Distributed spatio-temporal spectrum sensing: An experimental study

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Spatio-temporal spectrum sensing

How do we localize multiple transmitters in space and frequency using multiple (collaborating) sensors?
Spectrum sensing for Dynamic Spectrum Access

- Spectrum sensing mandated in cognitive radio standards, e.g., IEEE 802.22
- Usage of unused white spaces require faster sensing
  - coarse localization OK
- Challenges of identifying transmitters in unlicensed band
  - multiple heterogeneous radios
  - sporadic transmissions
  - transmission over a wide band
Radio platforms in ORBIT, WINLAB

Radio Mapping Concept for ORBIT Emulator

Interfaces supported: Zigbee, WiFi, Bluetooth, GNU Radio

Programmable ORBIT radio node

Planned upgrade (2007-08)

400-node Radio Grid Facility at WINLAB Tech Center

Current ORBIT sandbox with GNU radio

URSP2 CR board

http://www.orbit-lab.org
GNU Hardware/Software platform (Blossom)

- GNU/USRP boards with GNU Software with API's for flexible PHY and MAC are currently available for experimentation
- Various RF front-ends (0-100MHz, 400MHz, 900MHz, 2.4GHz) with data rates upto 64 MSamples/sec
  - Limitation of USB 2.0 interface
- All DSP functions in software on general-purpose CPU
Spectrum sensing problem

- Using frequency agile sensors capable of sensing limited band
  - How do we localize interfering transmitters in space?
  - How can we find the spectral occupancy in a given band of frequencies?
Overview of topics

- Localization of single transmitter
- Localization of two transmitters in the same band
- Spectral occupancy over a wide band
  - Localizing the frequency of a single transmitter
- Challenges and future work
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Algorithm for localizing single transmitter

- Assumption: Transmitting bandwidth $W$ known, i.e., $[f_0-W/2, f_0+W/2]$
- Sensors tuned to center frequency $f_c \in [f_0-W/2, f_0+W/2]$
- Multiple snapshots of time samples collected
- Find sensed power over sensing bandwidth
- Transmitter localized from sensed power at each sensor by triangulation
Example: Localizing one transmitter using 4 sensors

1. Transmitting source
2. Sampling/Decimation (64 MS/s)
3. 256 pt FFT
4. \( \sum |X_i(f)|^2 \)
5. Threshold \((Y_j > T_j)\)
6. Localize Source \((x, y)\)
Experiment set-up

IEEE 802.11b Transmitter

Sensor 1
Sensor 2
Sensor 3
Sensor 4

Sensor
Transmitter
Sensed power over 4 MHz band

≈ 2 sec
Histogram of sensed power (after thresholding)

Sensor 1

Sensor 2

Sensor 3

Sensor 4
Localized regions of transmission

Error ≈ 16 ft

Sensor
Transmitter
Localized Regions
Overview of topics

- Localization of single transmitter
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  - Localizing the frequency of a single transmitter
- Challenges and future work
Localizing two sources

**Challenge:**
- Localizing two interfering transmitters
- Multiple access schemes, e.g., collision avoidance necessary to distinguish transmitters

**Solution:**
- Synchronous sensing
- Exploit asynchronous transmissions
Experiment set-up
Sensed power over 4 MHz band

Sensor 1

Sensor 2

Sensor 3

Sensor 4
Histogram of sensed power (after thresholding)

Sensor 1

Sensor 2

Sensor 3

Sensor 4

Sensed power over 4 MHz $\times 10^{10}$

Sensed power over 4 MHz $\times 10^{10}$

Sensed power over 4 MHz $\times 10^{10}$

Sensed power over 4 MHz $\times 10^{10}$
Localized regions of transmission

Error 1 \approx 13 \text{ ft}

Error 2 \approx 9 \text{ ft}

- Sensor
- Transmitter
- Localized Regions

WINLAB

WIRELESS INFORMATION NETWORK LABORATORY
Overview of topics

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- Spectral occupancy over a wide band
  - Localizing the frequency of a single transmitter
- Challenges and future work
Determining spectral occupancy

- In reality, transmission frequency is unknown
- Localization techniques require localizing the transmitters in frequency
- Sweeping contiguous bands leads to longer sensing time
- Dividing band among sensors => more sensors required
Algorithm to determine spectral occupancy

- Assume single transmitter in band of width $W$ Hz centered at $f_0$, i.e., $[f_0 - W/2, f_0 + W/2]$
- Sensor $j$ randomly jumps to center frequency $f_j \in [f_0 - W/2, f_0 + W/2]$
- Each sensor senses the spectrum in the band $[f_j-2, f_j+2]$
- Samples taken for enough time to capture burstiness, e.g., 5 - 7 mins
- Sensor data “correlated” to detect activity in the band of $W$ Hz
Spectral occupancy

Sensor 1

Sensor 2

Sensor 3

Sensor 4
Spectral occupancy
(two dimensional projection)

Sensor 1

Sensor 2

Sensor 3

Sensor 4
Envelope of sensed power

Activity detected on channel 11 of 802.11b band
Challenges in spectrum sensing

- Calibration of sensing devices
  - Problem when there is a large number of sensors
- Trade-off between Cost and Complexity of sensing
  - Advanced signal processing/detection techniques for better localization
- Localizing heterogeneous transmitters
  - Device identification e.g., Bluetooth and Wi-Fi
- Granularity of coordination among sensors
- Improving time for localization