Understanding Spectrum

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Co-Advisors: Ivan Seskar, Larry Greenstein, and Melike Gursoy

WINLAB Industrial Advisory Board Meeting
Spring 2013

Topics

- ORBIT Propagation Characterization (Haris Kremo)
- Localization of Packet Based Radio Transmitters in Space, Time, and Frequency (Goran Ivkovic)
- Channel Occupancy Analysis in Packet-Based Wireless Networks (Shridatt Sugrim)
- Other topics (not covered):
  - Vehicular channel spectrum sensing (Dusan Borota)
  - White Space Sensing (Jonathan Shah)

Propagation Characterization of the ORBIT Radio Testbed

Haris Kremo

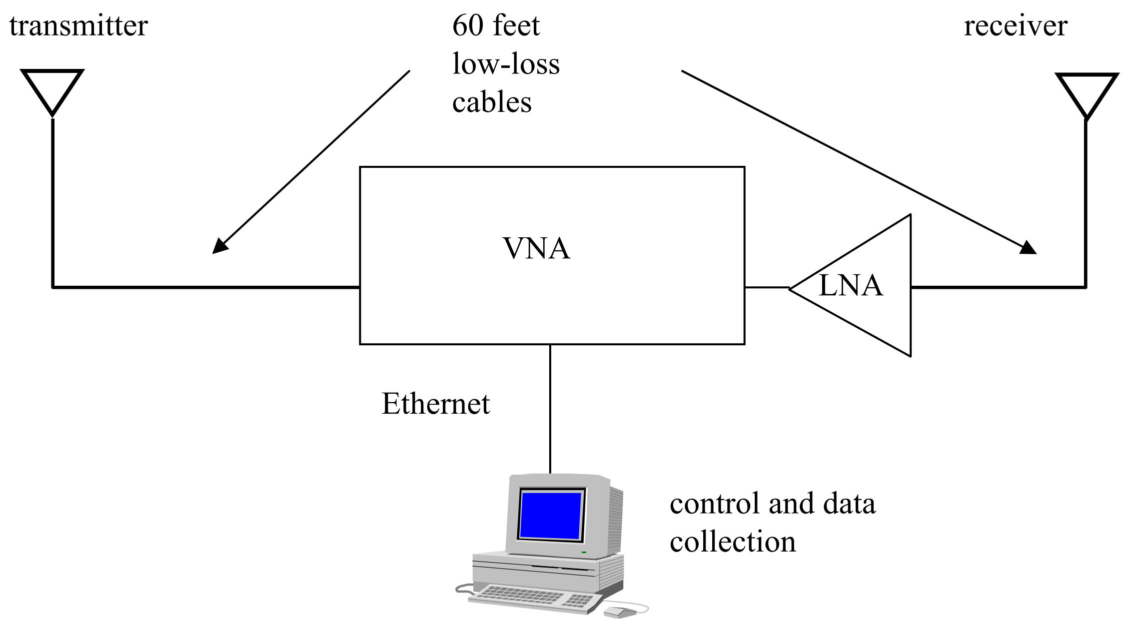
Ivan Šeškar, Larry Greenstein, and
Predrag Spasojević

Outline

- Motivation
- Measurements setup
  - vector network analyzer
- Measurements goals
  - determine path loss model
  - determine impulse responses (multipath intensity profile - MIP)
- MIP from two case studies compared to WISE simulations
  - 15 measurements diagonally across the room
  - 66 measurements for two symmetric transmitter positions
- Influence of antenna patterns on measurements
  - conclusions supported using WISE simulations

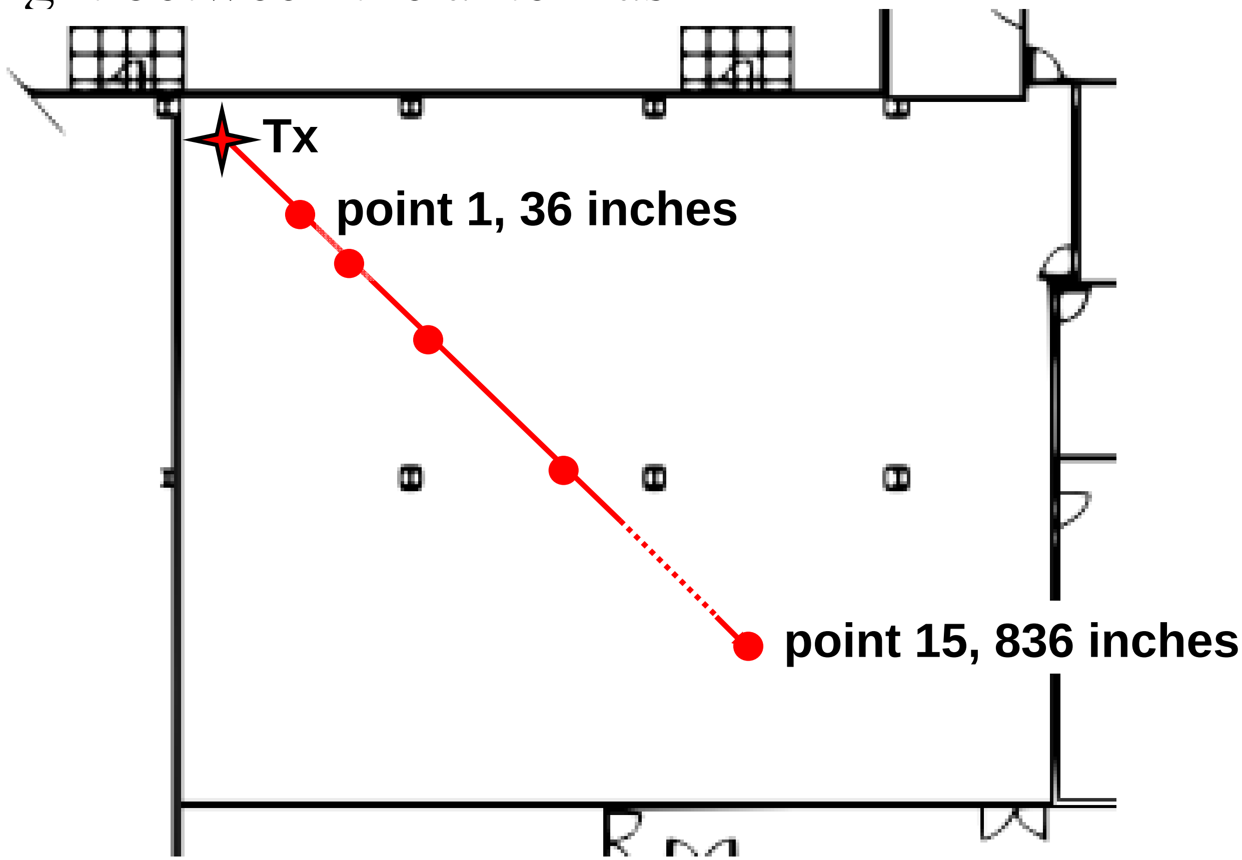
Vector network analyzer (VNA): ORBIT Study

- Measure S-parameters
  - ISM/UNII 100 MHz bands

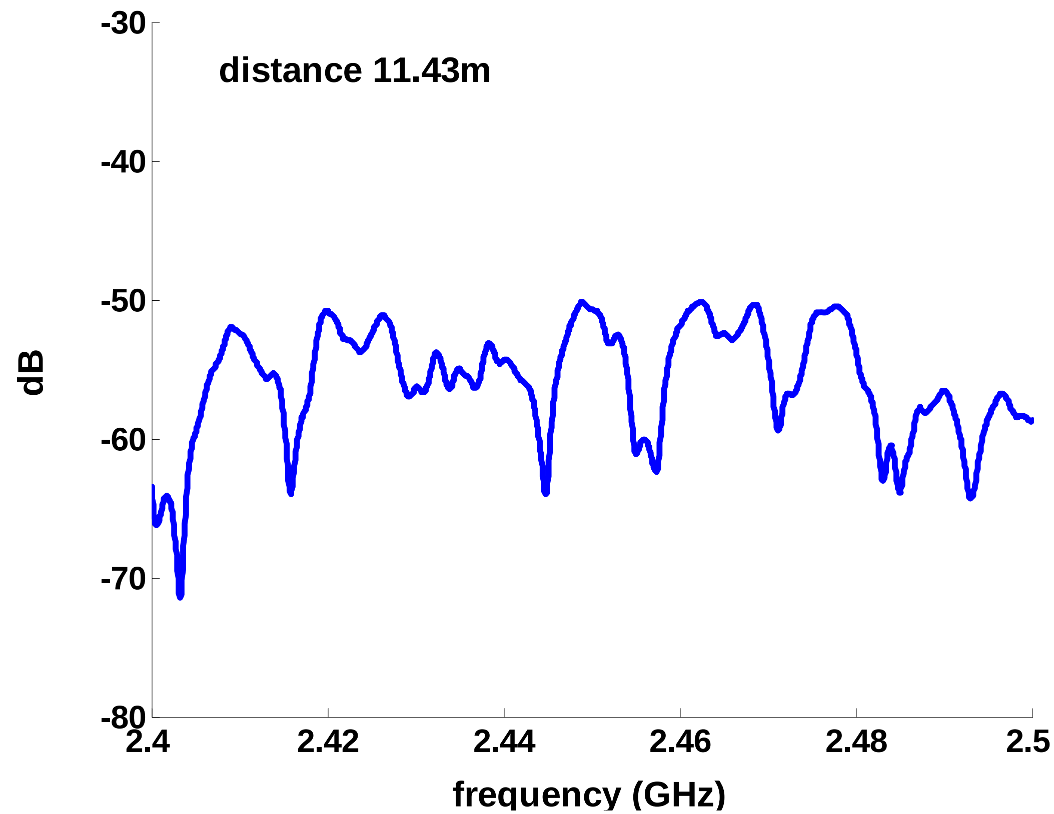


Case study “receiver on a diagonal”

- Logarithmically distributed distances
- Line-of-sight between the antennas

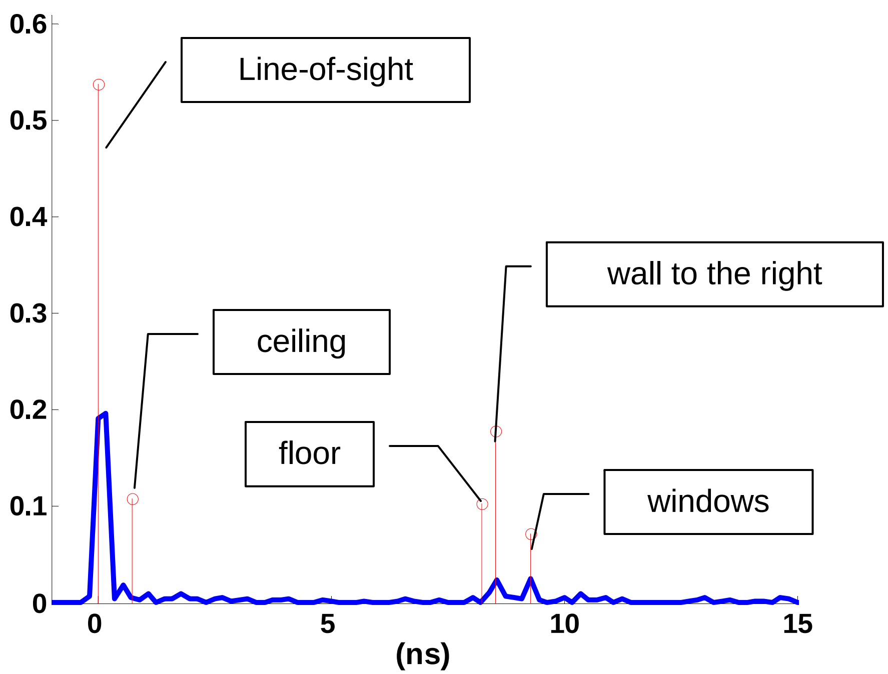


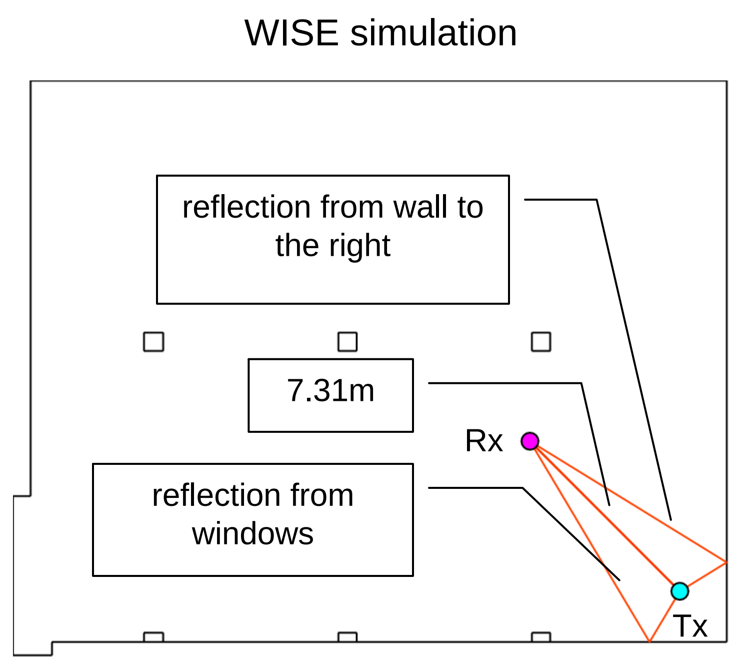
Example channel response magnitude



Example of Multipath Intensity Profile

- MIP compared to the results of WISE
  - Walls, windows significant source of reflections
  - Ceiling, roof, floor negligible source of reflections (due to antenna radiation pattern)





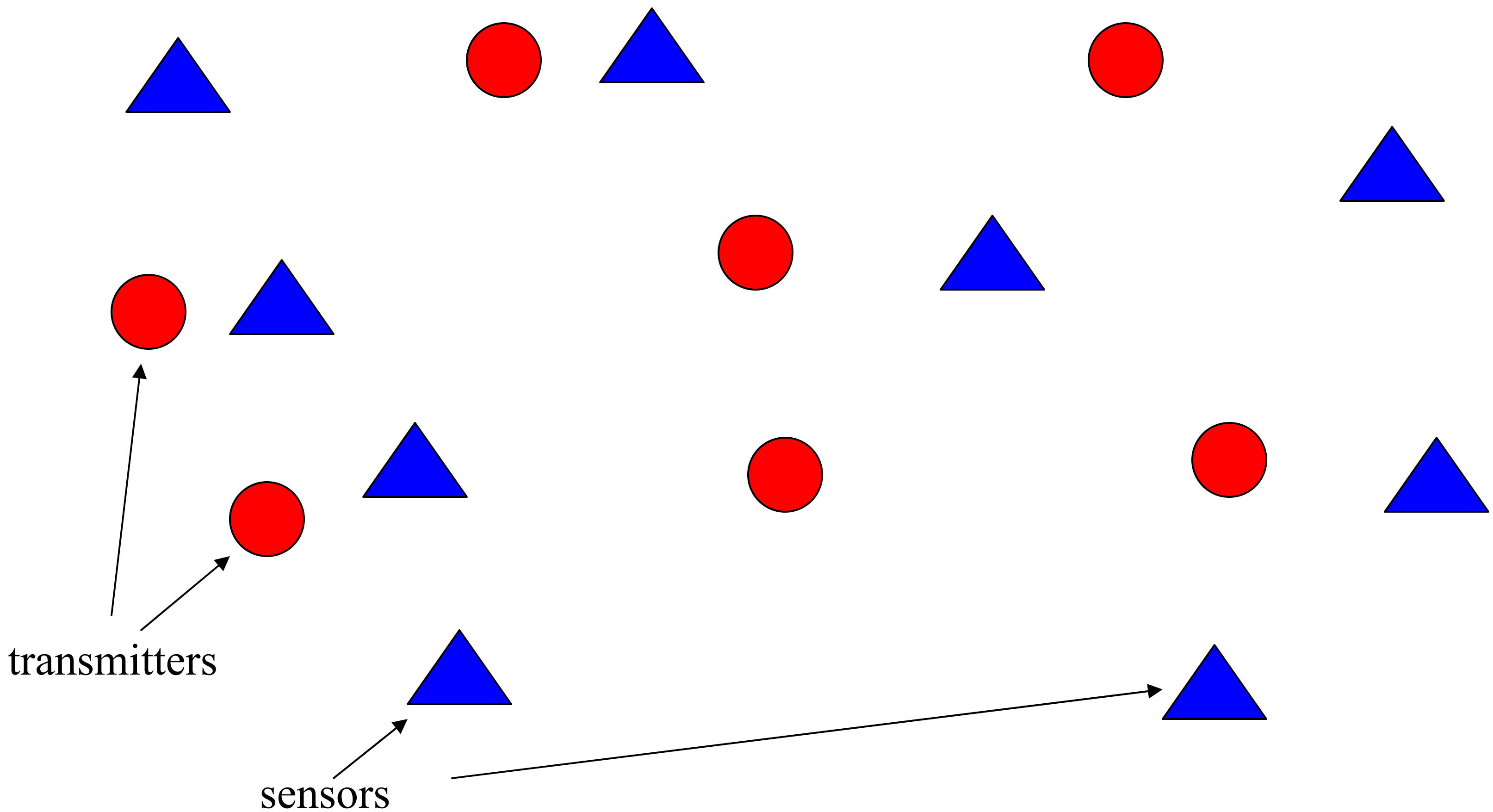
Localization of Packet Based Radio Transmitters in Space, Time and Frequency

Goran Ivkovic

Advisors: Predrag Spasojevic and Ivan Seskar

Spectrum Sensing Network

We consider the scenario where one or more sensors observe a frequency band possibly used by transmitters forming packet based radio networks



Goal: Transmission Characterization

- Transmitters in these networks exchange packets using certain protocols
  - there are multiple transmitters producing signals with nonpersistent excitation
  - e. g., 802.11a/b/g, Bluetooth, Zig-Bee, various types of cordless phones, etc.

- Each transmitted signal can be characterized with
  - its spectra which are determined by the signal modulation format
  - its on/off sequence representing the signal activity in time

- Goal of the analysis is to estimate transmitter
  - its spectral occupancy
  - its activity sequence in time
  - its location in space

Radio Scene Analysis for packet based radio signals

- Estimate
  - spectra
  - channels
  - on/off activity sequences

- Two stage algorithm
  - Signal segmentation
  - Fourth order spectrum based analysis

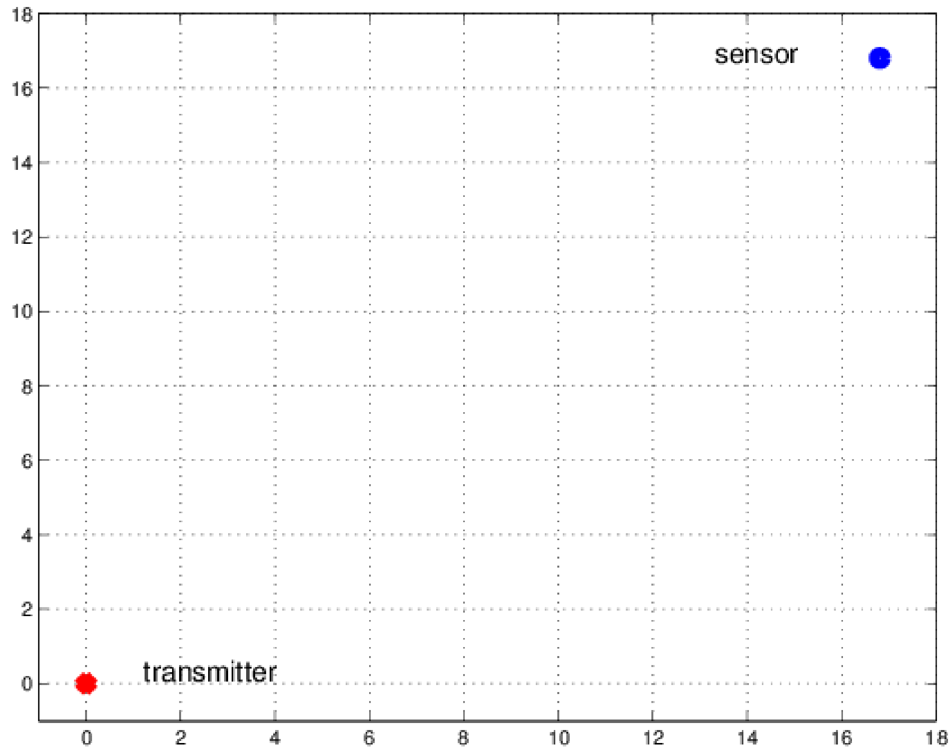
Activity Segmentation via Mean Shift Analysis

- MSA segmentation algorithm localizes in time statistically homogeneous intervals in the received signal

- Segmented intervals may correspond to a transmission from zero, one, or more transmitters

- Similar intervals are clustered/segmented

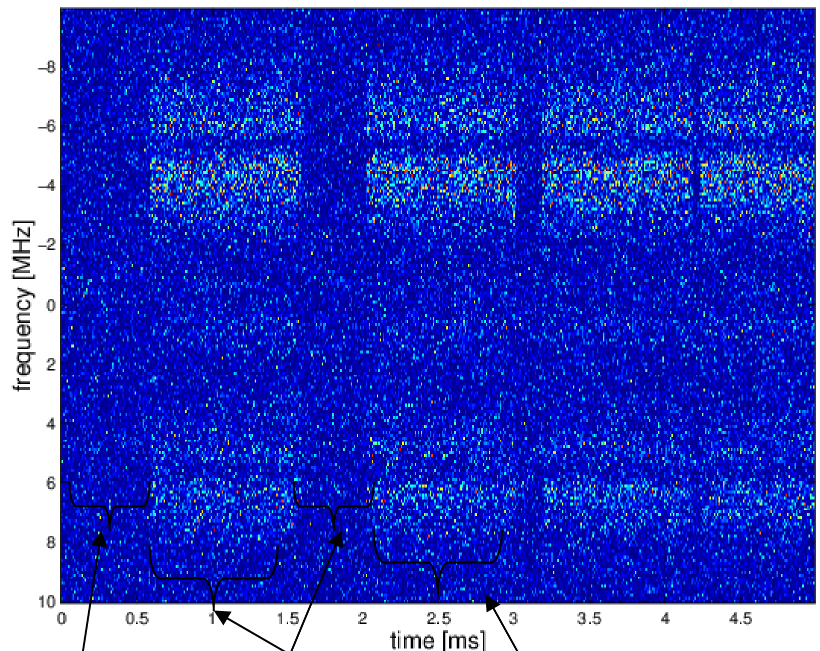
Single Transmitter-Single Sensor Example



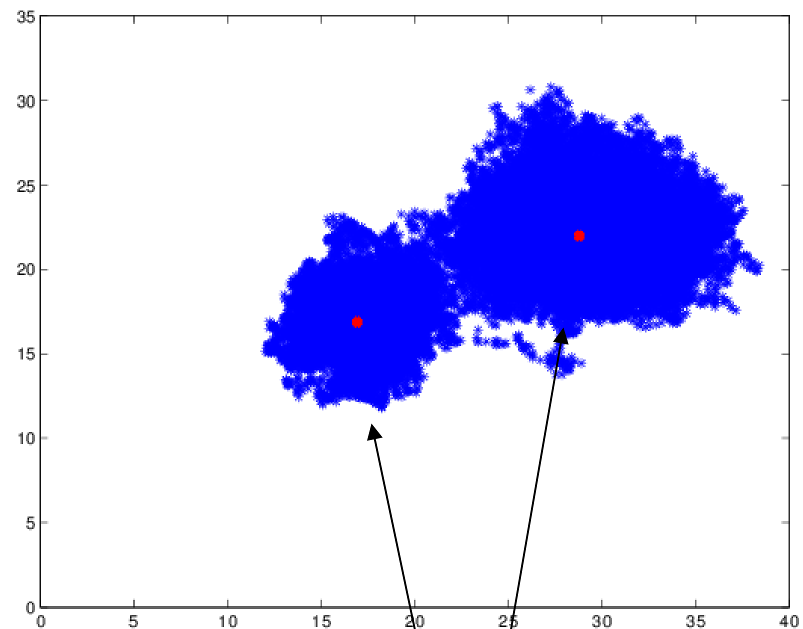
- One sensing node and one source transmitting DBPSK with Barker sequence spreading(802.11b at 1Mbit/sec)
- Measured channel transfer functions from(H. Kremo, et al. VTC ’07)

Spectra (Second Order Statistics) Clustering

Spectrogram of the received signal (W=20MHz, total observation time 5 ms)



Scatter plot of the feature vectors $\mathbf{x}_n$

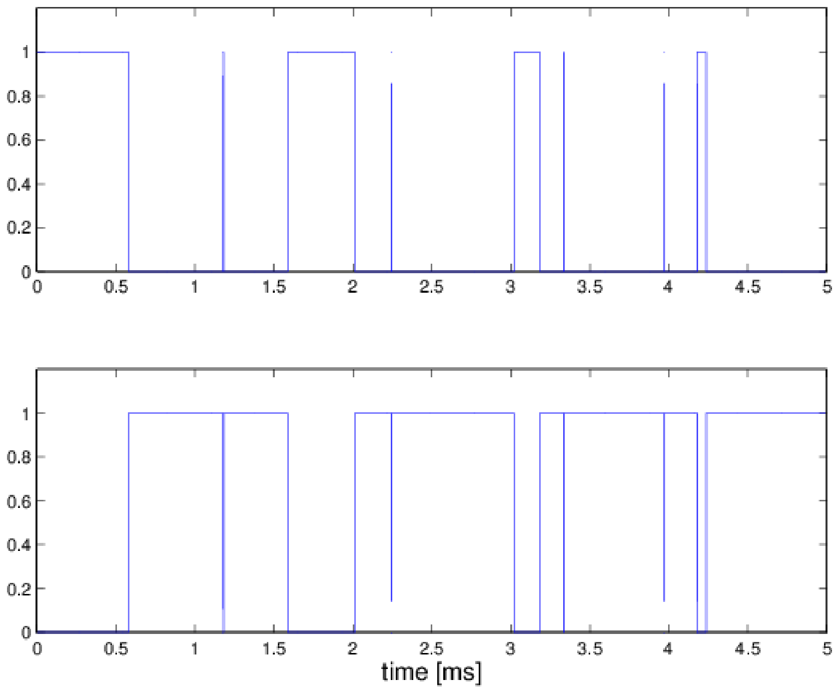


noise segments

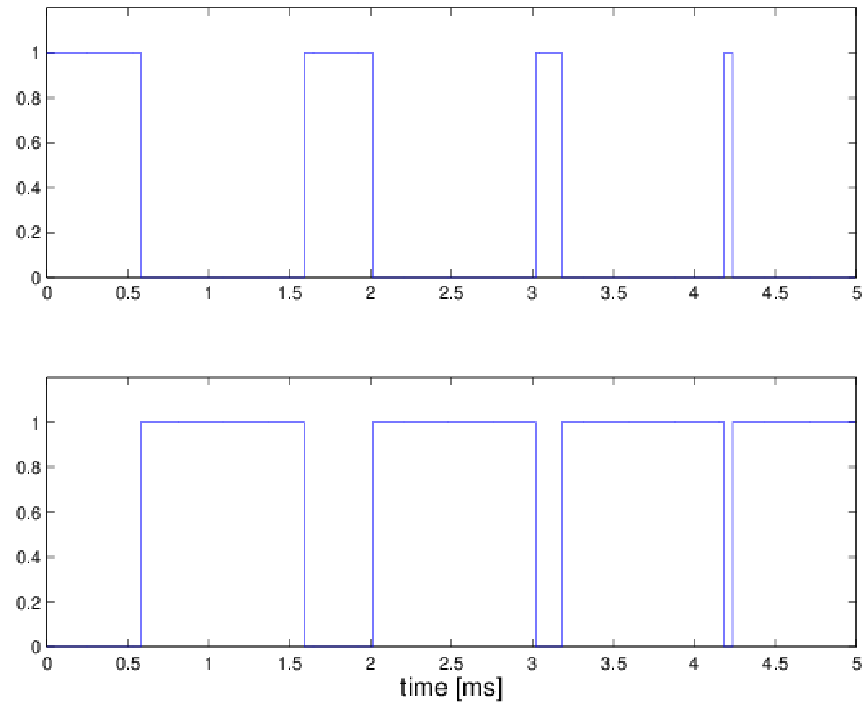
DBPSK signal plus noise segments(SNR=-3dB)

There are two clusters

Activity Segmentation and Impulse Noise Removal

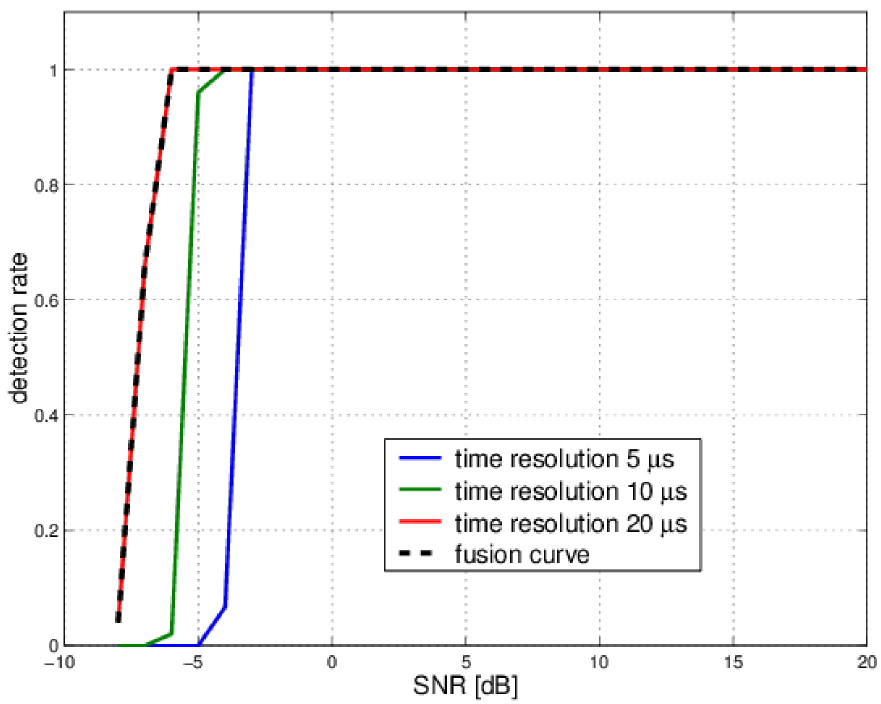


Segmentation results before impulse noise removal

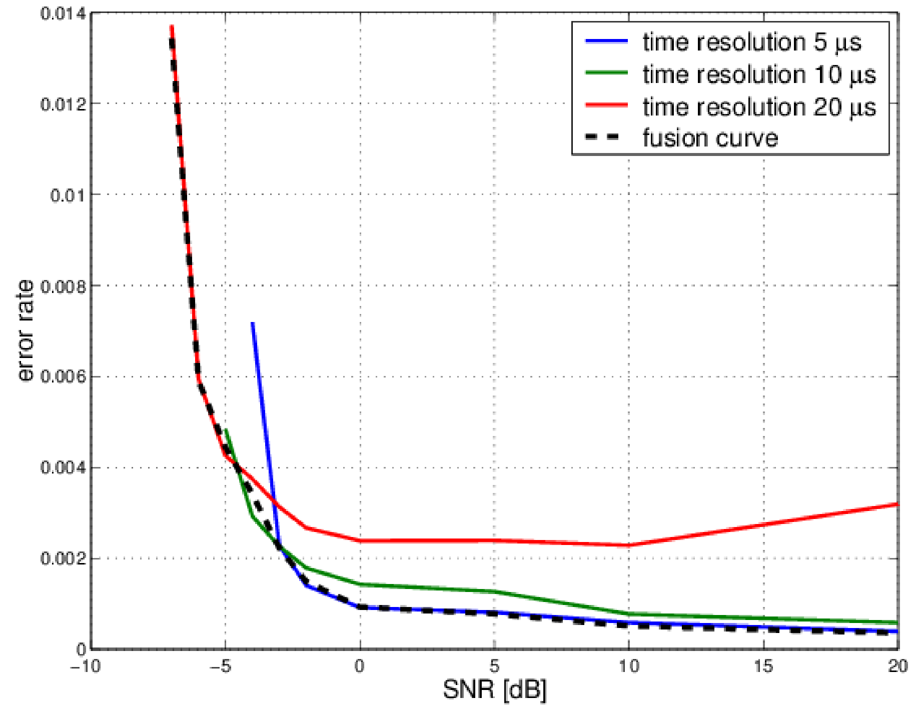


Segmentation results after impulse noise removal

Multiresolution Segmentation Fusion



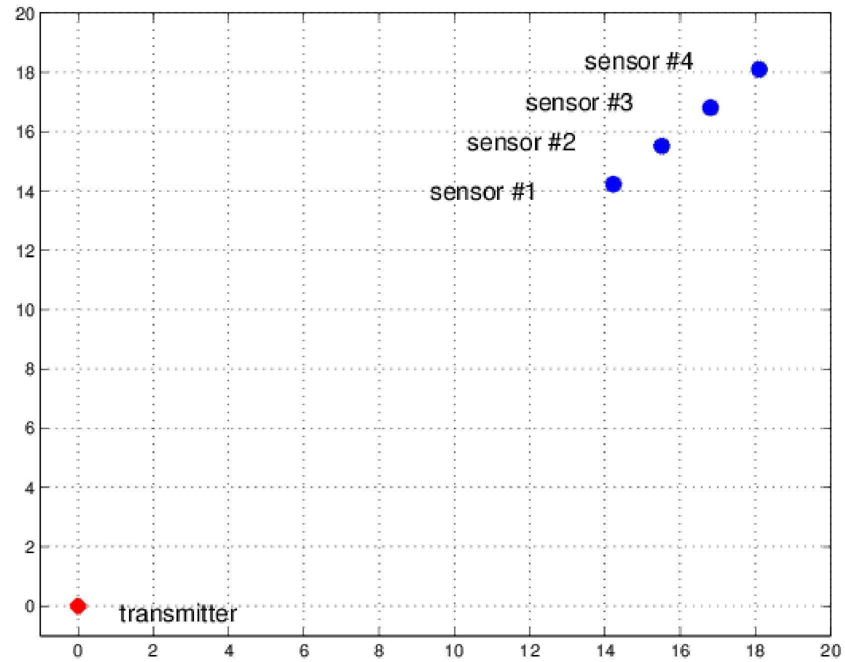
Detection rate of the correct number of clusters



Segmentation error rate

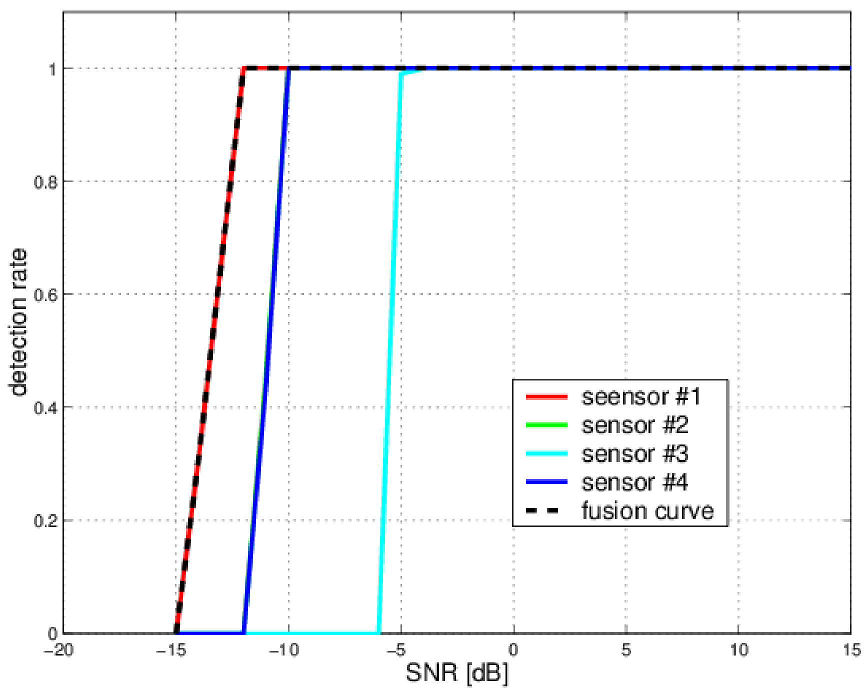
The algorithm is useful up to a threshold SNR

Single Transmitter-Multiple Sensor Example: Collaborative Segmentation via Mean Shift Analysis

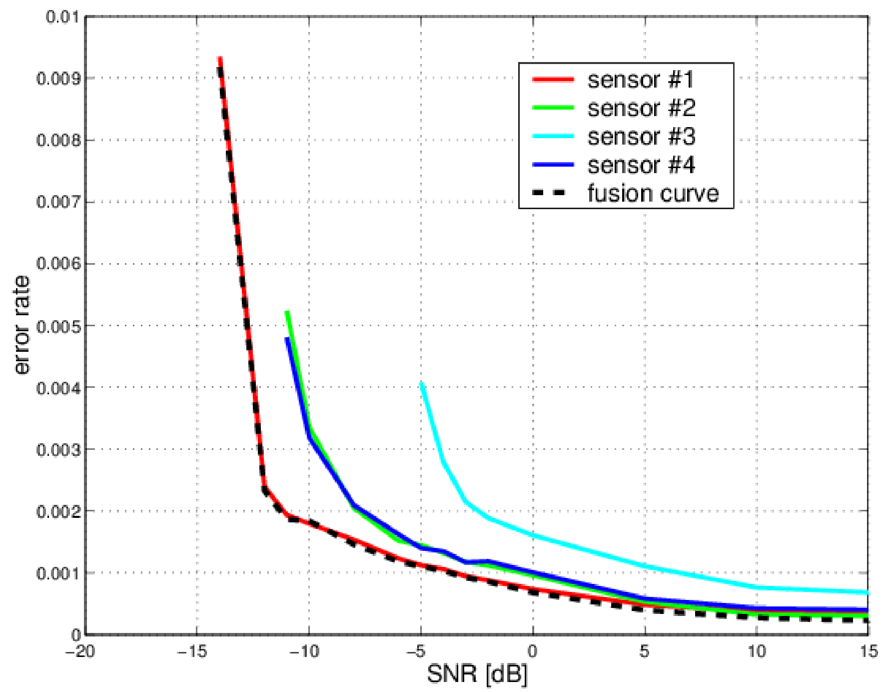


- Four sensing nodes and one source transmitting DBPSK with Barker sequence spreading(802.11b at 1Mbit/sec)
- Measured channel transfer functions from(H. Kremo, et al. VTC '07)

Collaborative Segmentation Fusion



Detection rate of the correct number of clusters

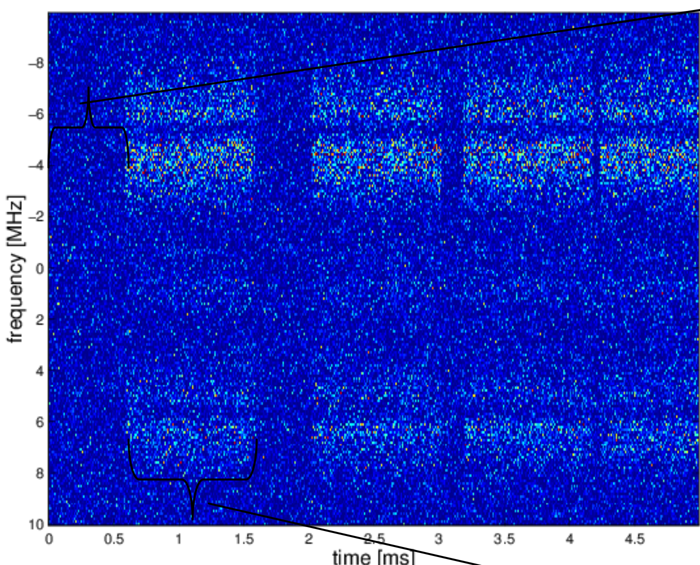


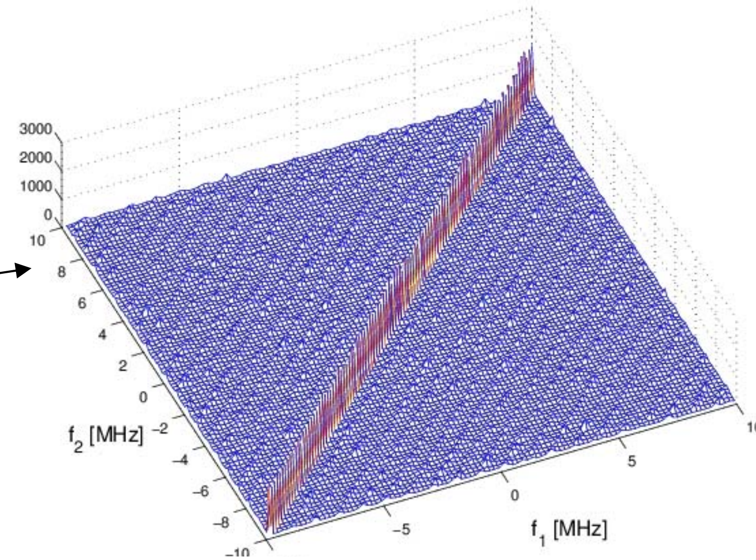
Segmentation error rate

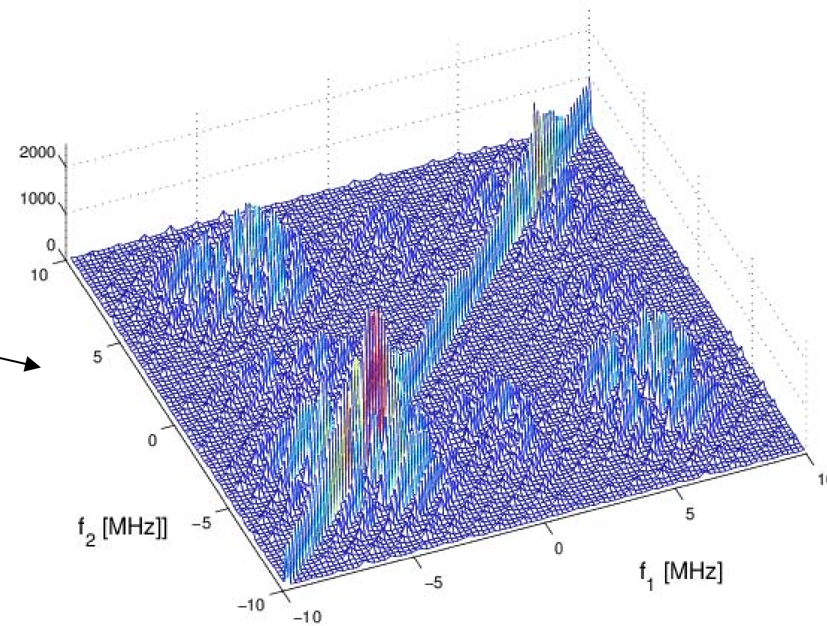
Fusion curves follow the sensor with the best SNR

Beyond segmentation: signal analysis

Noise only segment: there is PSD and no cyclostationary spectra







DBPSK signal plus noise: There are cyclostationary spectra at f1-f2=k/T (T=1μs)

Activity Segment Characterization: Fourth order spectrum (FOS) analysis

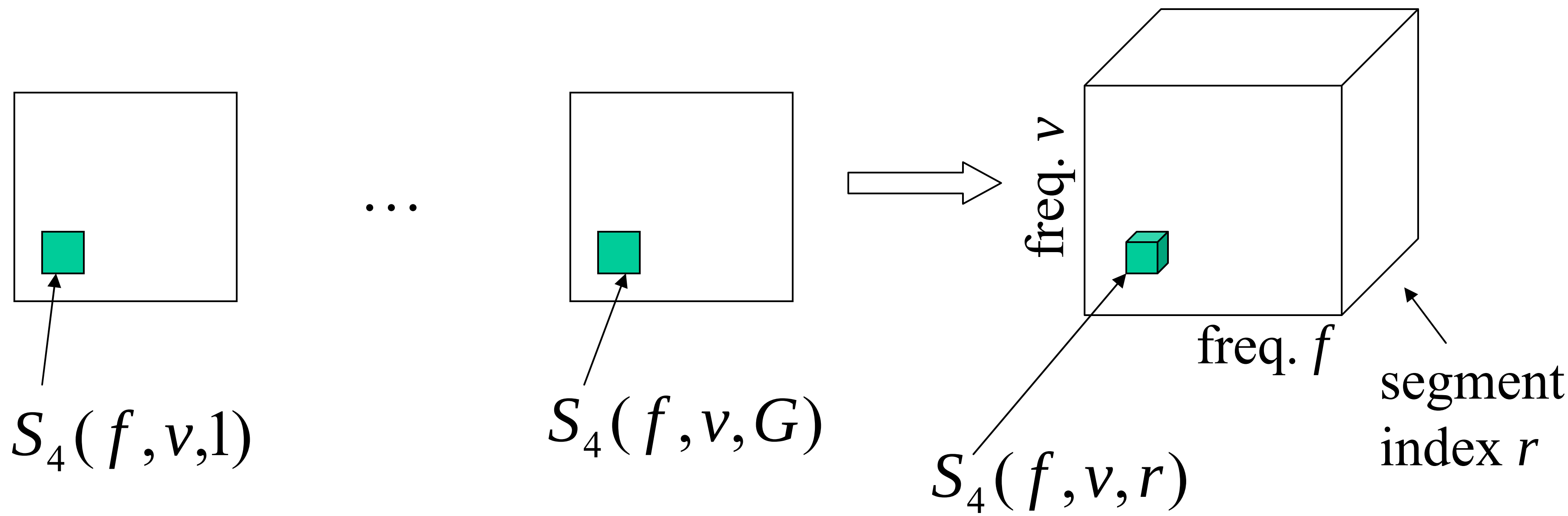
Characterizing transmissions over segments

- Determining transmission activity patterns for different possibly overlapping transmitters (blind source separation)

- Characterizing transmitter to sensor channels and/or spectra

- Characterizing transmitted spectra (blind deconvolution)

Three-way array of FOS/trispectrum slices



$$S_4(f,v,r) = \sum_{p=1}^{M} |H_p(f)|^2 |H_p(v)|^2 \; S_{4p}(f,v) c_{rp} + S_N(f,v)$$

channel

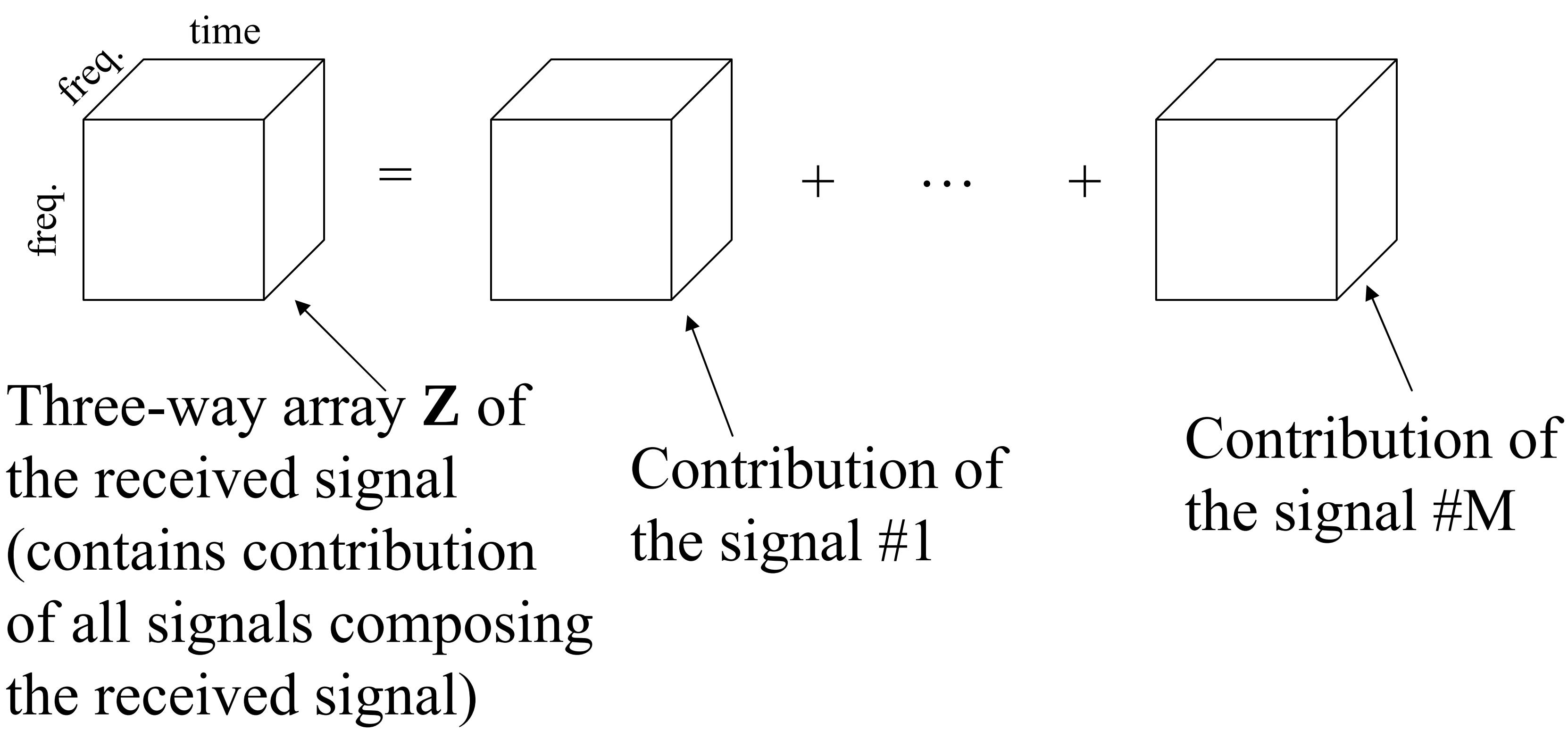
Tx Spectra

on/off sequence
of the p-th source

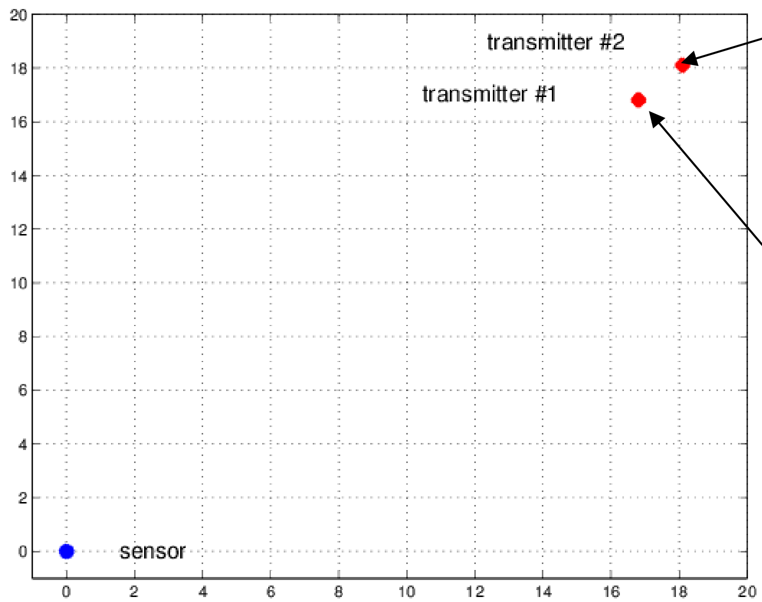
This is zero for
Gaussian noise

Tensor decomposition

- When the uniqueness conditions hold block terms representing contributions of individual signals can be ***uniquely*** recovered from **Z**



Bluetooth vs 802.11b interference

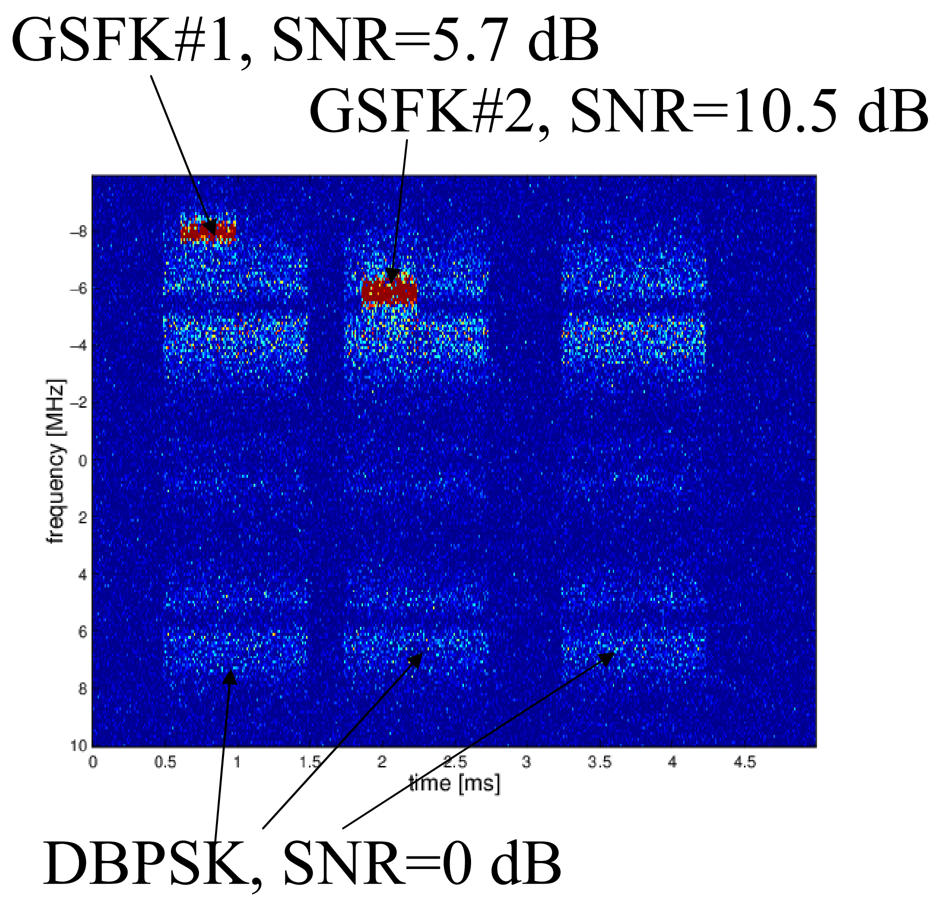


One source transmitting GFSK signal with frequency hopping (Bluetooth)

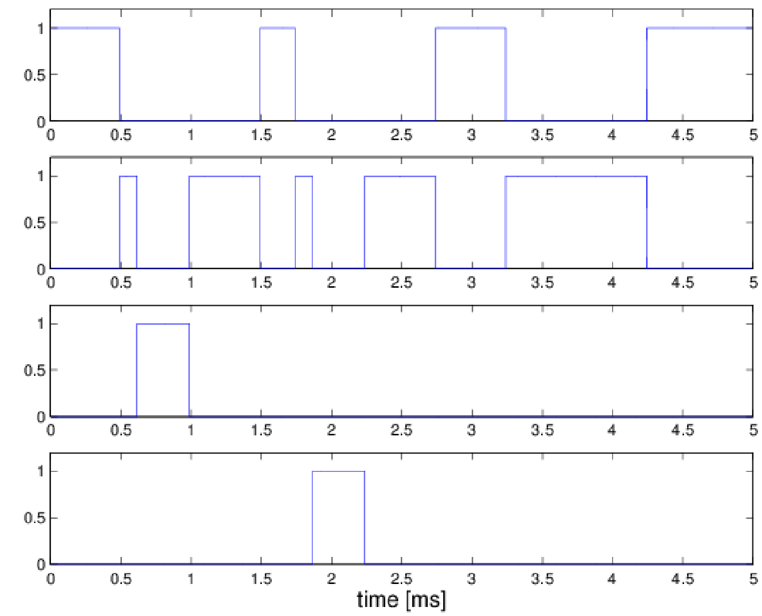
One source transmitting DBPSK with Barker sequence spreading (802.11b)

- One sensing node observes the 20MHz channel used by DBPSK transmitter
- Simulation uses the same measured channel transfer functions from(H. Kremo, et al. VTC '07)

Mean Shift Segmentation

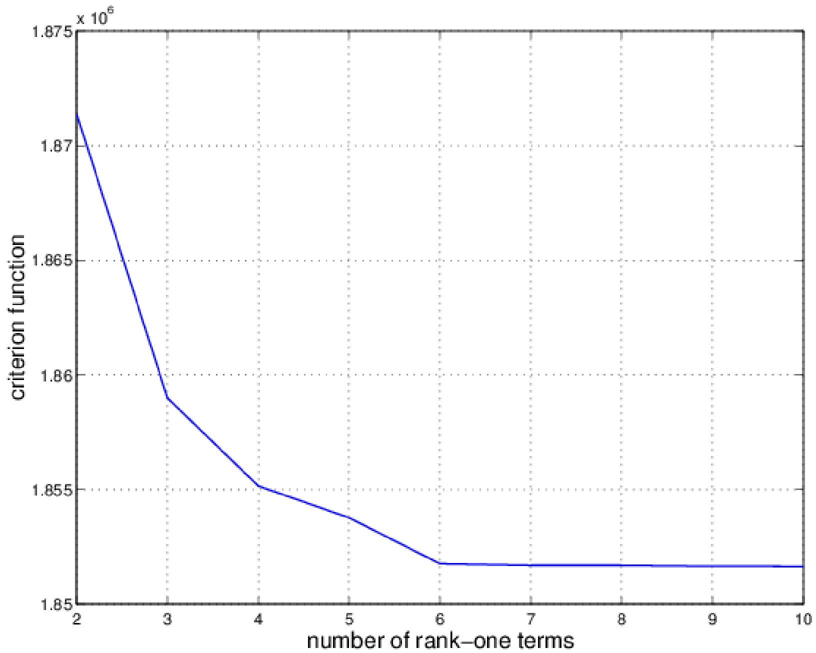


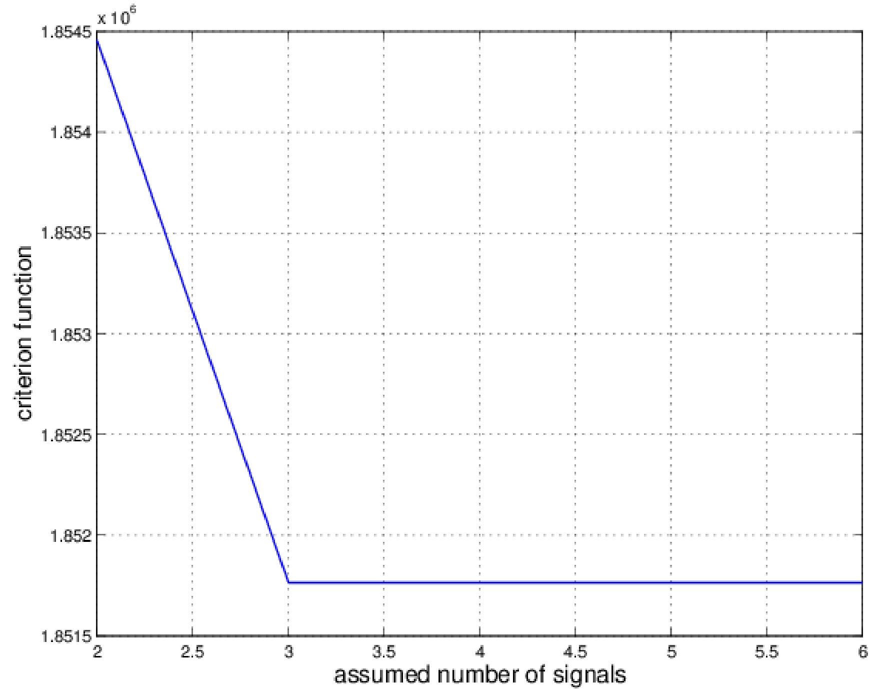
Spectrogram of the received signal
W=20 MHz, total observation
time 5 ms



Recovered segmentation
sequences

Finding the model parameters

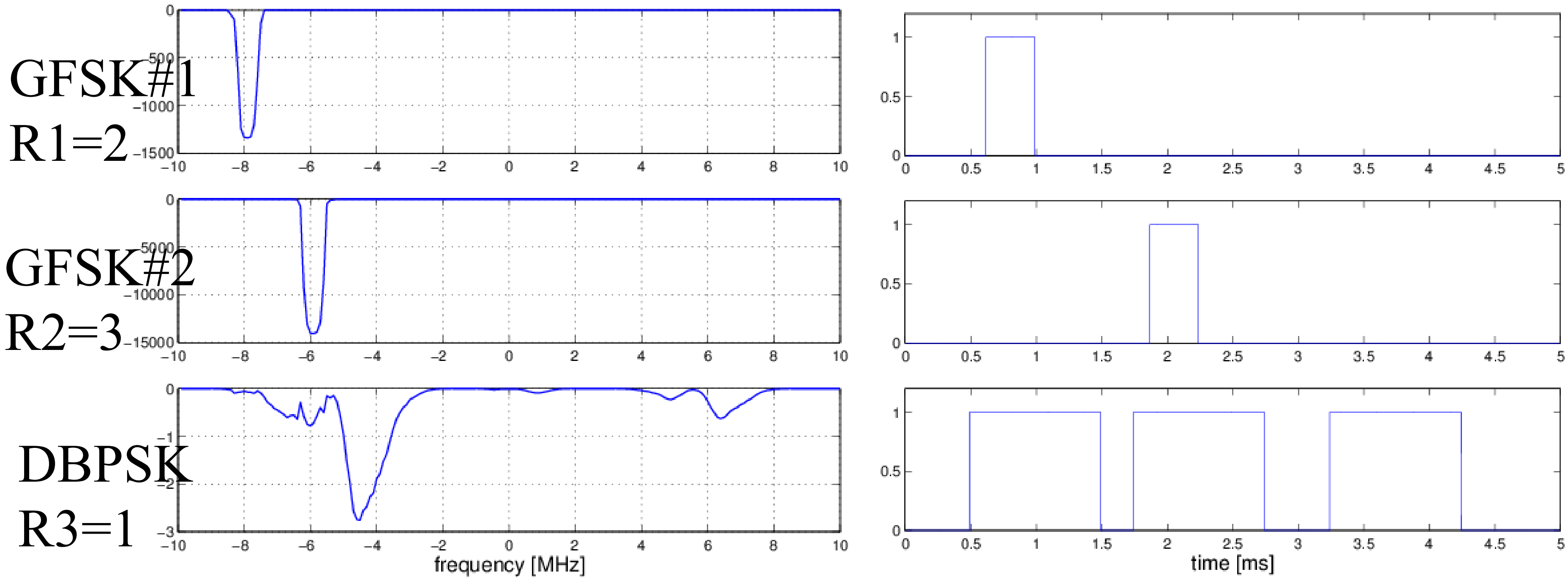




There are R=6 rank-one terms

There are M=3 signals

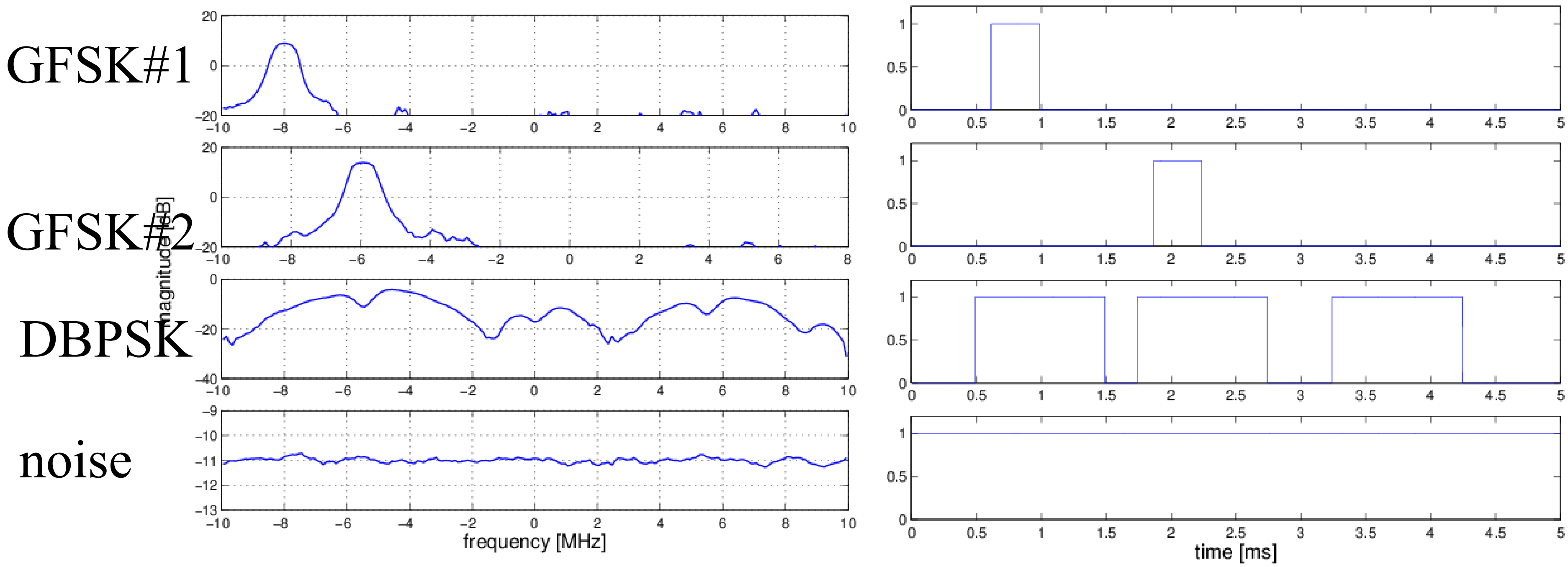
FOS analysis results



Recovered diagonal entries of the FOS slices

Recovered activity sequences

Recovered power spectra



Conclusion

- We proposed an algorithm which estimates spectra and on/off activity sequences of packet based radio signals
- The algorithm consists of two steps:
  - Signal segmentation
  - Fourth order spectrum based analysis
- Performance limitations
  - Segmentation algorithm typically breaks down at some threshold SNR
  - FOS based analysis can recover only sufficiently strong signals or their rank-one terms
- When multiple sensors are available
  - single sensor performance limitations can be overcome
  - it is possible to localize identified transmitters in space

Greedy Channel Surfing for Occupancy Analysis in Packet-Based Wireless Networks

Shridatt Sugrim

Advisors: Melike Baykal-Gursoy and Predrag Spasojevic