

Activity Monitoring/ Radio Scene Analysis and Radio Channel Characterization

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September 2013

Topics

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

Propagation Characterization of the ORBIT Radio Testbed

Student: 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



transmitter

60 feet
low-loss
cables

receiver

VNA

- LNA

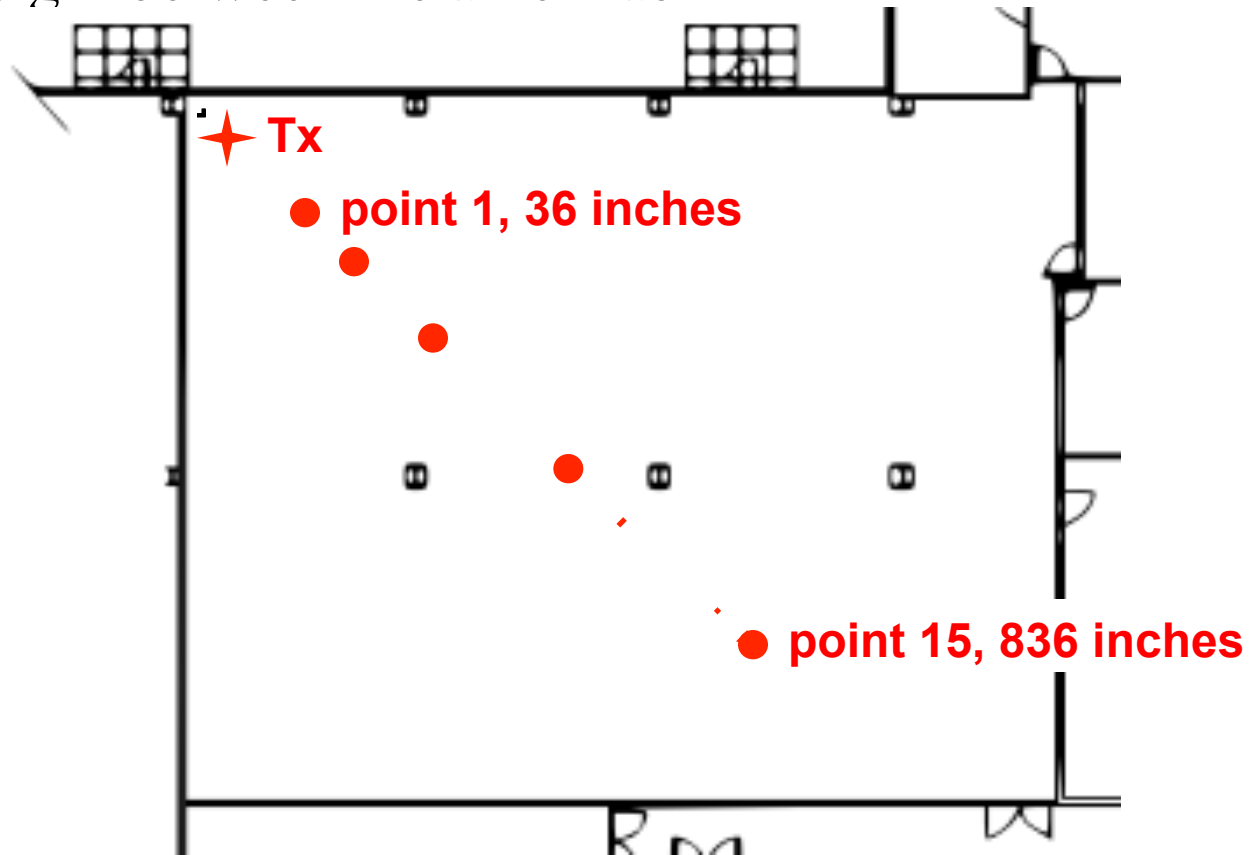
Ethernet

control and data
collection

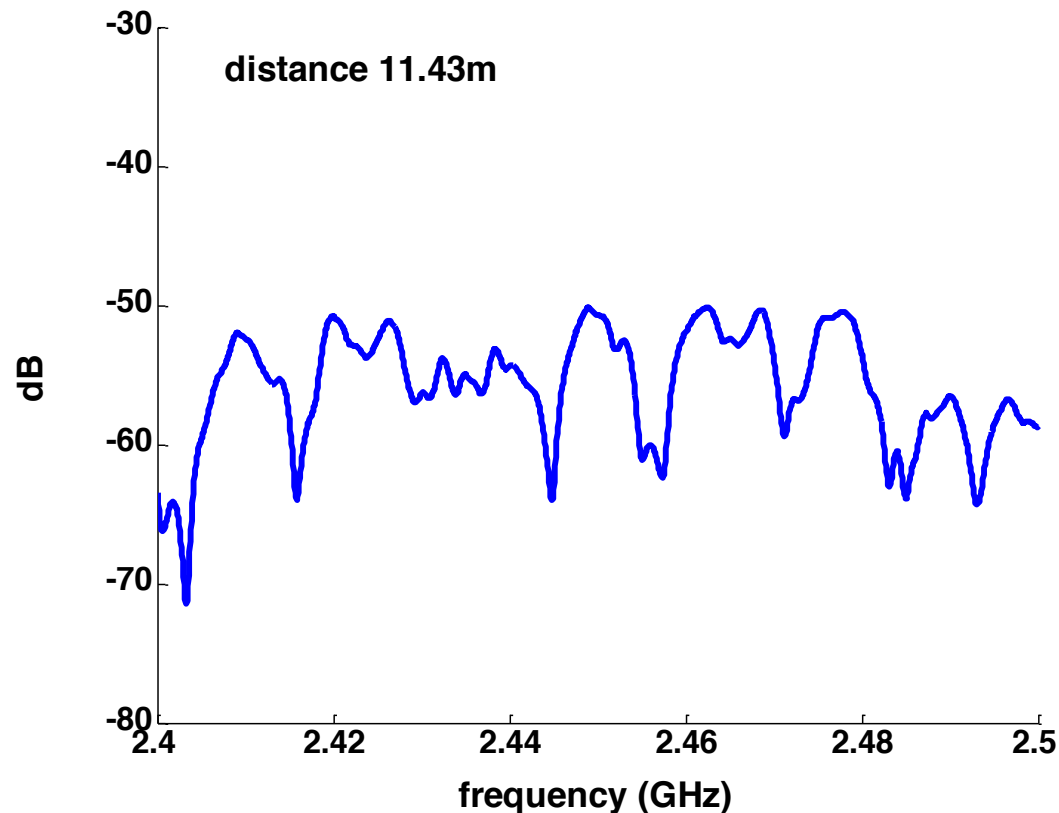


Case study “receiver on a diagonal”

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

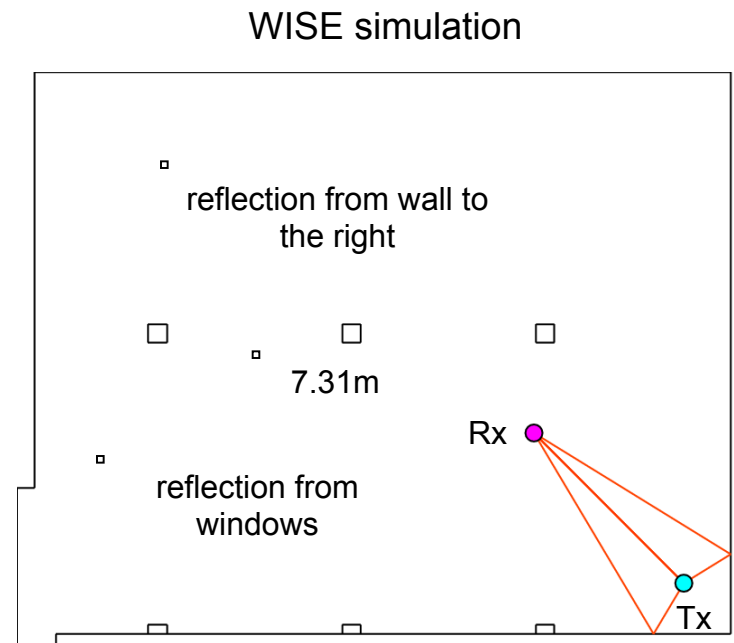
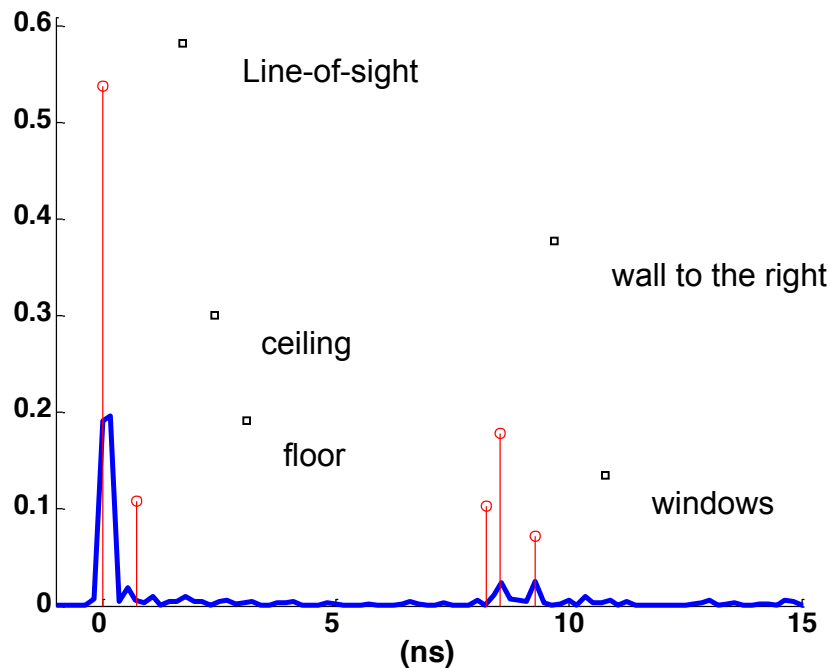


Example channel response magnitude



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)



References

H. Kremo, J. Lei, I. Seskar, L. Greenstein, and P. Spasojevic, "Characterization of the ORBIT Indoor Testbed Radio Environment," IEEE 66th Vehicular Technology Conference (VTC), Baltimore, Maryland, USA, October 2007

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

Student: Goran Ivkovic

Advisors: Predrag Spasojevic and Ivan Seskar

ISM Band Monitoring: Current Tools

- Wifi Scanners/Discovery tools
- Handheld/USB Spectrum Analyzers
- Automated Monitoring and Spectrum Management Systems
 - E.g., Cisco, Aruba, etc.

Radio Monitoring: State of the art

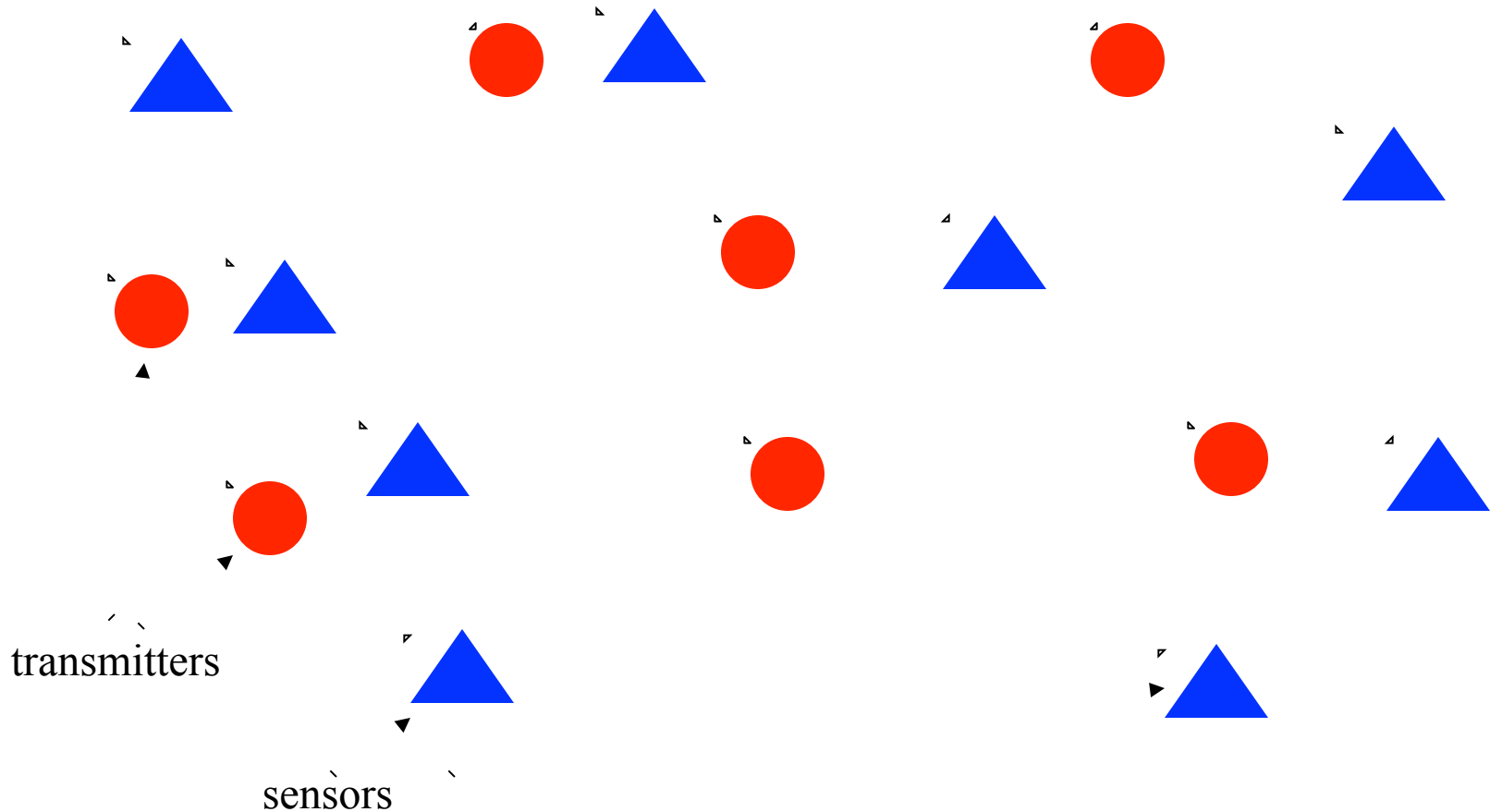
- Focus on visualization
- Average channel quality
- channel utilization
- duty cycle
- channel availability
- interference power
- Device identification
- Long term averaging analysis (10s of seconds)

Radio Scene Analysis

- Fine grained activity analysis
 - Short term analysis (on a per packet basis)
 - Short burst transmissions (e.g., BLE)
 - Protocol monitoring (is the Wifi system backing off as per spec)
- Collision analysis
 - resolving signal transmissions simultaneous in time and frequency
- Signal and channel identification, characterization, and locationing
 - Locating signals in time, frequency, and space
- Unknown/non-parametric signal analysis
 - Not a lookup table approach
 - Allows new/different signal characterization
- Multi-resolution analysis
 - In time/activity and frequency
- Collaborative multi-sensor analysis
- Sub-millisecond resolution (capturing SIFS, DIFS, etc)

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

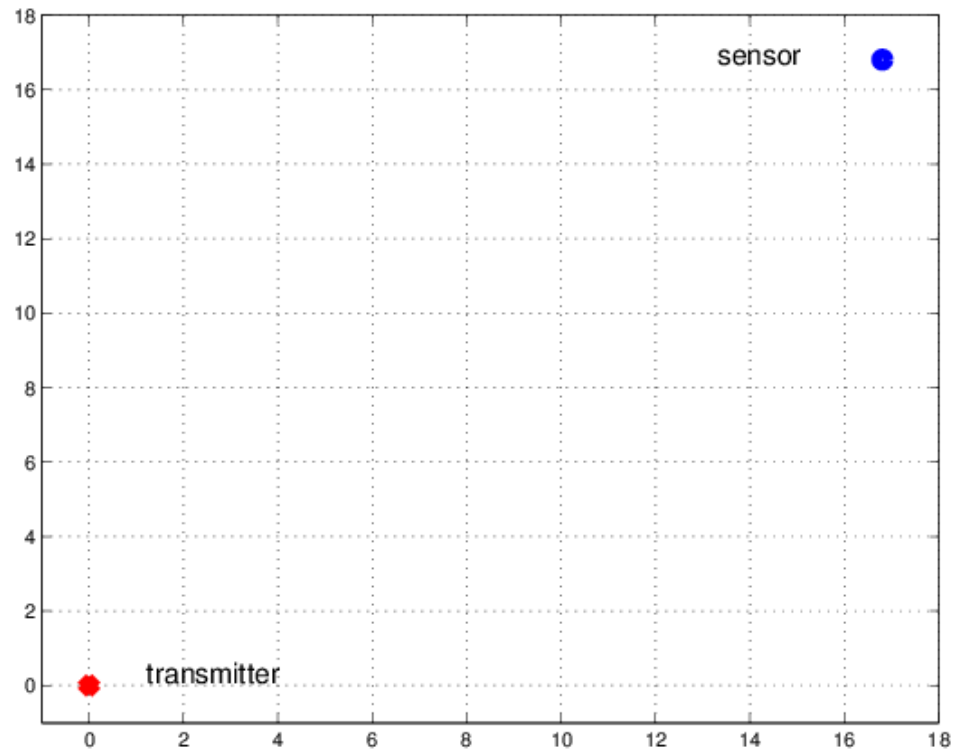
Main technical problems

- Signal segmentation:
 - We developed a nonparametric segmentation method which finds statistically homogeneous segments in the received signal
- Fourth order spectrum based signal analysis:
 - We developed a method which under certain assumptions can estimate spectrum and an associated on/off activity sequence for each present signal
- Blind deconvolution:
 - When multiple sensors are available it is possible to separate source spectrum and the sensors to sources channel transfer functions for each identified transmitter

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

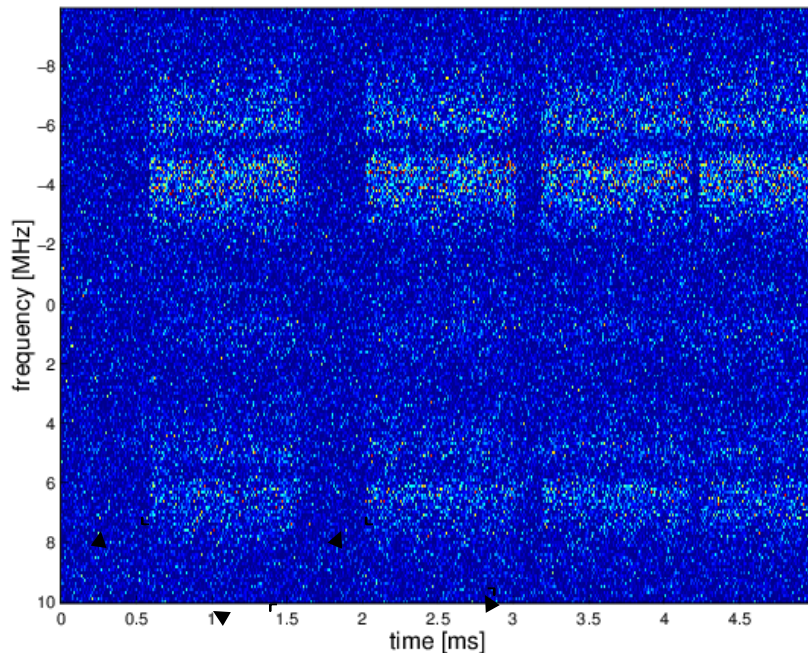
Single Transmitter-Single Sensor Example



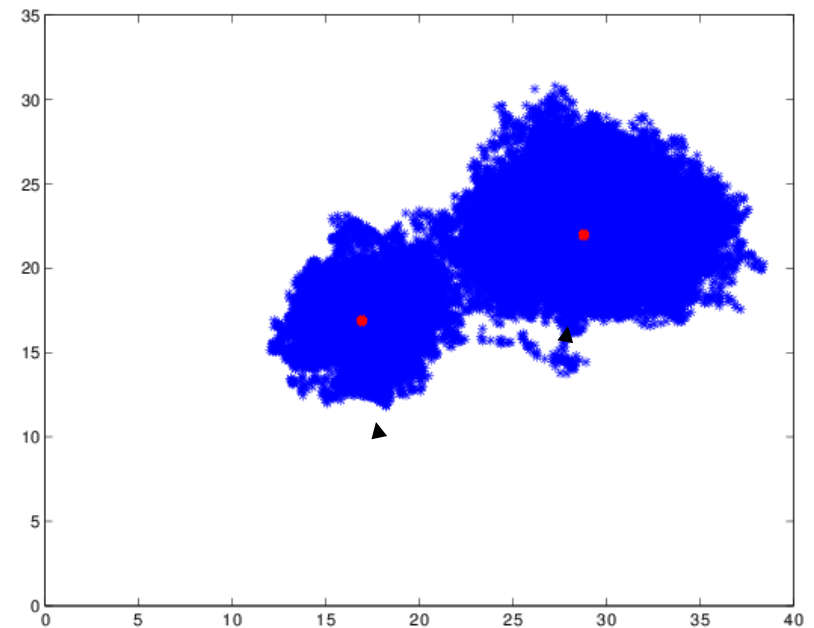
- One sensing node and one source transmitting DBPSK with Barker sequence spreading(802.11b at 1Mbit/sec)
- Measured channel transfer functions from(H. Kremo, et al. VTC ' 07)

Spectra (Second Order Statistics) Clustering

Spectrogram of the received signal ($W=20\text{MHz}$, total observation time 5 ms)



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

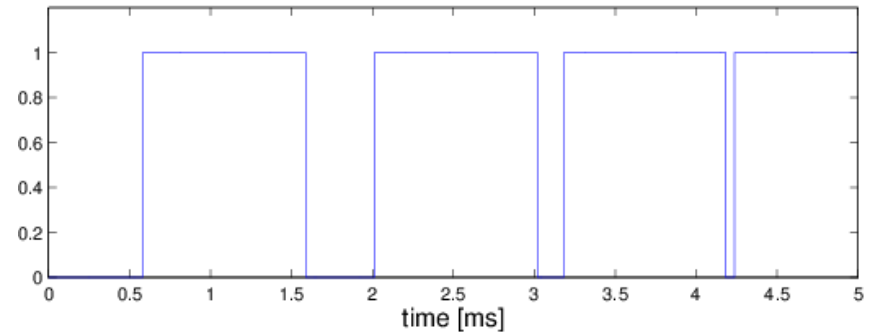
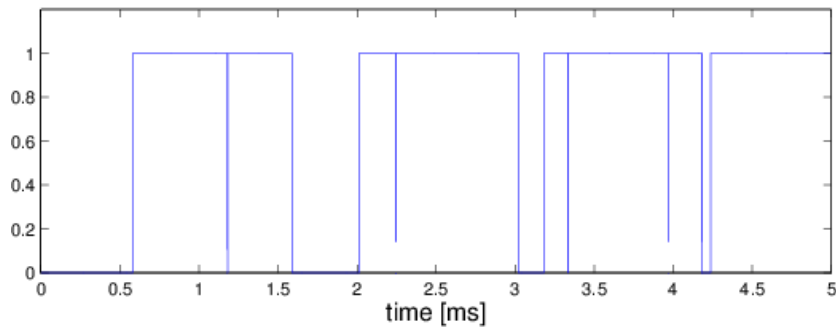
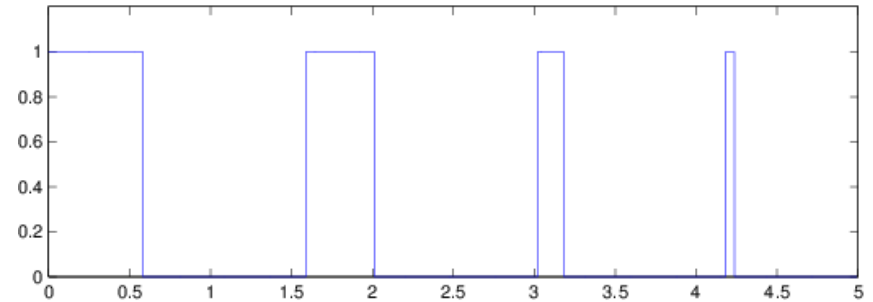
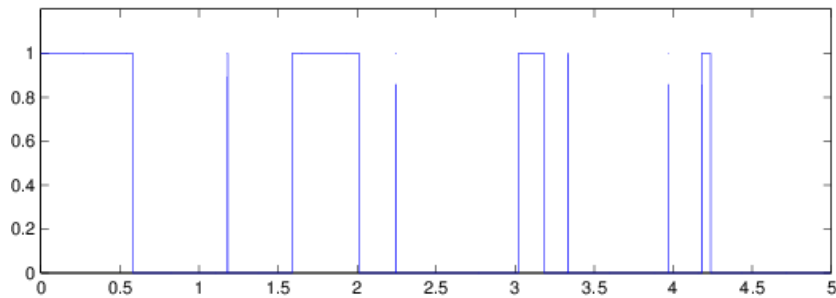


noise segments

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

There are two clusters

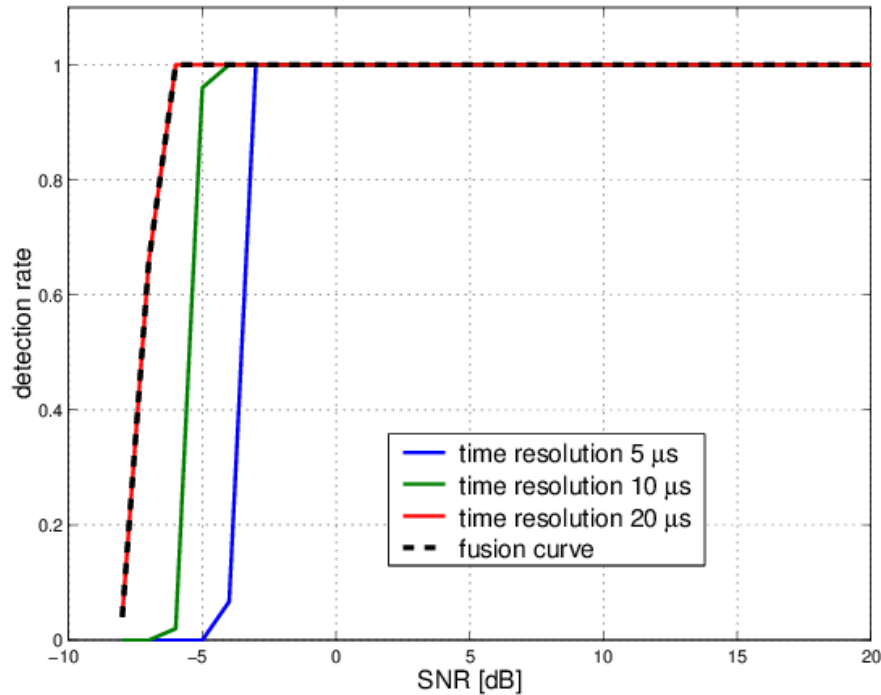
Activity Segmentation and Impulse Noise Removal



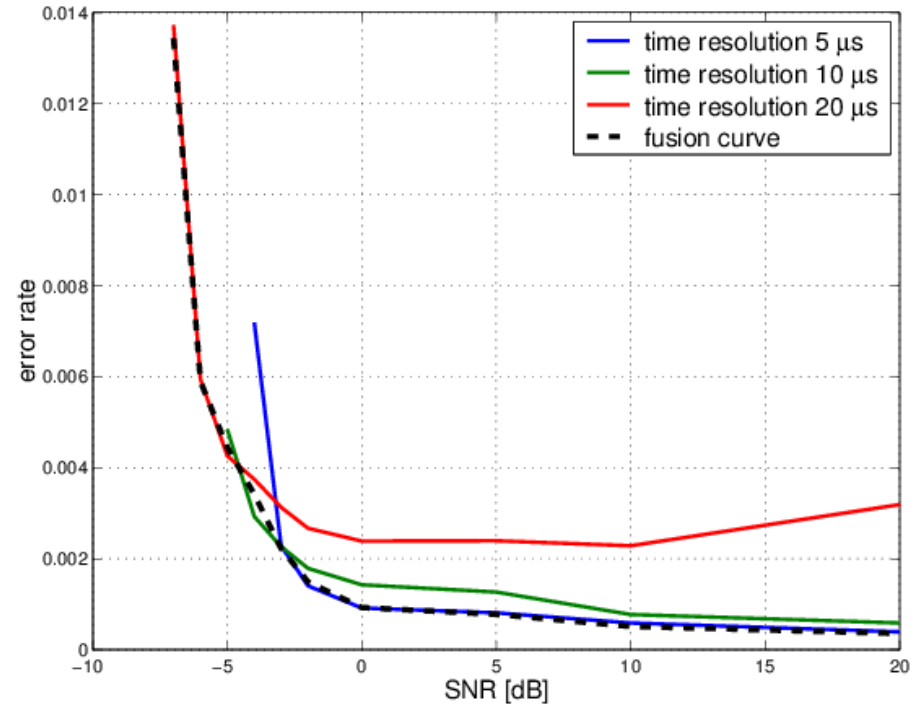
Segmentation results before
impulse noise removal

Segmentation results after
impulse noise removal

Multiresolution Segmentation Fusion



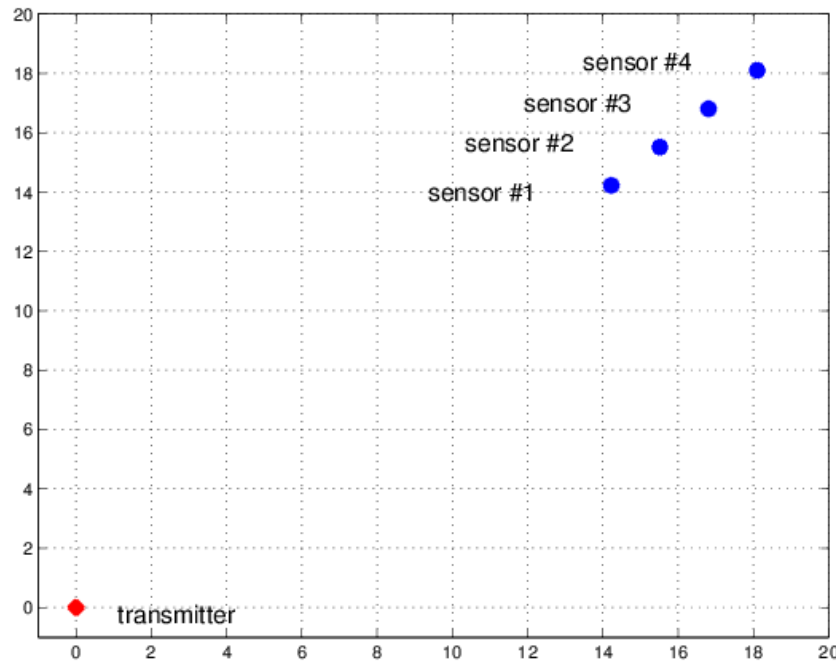
Detection rate of the correct number of clusters



Segmentation error rate

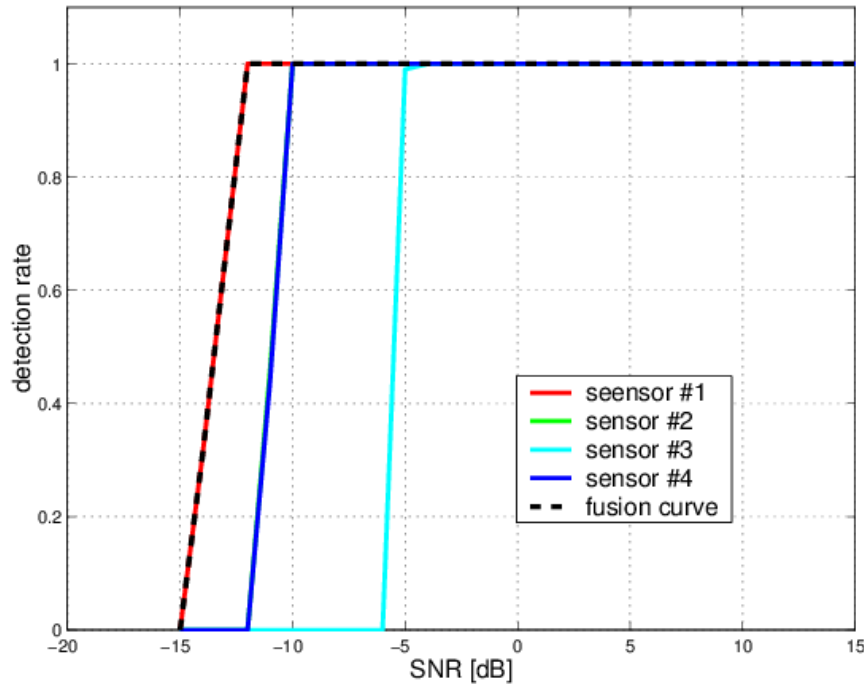
The algorithm is useful up to a threshold SNR

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

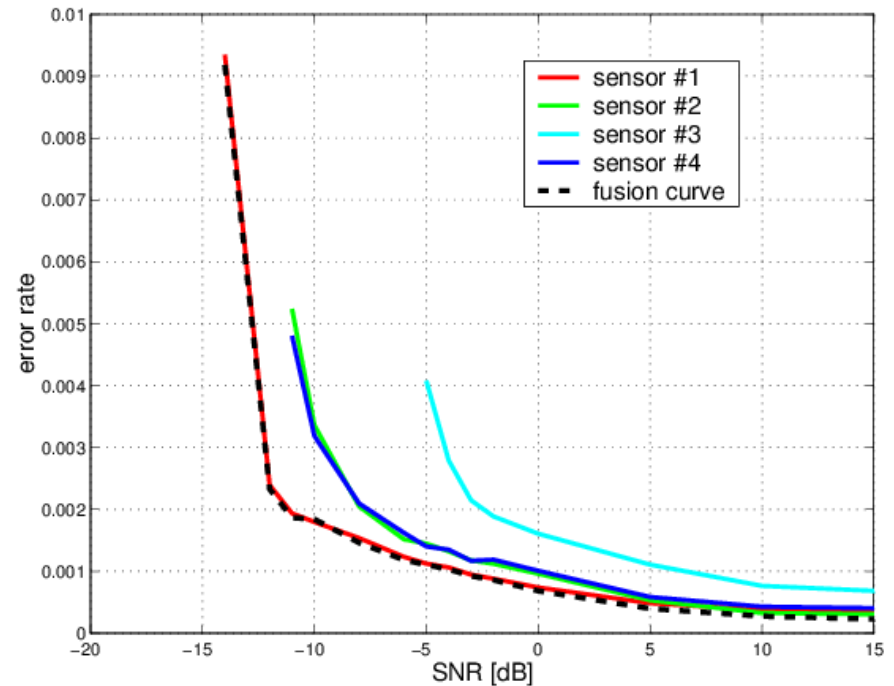


- Four sensing nodes and one source transmitting DBPSK with Barker sequence spreading(802.11b at 1Mbit/sec)
- Measured channel transfer functions from(H. Kremo, et al. VTC ' 07)

Collaborative Segmentation Fusion



Detection rate of the correct number of clusters

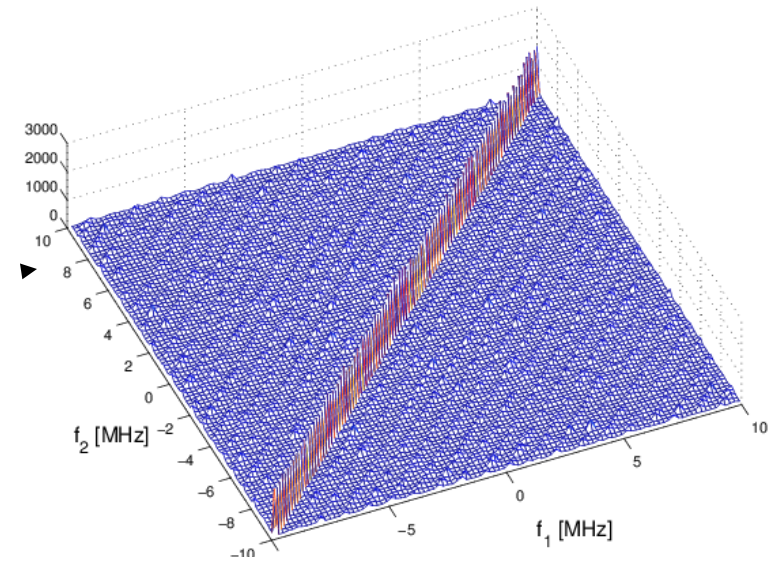
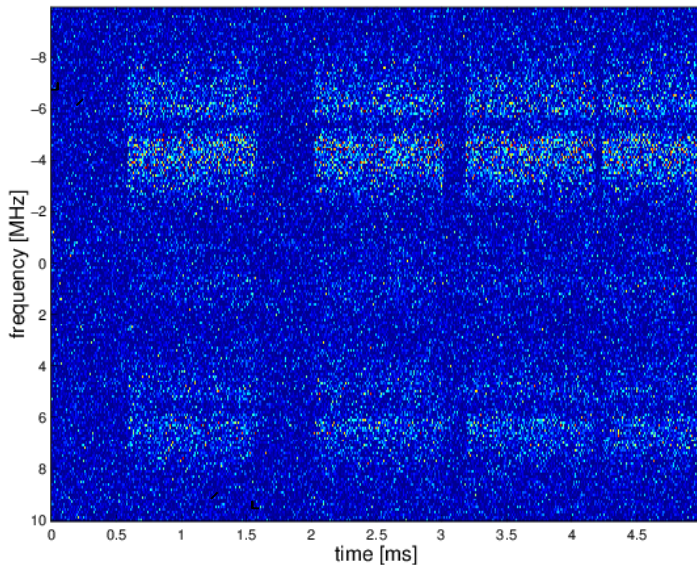


Segmentation error rate

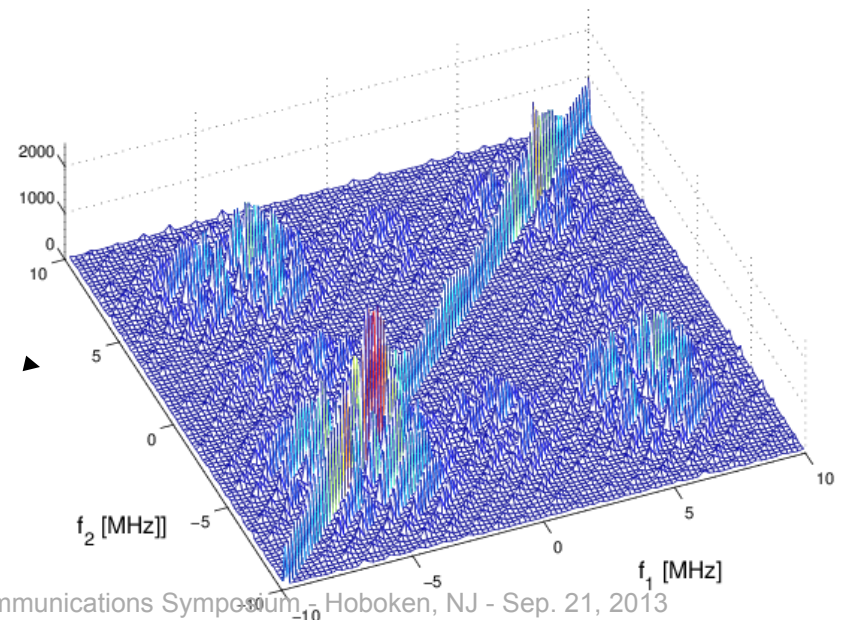
Fusion curves follow the sensor with the best SNR

Beyond segmentation: signal analysis

Noise only segment: there is PSD and no cyclostationary spectra



DBPSK signal plus noise:
There are cyclostationary
spectra at $f_1 - f_2 = k/T$ ($T = 1\mu s$)

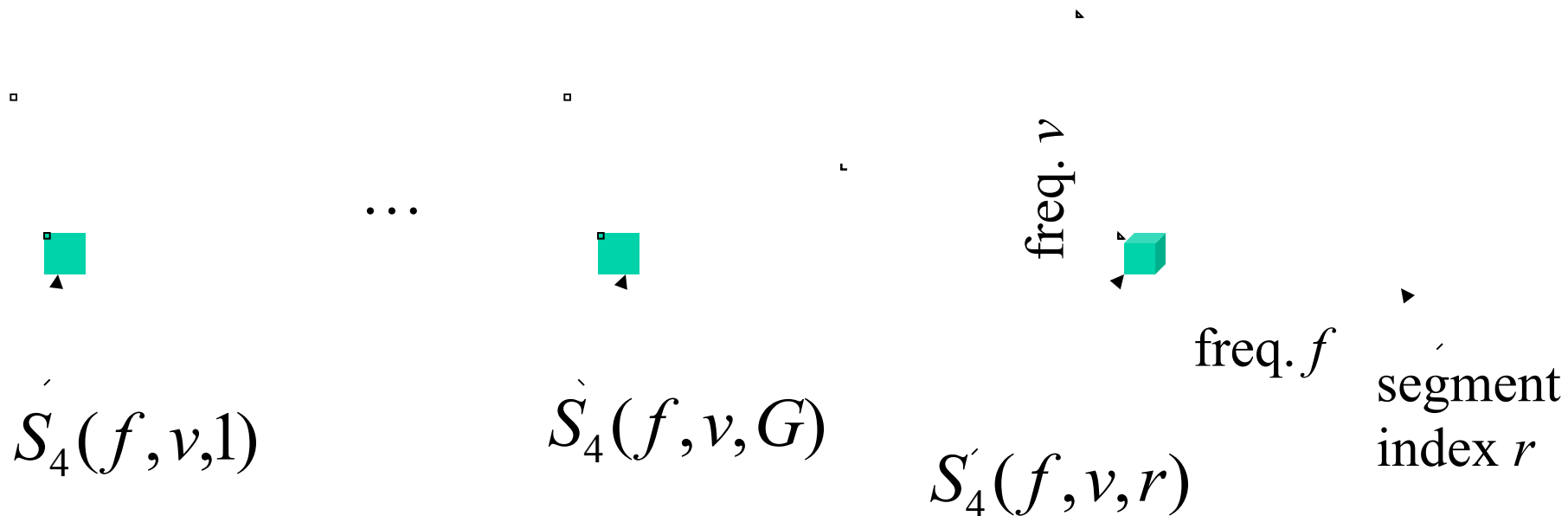


Activity Segment Characterization: Fourth order spectrum (FOS) analysis

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

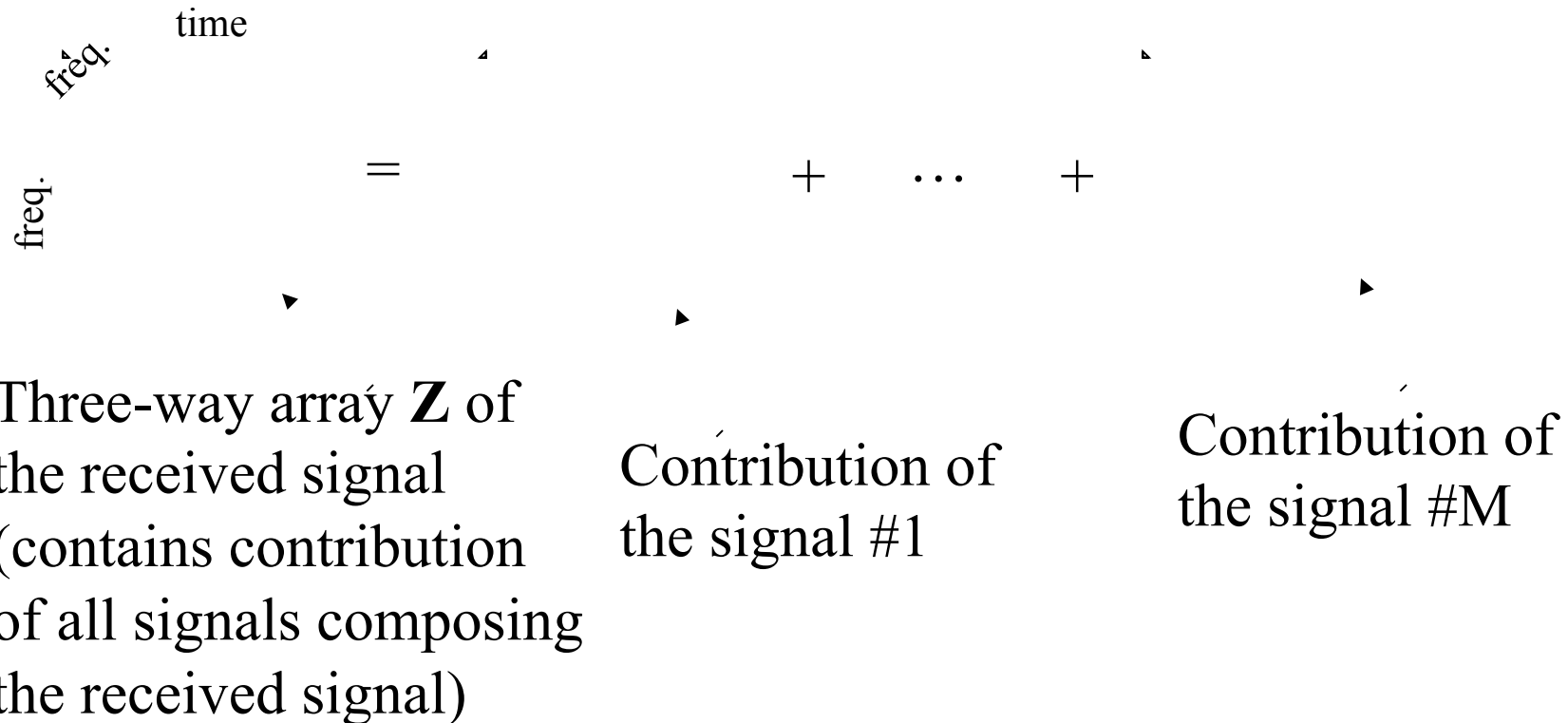
Tx Spectra

on/off sequence
of the p-th source

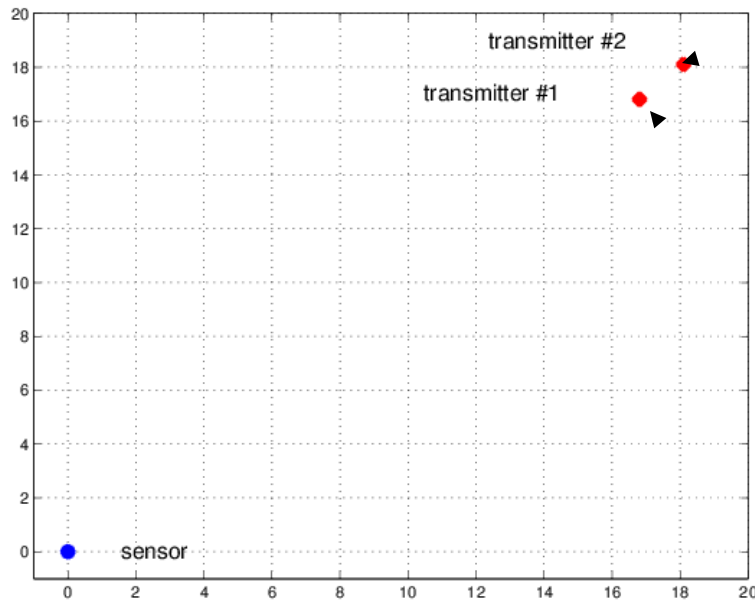
This is zero for
Gaussian noise

Tensor decomposition

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



Bluetooth vs 802.11b interference



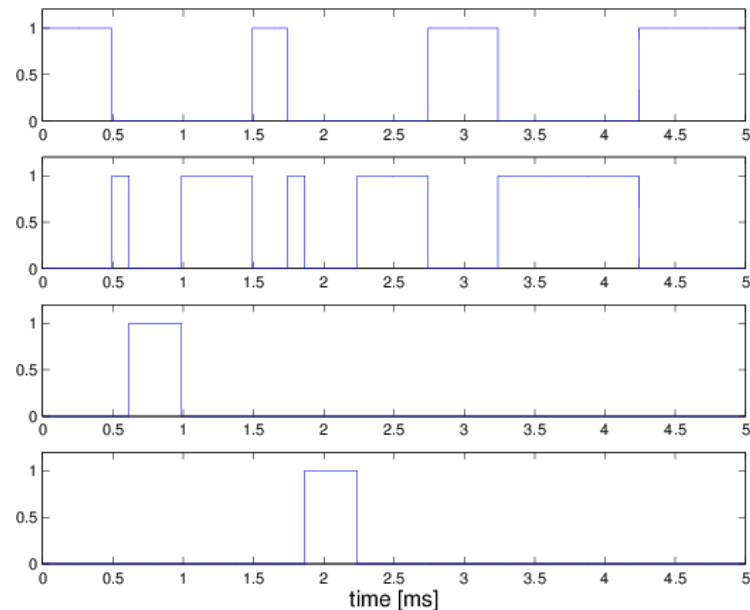
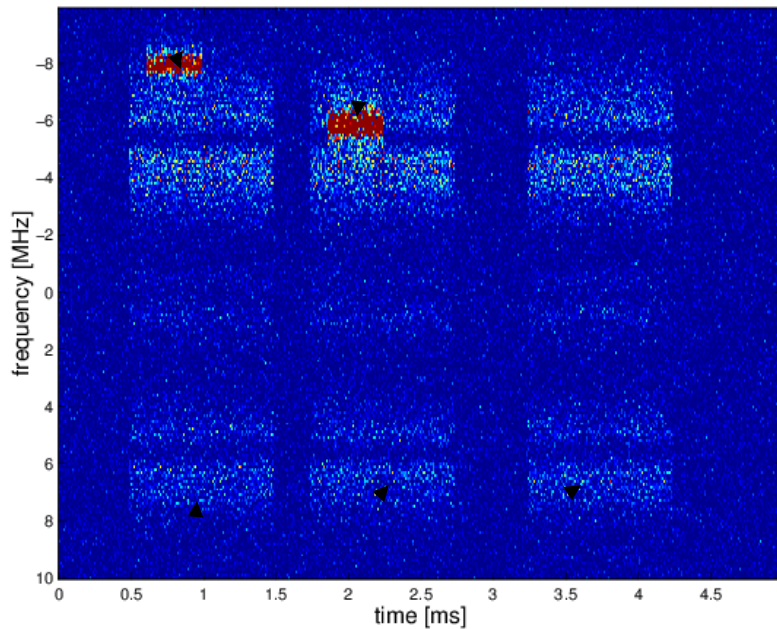
- One source transmitting GFSK signal with frequency hopping (Bluetooth)
- One source transmitting DBPSK with Barker sequence spreading (802.11b)

- 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

GSFK#1, SNR=5.7 dB

GSFK#2, SNR=10.5 dB

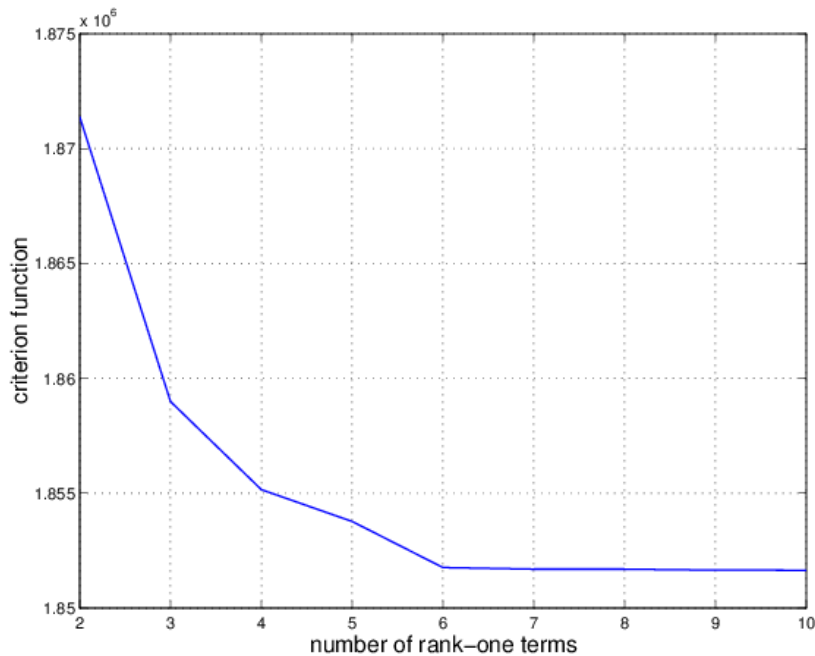


DBPSK, SNR=0 dB

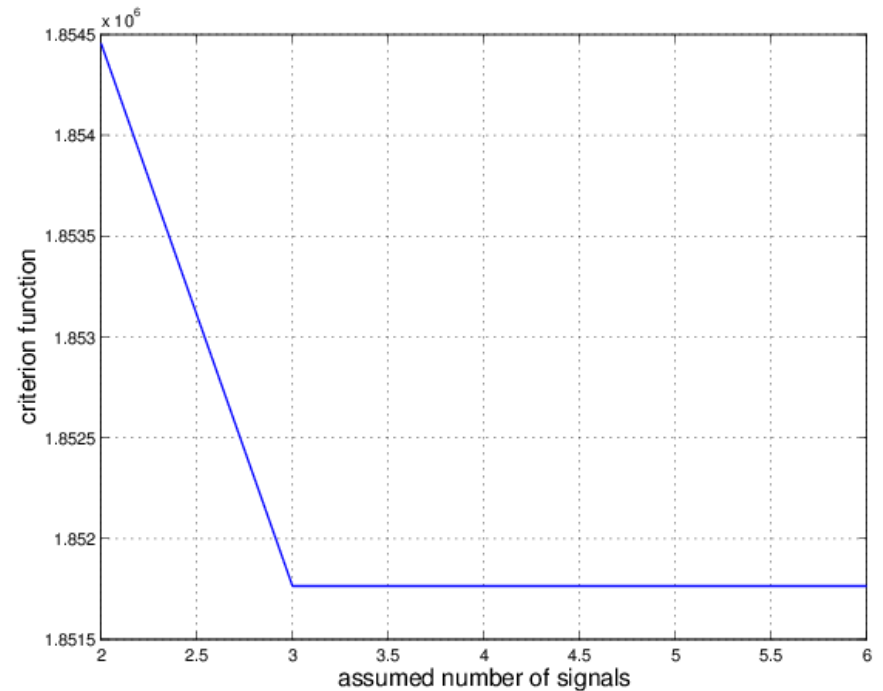
Spectrogram of the received signal
W=20 MHz, total observation
time 5 ms

Recovered segmentation
sequences

Finding the model parameters

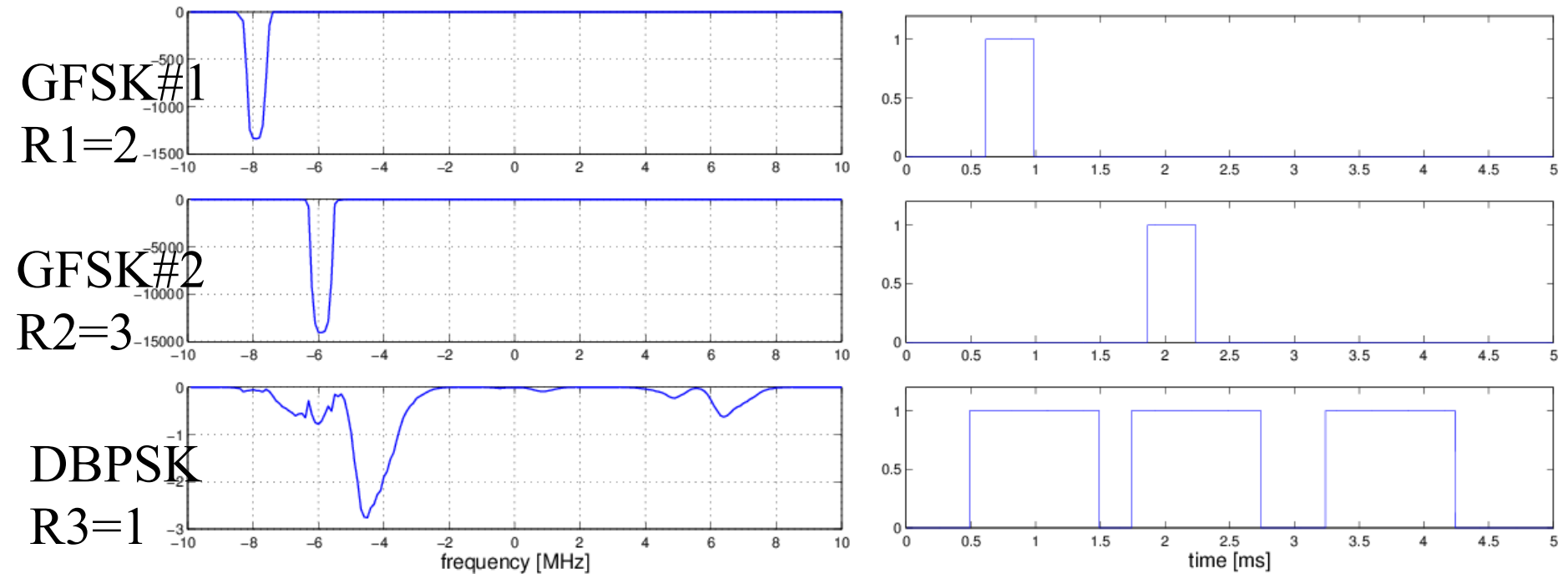


There are $R=6$ rank-one terms



There are $M=3$ signals

FOS analysis results

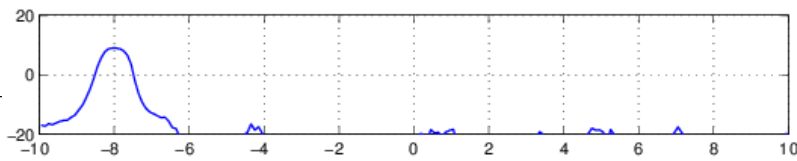


Recovered diagonal entries of the
FOS slices

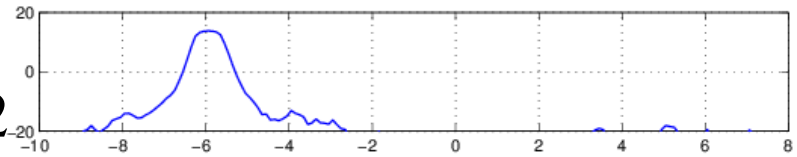
Recovered activity sequences

Recovered power spectra

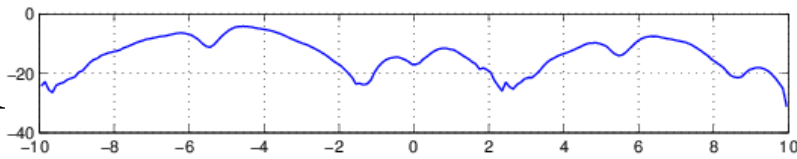
GFSK#1



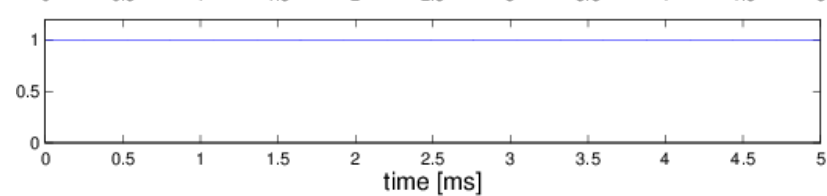
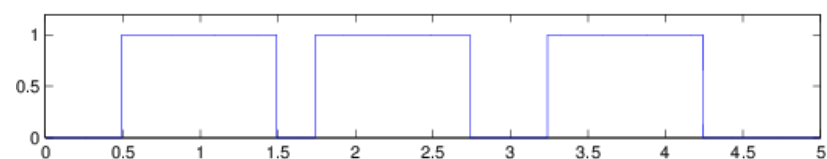
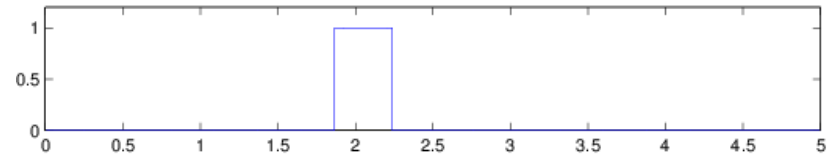
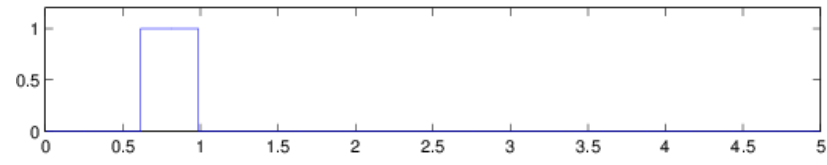
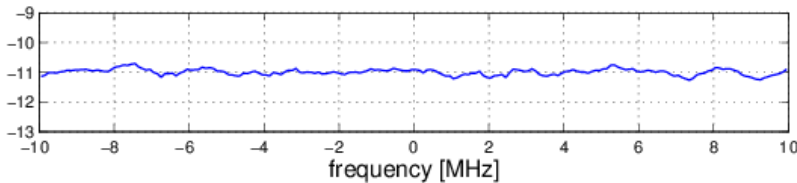
GFSK#2



DBPSK



noise



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

References

- G. Ivkovic, P. Spasojevic and I. Seskar: "Mean shift segmentation for time-frequency analysis of packet based radio signals" in Proc. Asilomar Conf. on Signals, Systems and Computers, Pacific Grove, CA, Nov. 2010
- G. Ivkovic, P. Spasojevic, and I. Seskar, "Single sensor radio scene analysis for packet based signals," Workshop on Information Theory and Applications (invited talk), UCSD, La Jolla, CA, Jan. 2010.
- G. Ivkovic, P. Spasojevic, and I. Seskar, "Localization of packet based radio transmitters in space, time, and frequency," in *Proc. Asilomar Conf. on Signals, Systems and Computers*, Pacific Grove, CA, Oct. 2008, pp. 288–292.
- G. Ivkovic, P. Spasojević, and I. Seskar, "Radio scene analysis using trilinear decomposition," in *Proc. Conf. on Information Science and Systems*, Princeton, NJ, March 2008, pp. 128–133.
- G. Ivkovic, P. Spasojevic, and I. Seskar, "A power sensor network for identification of heterogeneous wireless networks," in *Proc. Conf. on Information Science and Systems*, Baltimore, MD, March 2007, pp. 765–770.