Binary Blind Identification of Wireless Transmission Technologies for Wide-band Spectrum Monitoring

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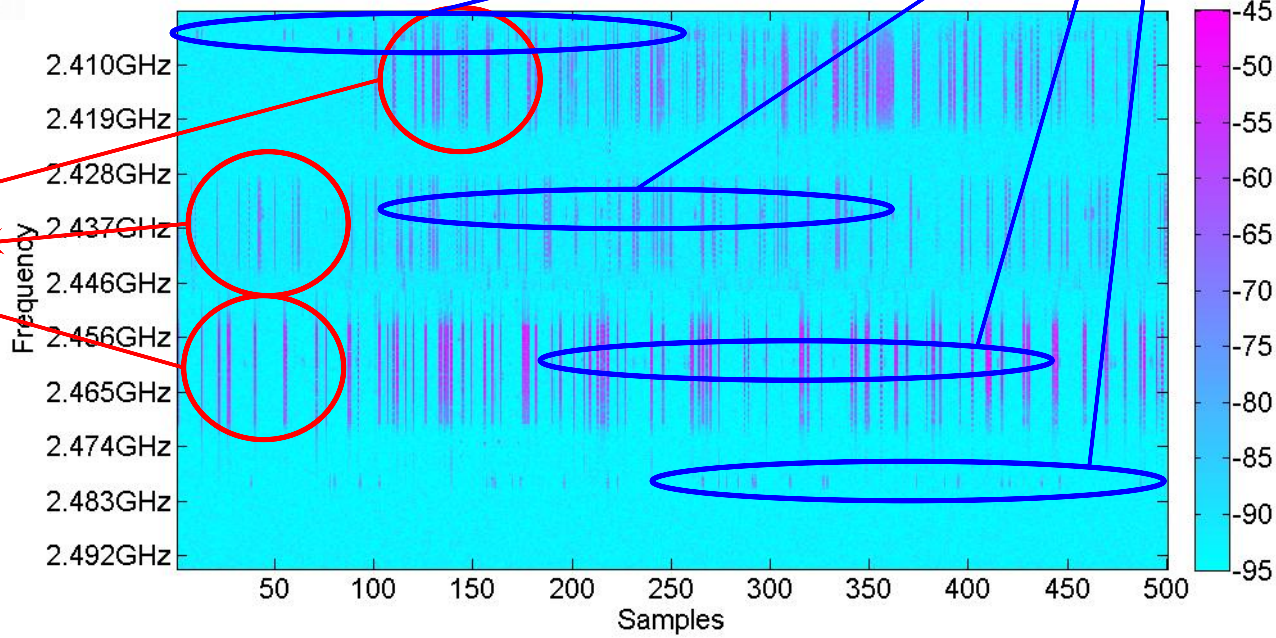
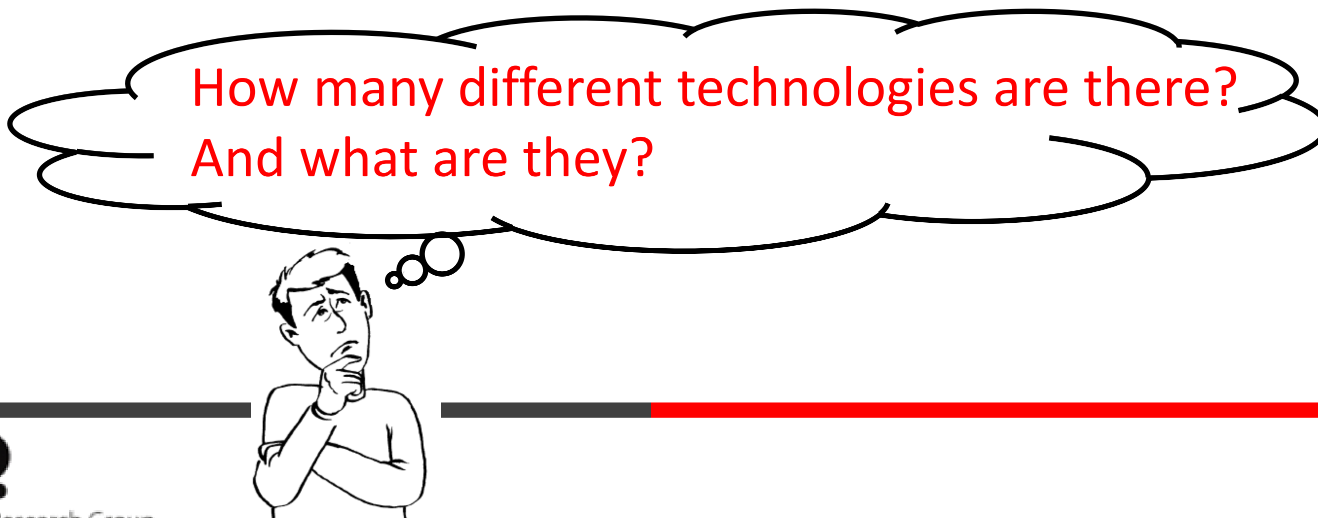
Some Zigbee devices?

WiFi 1,6,11?



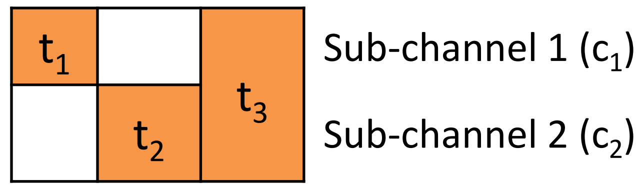


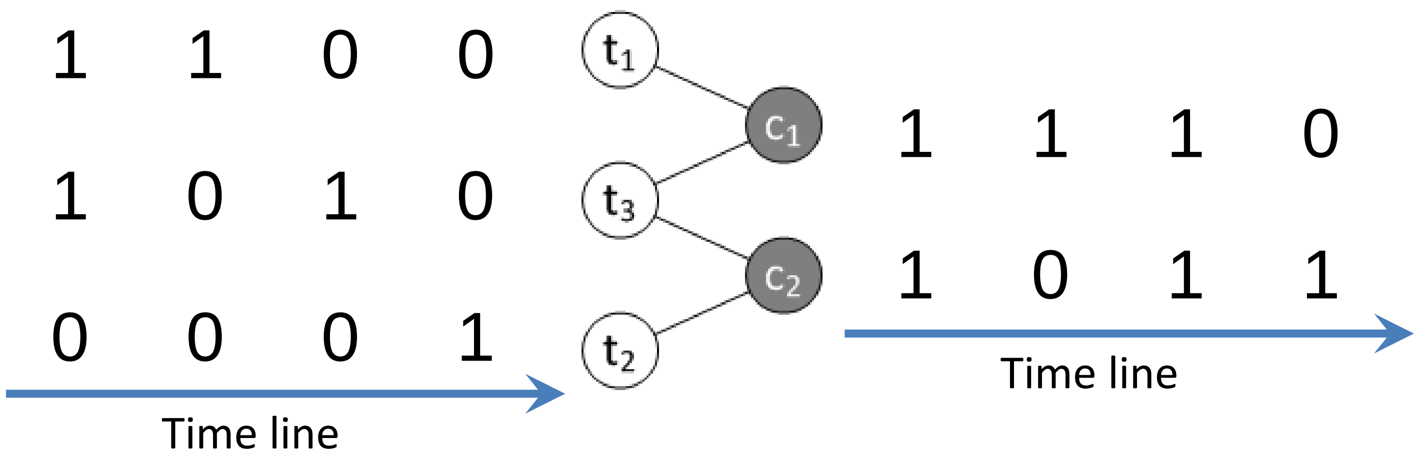
Observations and Contributions

- Technologies occupy different ranges of spectrum
- When a wireless device occupies a sub-channel, adjacent sub-channels are likely to be activated (correlated)
- Blind identification: no prior knowledge about the high level features wireless technologies, purely based on spectrum occupation
- Contributions:
  - Formulate the blind technology identification problem
  - Propose a binary framework to solve the problem

Problem Binary Formulation

- Assuming the activities of devices using different technologies are independent
- A RF transmission will cause a power surge in its associated sub-channels
- Consider an example: 3 technologies operate on 2 sub-channels
- Sub-channel occupancy:

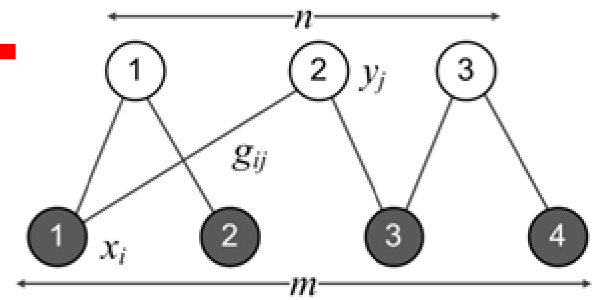




$$\boldsymbol{Y} \otimes \boldsymbol{G} = \boldsymbol{X}$$

(unknown) **(unknown)**

Binary Independent Component Analysis (bICA)



- Network model: a bipartite graph $\boldsymbol{G} = g_{ij}$

  n independent binary sources $\mathbf{y} = [y_1, y_2, \dots, y_n]$

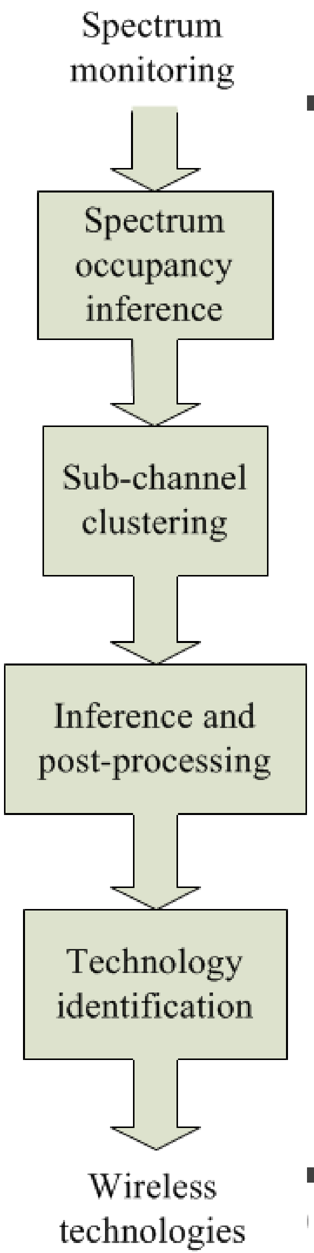
  m observable binary variables $\mathbf{x} = [x_1, x_2, \dots, x_m]$

- Observations $\boldsymbol{X}$ are disjunctive mixtures of latent sources $\boldsymbol{Y}$

$$x_i = \bigvee_{j=1}^{n}(g_{ij} \wedge y_j),\ i = 1, 2, \dots, m \quad \text{or} \quad \boldsymbol{X} = \boldsymbol{G} \otimes \boldsymbol{Y}$$

- Problem: given $\boldsymbol{X}$, infer the mixing matrix $\boldsymbol{G}$ and the source $\boldsymbol{Y}$
- Original ICA assumes continuous variables → not applicable

Proposed Procedure



1. Spectrum occupancy inference: remove noise and identify useful signals
2. Sub-channel clustering: cluster similar sub-channels to reduce inference complexity
3. Inference and post processing: use bICA to infer the channel occupancy matrix
4. Technology identification: from the center frequencies and bandwidths

Spectrum Occupancy Inference

- Separate useful signals from noise
- Mean Shift (MS) clustering method
- Noise and useful signals form different clusters
- Two-step procedure:
  - Cluster the spectrum power by applying FFT to the measurement data, determine the noise floor
  - Apply MS on 2-d data to determine all cluster means
- Clusters with means > noise floor are useful clusters

Sub-Channel Clustering

- Reducing computation complexity of bICA
- Observation: wireless technologies tend to occupy contiguous sub-channels

→ Cluster similar, contiguous sub-channels using Girvan-Newman community detection algorithm

Wireless Technology Inference

- Use bICA to infer the independent technologies occupying sub-channels
- Un-cluster the inferred result to obtain the original channel occupancy matrix ($\boldsymbol{G}$)
- From $\boldsymbol{G}$, determine the center frequency and bandwidth of each group
- Identify the associated wireless transmission technologies

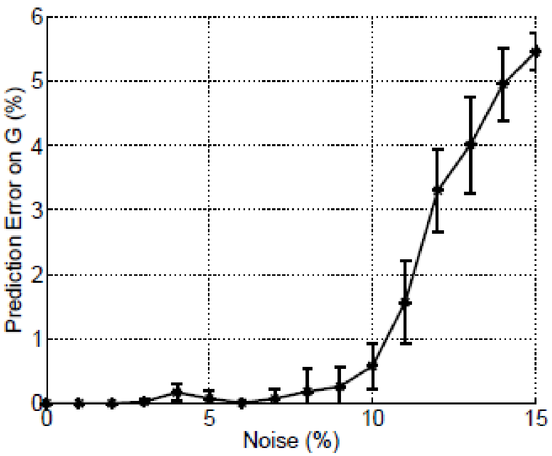
Evaluation Setup

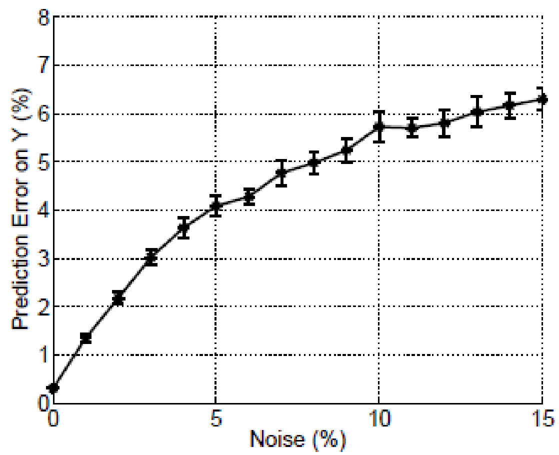
- Synthetic trace
  - 3 WiFi devices on channels 1, 6, 11 and 8 ZigBee devices on channels 11 – 18
  - Device transmission prob. in [0.05, 0.1]
  - Data noise ratio in [0, 0.1]
- Real trace
  - 3 WLAN devices on channels 1, 6, 11 and 4 TmoteSky ZigBee devices on channels 11, 17, 22, 26
  - 1024 points sampling for each measurement
  - Measure each 10 secs, for 500 times

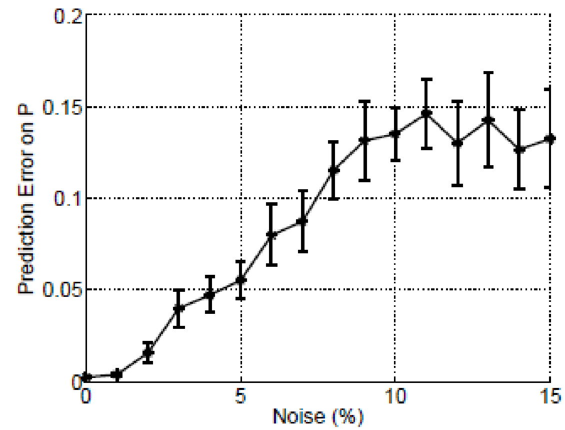
Synthetic Trace Result

Matlab implementation

Channel noise = 0% – 15%







Structure error ratio: % inference error on $\boldsymbol{G}$	**Activity error ratio**: % inference error on $\boldsymbol{Y}$	**Transmission prob. error**: inference error on the active probability of technologies

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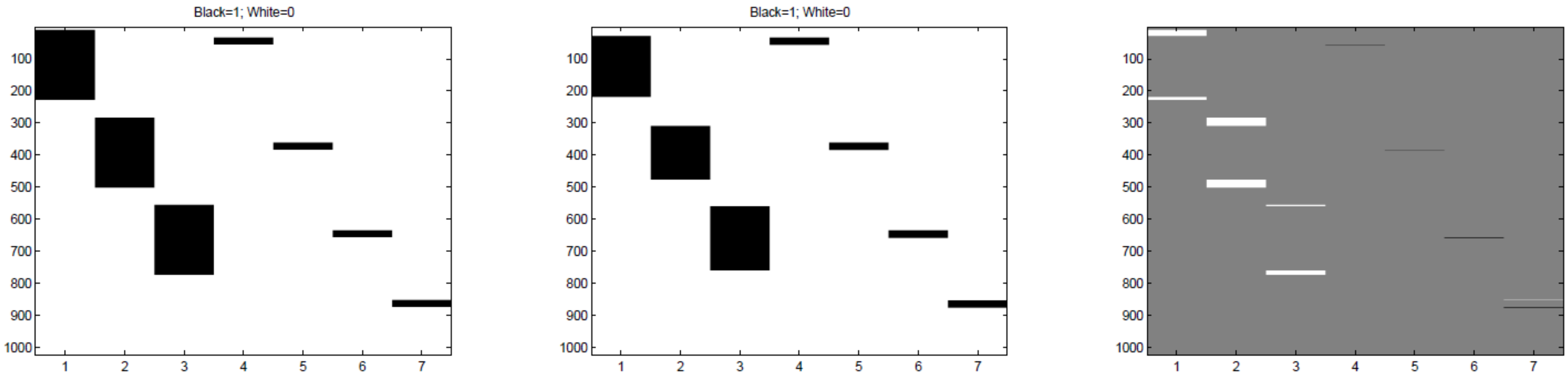
Real Trace Result



(a) Original $\boldsymbol{G}$ (b) Inferred $\hat{\boldsymbol{G}}$ after *structure matching* (c) Difference matrix

Component	f_c (GHz) Inferred	f_c (GHz) Ground truth	b (MHz) Inferred	b (MHz) Ground truth	Technology
1	2.4124	2.412	17.766	22	WiFi ch. 1
2	2.4371	2.437	15.604	22	WiFi ch. 6
3	2.4615	2.462	18.706	22	WiFi ch. 11
4	2.4052	2.405	2.068	2	ZigBee ch. 11
5	2.4352	2.435	2.068	2	ZigBee ch. 17
6	2.4603	2.460	2.162	2	ZigBee ch. 22
7	2.4803	2.480	2.068	2	ZigBee ch. 26

Conclusion

- Identifying transmission technologies without prior knowledge with only binary sensing is feasible
  - Frequency domain only
- What to do next?
  - Validation using large-scale spectrum data
  - Improve accuracy and computation efficiency of the proposed algorithm
  - Incorporate cyclostationary spectrum density

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THANK YOU FOR YOUR ATTENTION

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