Deinterleaving RADAR pulses

Manon MOTTIER

PhD students' day

Laboratoire des signaux et systèmes
CentraleSupélec, Université Paris-Saclay

September 23rd, 2021

Context

Industrial thesis (CIFRE)

- The Signals and System Laboratory of CentraleSupélec
  - Thesis director: Frédéric PASCAL
  - Co-supervisor: Gilles CHARDON
- Phd student, 3rd year

Context

AVANTIX (ATOS Group)

- French company specialized in Electronic Warfare
- Designs critical high-tech systems to provide homeland protection and military forces
- Radar processing chain
  - Data processing based on the interception of a signal by a listening system
  - Provides strategic information to military platforms

Context

The subject

- Use and development of machine learning tools for passive RADAR intelligence
- Improvement of the RADAR deinterlacing chain
- Passive RADAR(s):
  - Emit no electromagnetic waves
  - Only receivers
  - Detect, track and identify RADAR(s)

Context

Radar Deinterlacing process:

1. From a signal, separation and grouping of pulses
2. Extraction of characteristics
3. Comparison of groups to Radar database which contains all the characteristics of the RADARS
4. Identification of the RADAR present or updating of the database

Content

Content

Data description

- Work from simulated labeled data
- Each dataset is composed of RADAR pulses, described by only 4 features:
  - Frequency (F)
  - Pulse Width (PW)
  - Level (L)
  - Time of Arrival (TOA)

Data description

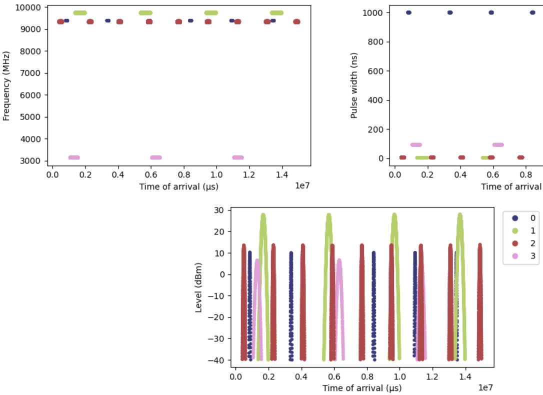

Figure: Example of a **simple** signal containing 4 RADARs.

Content

Methodology

Implementing a two-step strategy for signal deinterlacing:

1. **Clustering**: Cluster each observation of this signal under the constraint of not merging different radars in one cluster
2. **Cluster fusion**: Hierarchical agglomerative clustering combined with optimal transport distances

Step 1: Clustering with HDBSCAN

- Application of clustering algorithm on two features: Frequency and Pulse Width
- Why HDBSCAN ?
  - Unsupervised algorithm that allows us to search for clusters of varying densities
  - Few parameters to optimize
- Over-estimation of the number of clusters
  - Allows to receive RADARs that do not transmit continuously
  - Each cluster must not contain the observations of different RADARs

Output of HDBSCAN

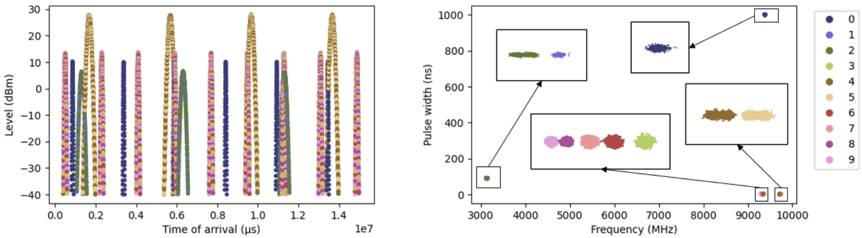

Figure: HDBSCAN Output. Colors represent the different clusters.

Step 2: Cluster fusion

Methodology:

1. Dimensionality reduction: each cluster is represented by a histogram of its TOA and LEVEL
2. Compute distances between cluster histograms using optimal transport
3. Aggregation of the 2 closest clusters i.e., the 2 clusters with the lowest transport costs
4. Computation of new costs between old clusters and the new ones
5. Repeat steps 2 to 4 until a single cluster is obtained

Histograms

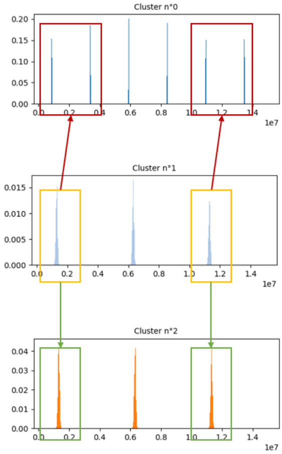

Figure: Histograms of the previous clusters.

Optimal Transport

- Transporting distribution to another has a cost:

$$C(\mathrm{P}) = \sum_{n=1}^{N} \sum_{m=1}^{M} C_{nm} P_{nm} = \langle \mathrm{C}, \mathrm{P} \rangle \tag{1}$$

$C(\mathrm{P})$ = Total cost

C_{nm} = cost transporting unit mass from x_n to y_n (transport cost)

P_{nm} =quantity of mass taken from x_n to y_n (transport plan)

- The optimal transport plan is a simple minimization problem:

$$\mathrm{P}^{\star} = \underset{\mathrm{P} \in \mathrm{R}_{+}^{N \times M}}{\operatorname{argmin}} \langle \mathrm{C}, \mathrm{P} \rangle \text{ such that } \mathrm{P}1_M = \mathrm{a}, \mathrm{P}^T 1_N = \mathrm{b}^T. \tag{2}$$

Dendrogram

- Decision model based on several unsupervised metrics to cut the dendrogram:
  - Silhouette score
  - Calinski-Harabasz score
  - Davies-Bouldin score

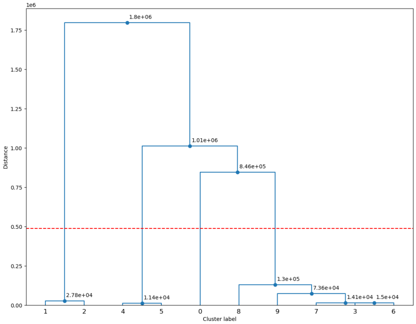

Figure: Dendrogram that presents in a simplified way the cluster aggregations with the distances of the optimal transport.

Final Grouping

- Perfect grouping
- Statistics:
  - Homogeneity = 1
  - Completeness = 1
  - Unclassified rate = 2%

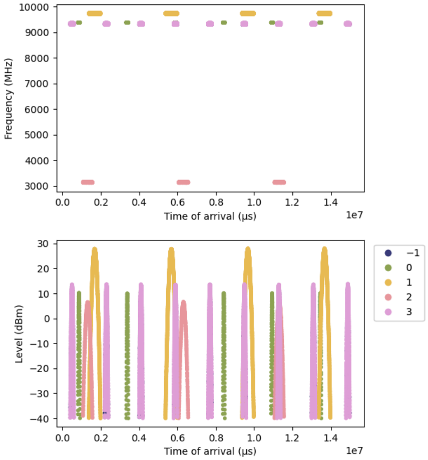

Figure: Final grouping

Content

Unlabeled data

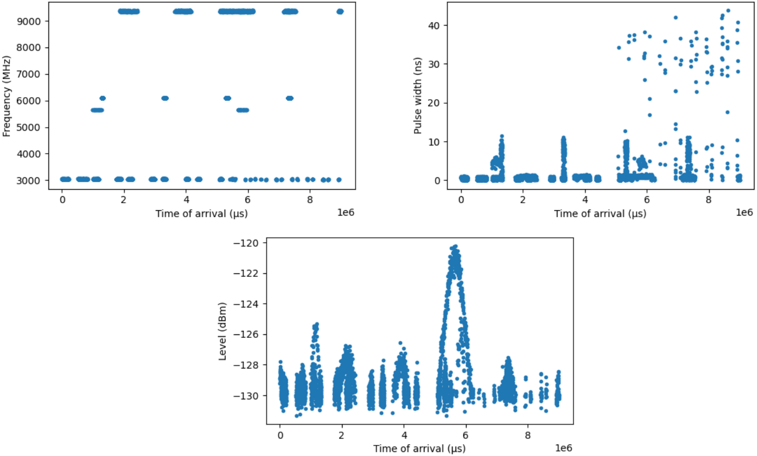

Figure: Unlabeled data with 5 RADARs.

Step 1: Clustering with HDBSCAN

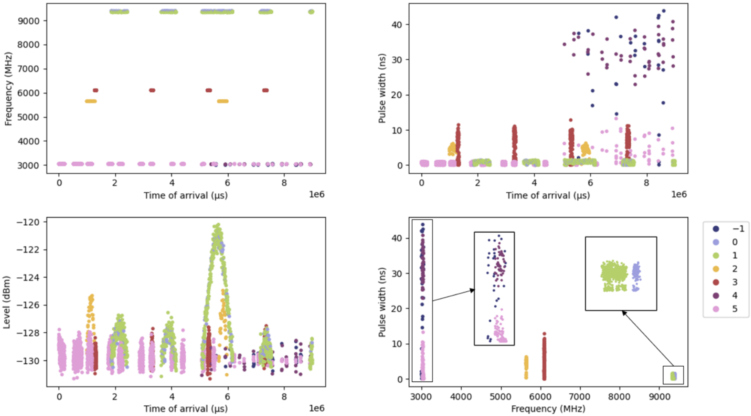

Figure: HDBSCAN Output.

Histograms

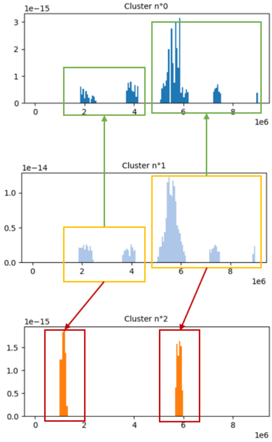

Figure: Histograms of the previous clusters.

Final Grouping

- Pulses of the 2 transmitters around 3GHz are mixed
- Hdbscan can not differentiate them at step 1
- Statistics:
  - Homogeneity = 0,94
  - Completeness = 1
  - Unclassified rate = 0,9%

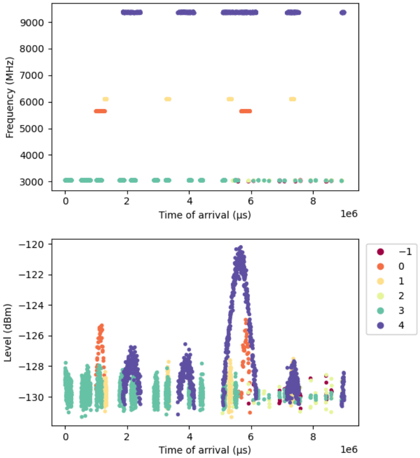

Figure: Final grouping.

Content

Conclusions and Next objectives

- Works on moderately complex cases
- Publication of a Conference paper: "Deinterleaving and Clustering unknown RADAR pulses" - Manon Mottier; Gilles Chardon; Frédéric Pascal
- Next objectives:
  - Improvement of the proposed approach
    - Define a metric to identify identical RADARs in Frequency and Pulse Width
    - Improve model decision to cut the dendrogram
  - Classification and RADAR identification from a reference database

Thank you for your attention

For more information please contact:

Manon MOTTIER

manon.mottier@atos.net