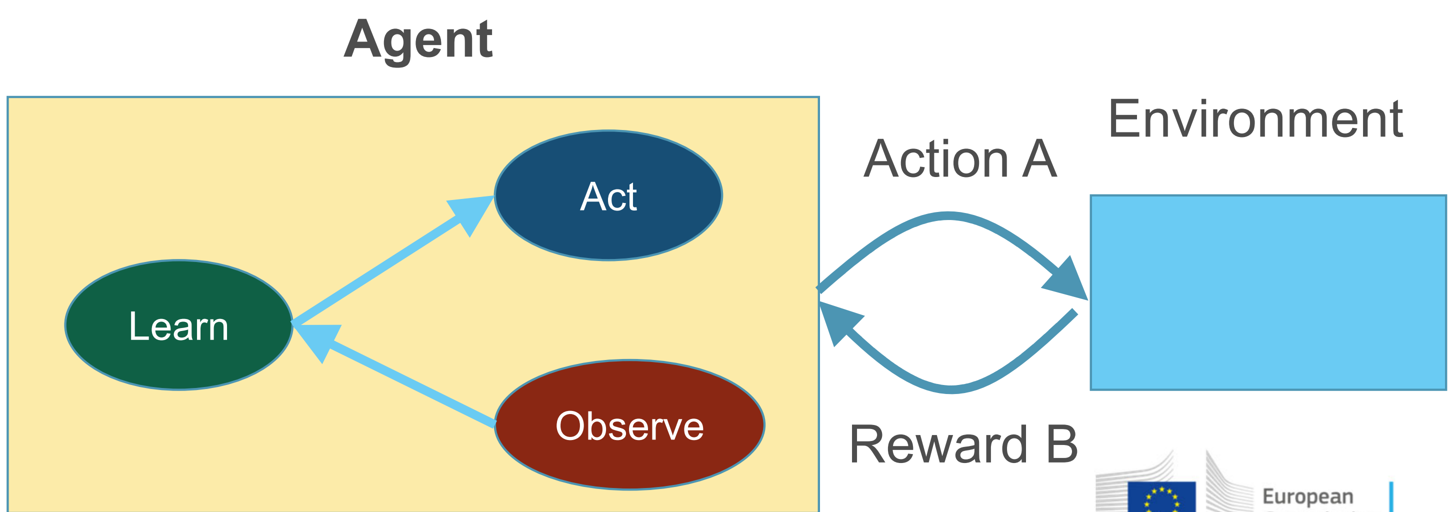
- No labelled data available.
- Answer to the question if we can group data based on specific features.
- Main goals are: cluster the data, identify outliers in the data, extract useful information and patterns from big data
- Dimension reduction of the data set
- Algorithms: K-means, hierarchical clustering..

Data clusters



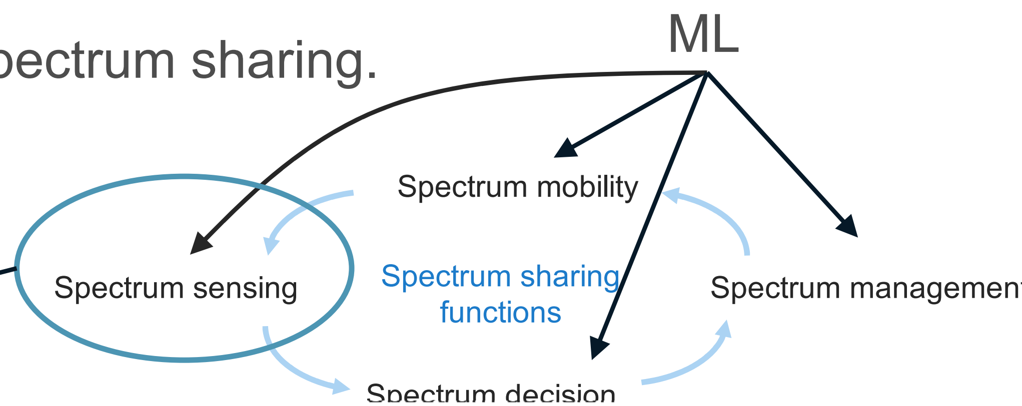
# ML Algorithms for Spectrum sharing (reinforcement learning)

- No explicit supervision.
- Learn while processing data.
- Useful for dynamic spectrum sharing environments, which can change in time

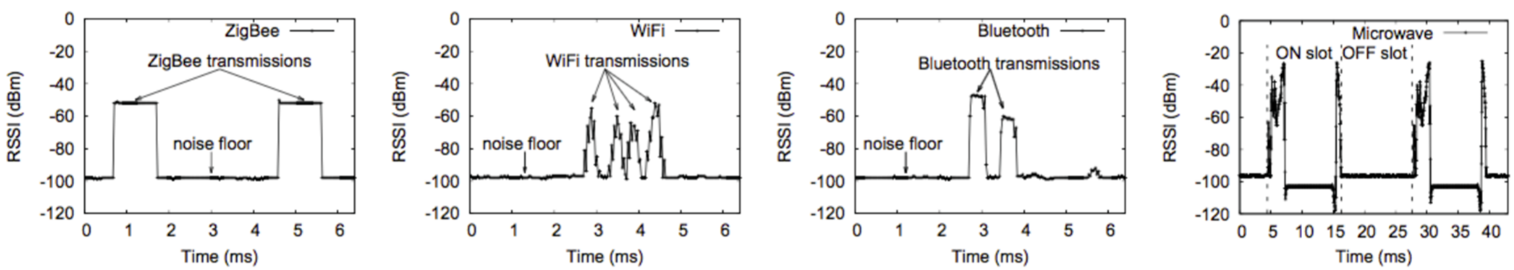


# ML Algorithms for Spectrum sharing

ML can be applied to all the functions in Spectrum sharing.




Signal classification




(a) ZigBee (b) WiFi (c) Bluetooth (d) Microwave oven

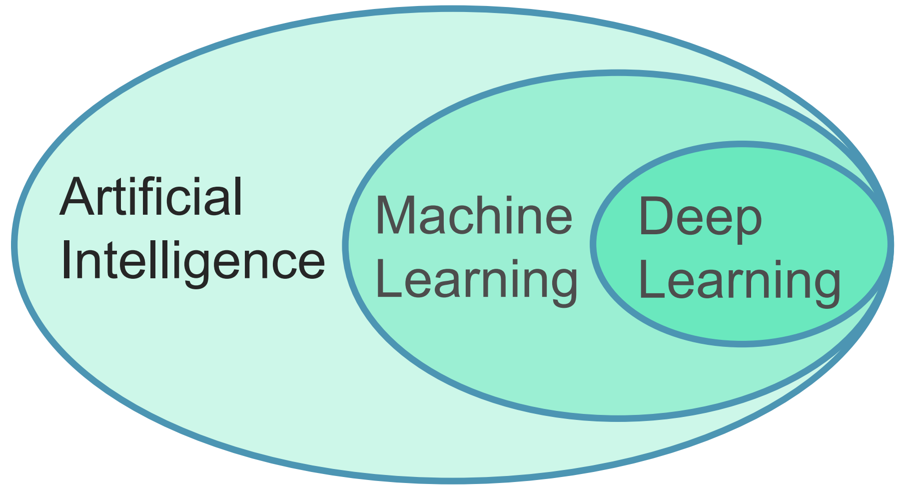
Source: Zheng, Xiaolong, et al. "ZiSense: towards interference resilient duty cycling in wireless sensor networks." ACM Sensys, 2014.

# ML Algorithms for Spectrum sharing

Machine Learning and Deep Learning

**Traditional Machine Learning (e.g., SVM)**

- Traditional machine learning requires
- manual feature extraction/engineering
- Feature extraction for unstructured data is very difficult




**Deep Learning (e.g., CNN)**

- Deep Learning can automatically extract features from data
- Deep Learning is largely a black box tecnique updating learning weights while processing data.

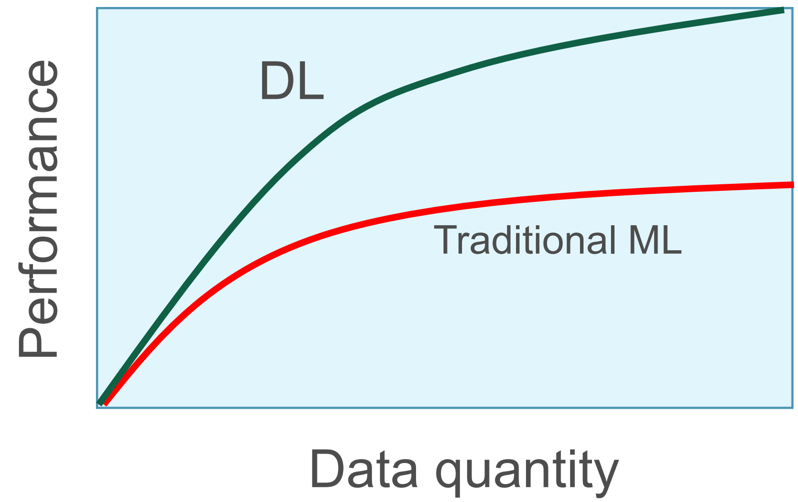
# Deep Learning for Spectrum sharing

Many Deep Learning algorithms have been proposed in literature for spectrum sharing:

- Convolutional Neural Networks (e.g., for signal classification, spectrum sensing)
- Autoencoders (e.g., for feature extraction, clustering of wireless propagation conditions)
- Deep reinforcement learning for spectrum coexistence and inter-network efficiency.
- Recurrent neural network (RNN) for channel or traffic predictions.

# Why Deep Learning is increasingly used ?

Deep Learning has demonstrated
its superior performance
 (e.g., classification accuracy) in many
Spectrum sharing problems when a large amount
of data is available.



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# ML vs DL

DL has been increasingly used in spectrum sharing because of its superior performance to conventional ML but there are pro and cons.

Table 1: ML VS DL in wireless signal recognition.

| Leaning model | Machine learning | Deep learning |
|---|---|---|
| Application scenarios | (i) small signal data<br>(ii) signal under relatively ideal conditions | (i) high-dimensional signal data<br>(ii) good feasibility in real field environment |
| Algorithms | (i) ANN [26, 37]<br>(ii) KNN [38, 91]<br>(iii) SVM [6, 27, 47, 48, 92]<br>(iv) Naïve Bayes [39]<br>(v) HMM [46]<br>(vi) Fuzzy classifier [93]<br>(vii) Polynomial classifier [40, 94] | (i) DNN [24, 30, 31, 61]<br>(ii) DBN [49, 63]<br>(iii) CNN [17, 19–21, 54, 64, 65, 70, 73–76, 79, 81, 82, 95, 96]<br>(iv) LSTM [29, 69]<br>(v) CRBM [53]<br>(vi) Autoencoder network [50, 62]<br>(vii) Generative adversarial networks [66, 67]<br>(viii) HDMF [71, 72]<br>(ix) NFSC [78] |
| Pros | (i) works better on small data<br>(ii) low implementation cost | (i) simple pre-processing<br>(ii) high accuracy and efficiency<br>(iii) adaptive to different applications |
| Cons | (i) time demanding<br>(ii) complex feature engineering<br>(iii) depends heavily on the representation of the data<br>(iv) prone to curse of dimensionality | (i) demanding large amounts of data<br>(ii) high hardware cost |

Source: Li, X., Dong, F., Zhang, S., & Guo, W. (2019). A survey on deep learning techniques in wireless signal recognition. Wireless Communications and Mobile Computing, 2019

# Deep Learning specific challenges in spectrum sharing:

- Require a large quantity of data which may be difficult to obtain in a real-time telecommunication environment.

- DL algorithms are mostly black boxes which do not give a clear indication on the optimal selected features. They have low interpretability.

- DL algorithms may be vulnerable to adversarial attacks, but this is less common in spectrum sharing at the moment.

- DL algorithms require significant computing resources which may not be available in all spectrum sharing scenarios (e.g., ad-hoc networks or end-user devices)

- DL algorithm have many hyper-parameters to tune.

# Conclusions and future developments

- The evolution of machine learning to deep learning supports a paradigm shift from modelling to data analysis as an enabler for many spectrum sharing functions.

- The computing resources needed for DL may be still an obstacle for its application in wireless equipment with limited resources.

- The integration of AI (ML and DL) in 5G and future 6G standardization activities can support a migration from research to industry deployment of ML/DL concepts.

- The availability of high quality data sets for research of AI in spectrum sharing can be helpful to the research community.

# Relevant References


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- Zhang, C., Patras, P., & Haddadi, H. (2019). Deep learning in mobile and wireless networking: A survey. *IEEE Communications surveys & tutorials*, *21*(3), 2224-2287.
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# Thank you





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