Implementing cognitive radio principles on VSN

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Outline

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- ISM Bands and Regulatory
- Spectrum sensing
- Versatile Sensor Node Platform
- CC1101/CC2500 Transceivers
- Measurement Setup and Results
- Conclusion
Introduction

The wireless medium:
- Limited resource
- Shared among many users
- Requires coordinated usage

The transmission of radio waves is regulated by international and national regulatory authorities, determining:
- Frequency allocation
- Licensing to different technologies and systems
Introduction

- Licensed spectrum for exclusive use became a scarce resource:
  - New wireless technologies
  - Increasing frequency demands
- Measurement campaigns show that only between 15% and 85% of the assigned spectrum in frequency bands up to 3GHz is utilized.
- This motivated the concepts of:
  - Dynamic spectrum access
  - Cognitive radio networks
Devices operating in the ISM band have to follow the statutory rules including:

- Effective radiated power (ERP)
- Effective isotropic radiated power (EIRP)
- Bandwidth
- Spurious emission
- Duty cycle
- Interference level
ISM Bands

• 315/433 MHz (US, EU):
  - 10 mW ERP, 10% Duty Cycle
  - Long ranges, reduced data rate

• 868/915 MHz (EU, US):
  - 5 mW ERP to 500 mW ERP, 1% - 100% Duty Cycle
  - Medim ranges and data rates, 8 sub-bands, Wireless M-BUS

ISM Bands

Å 2.4 GHz (Worldwide):
   - 10 mW EIRP to 100 mW (EU)
   - 1 mW EIRP to 1 W EIRP (US)
   - High Bandwidth

Å Technologies used in the 2.4 GHz band:
   - IEEE 802.11 (Wi-Fi)
   - IEEE 802.15.1 (Bluetooth)
   - IEEE 802.15.4 (Zigbee, WirelessHART, 6LoWPAN)
   - Commercial cordless devices
   - Proprietary WSN protocols
   - Active RFID
   - Microwave ovens
Spectrum sensing

Increased utilization of wireless technologies operating in ISM frequency bands:
  - Cross-interference
  - Performance degradation

To achieve coexistence and spectrum sharing among ISM band technologies the knowledge of the wireless medium utilization has to be obtained by making use of spectrum sensing.

Transmitter detection methods:
  - Matched filter
  - Energy detection
  - Feature-based detection
Energy detection based on RSSI

- RSSI (Received Signal Strength Indicator) is the input RF estimate of the signal level in the chosen channel.
- To analyse the spectrum a frequency sweep through more channels has to be performed.
- To correctly estimate the spectrum, the distance between central channel frequencies (channel spacing) has to be set as close as possible to the channel bandwidth.
- To acquire the proper RSSI value, the radio first needs to enter receive mode and then we have to wait for a response time before the RSSI value in the status register is valid.
Versatile Sensor Node Platform

Å VSC (Core): STM ARM Cortex-M3 32-bit MCU
- 72 MHz, 512 kB of FLASH, 64 kB of SRAM
- Interfaces: USB, SD card, SPI, I²C, UART, ADC,...

Å VSR (Radio): Chipcon (CC1101, CC2500), XBee

Å VSE (Expansion):
- Ethernet, GPRS
- Sensors

Å VSP (Power)
CC1101 Transceiver

Å CC1101 is a low-cost sub-GHz RF transceiver intended for low-power wireless applications in the ISM frequency bands:

- 315/433 MHz
- 868/915 MHz

Å Excellent receiver sensitivity:

- -116 dBm @ 433 MHz
- -112 dBm @ 868 MHz

Å Programmable output power up to 12 dBm.
Å Data rates from 0.6 kbps up to 600 kbps.
CC2500 Transceiver

- CC2500 is a pin and function compatible RF transceiver to CC1101, but intended for the operation in the ISM band from 2400 MHz to 2483.5 MHz.
- High receiver sensitivity of -104 dBm.
- Programmable output power up to 1 dBm.
- Data rates from 1.2 kbps up to 500 kbps.
RF Characteristics

CC1101 Filter (387-928 MHz)

CC2500 Filter (2.4-2.438 GHz)
Spectrum Sensing setup

A PC with MATLAB:
- User Interface for frequency sweep range selection
- CCxxx register settings calculation
- Spectrum display

A VSN:
- VSC+VSR (CC1101)
- VSC+VSR (CC2500)
MATLAB GUI for Spectrum Sensing

Parameter view:
- Base: 868158299.536 Hz
- Bandwidth: 337500 Hz
- Channel spacing: 320526.123 Hz

Control panel for spectrum sensing:
- Lower frequency: 868000000 Hz
- Higher frequency: 950000000 Hz
- Error: 0
- Bandwidth: 0
- Channel spacing: 0

Registry view:
- FREQ2: 0x20
- FREQ1: 0x27
- FREQ0: 0x27
- MDMCFG4: 0x87
- MDMCFG3: 0x87
- MDMCFG2: 0x85
- MDMCFG0: 0x85

Serial port control:
- COM port: COM14
- Parity type: none
- Status: opened
- Baud Rate: 115200
- Data bits: 8
- Stop bits: 1

Received data:
- Clear receive: [button]
- Send AT: [button]

Settings:
- [List of options]

Data Rate: 519104.0039 Mbit/s
- TU: 6.8759e-005
- T1,n: 3.5556e-005
- T1,n: 3.4352e-005
- T2: 2.4352e-005
- RSSI TIME: 0.00009148

AgroSense
- [Logo]

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- [Logo]
Radio settings for Frequency Sweep

- **Base frequency**
- **Channel bandwidth**
- **Channel spacing**

Parameter view:
- Fbase: 2441779953.002
- Bandwidth: 60267.8571
- Channel spacing: 62004.0894

Registry view:
- FREQ2: 0x5A
- FREQ1: 0x6F
- FREQ0: 0xB1
- MDMCFG4: 0xFE
- MDMCFG1: 0xA1
- MDMCFG0: 0x2D

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RSSI Response time for CCxxxxx Transceivers

\[ T_{RSSI} = T_0 + T_{1,1} + T_2 + 4 \times (T_{1,n} + T_2) \]

- \( T_0 \) – Demodulation time
- \( T_1 \) – AGC gain change time
- \( T_2 \) – AGC average time
RSSI Response time Calculation

<table>
<thead>
<tr>
<th>B_{CHAN}</th>
<th>T_0</th>
<th>T_{1,1}</th>
<th>T_{1,n}</th>
<th>T_2</th>
<th>T_{RSSI}</th>
</tr>
</thead>
<tbody>
<tr>
<td>420 kHz</td>
<td>66 µs</td>
<td>28 µs</td>
<td>27 µs</td>
<td>20 µs</td>
<td>300 µs</td>
</tr>
<tr>
<td>70 kHz</td>
<td>177 µs</td>
<td>170 µs</td>
<td>164 µs</td>
<td>114 µs</td>
<td>1.5 ms</td>
</tr>
</tbody>
</table>

\[
T_0 = \text{MAX} \left\{ \left\lceil \frac{1023 \cdot 2 \cdot B_{W_{channel}}}{f_{XOSC}} \right\rceil + 19 + \frac{2.5}{f_{XOSC}}, \left\lceil \frac{1022 \cdot 8 \cdot R_{DATA}}{f_{XOSC}} \right\rceil + 9 + \frac{4.5}{f_{XOSC}} \right\}
\]

\[
T_{L,1} = \frac{8 \cdot \text{WAIT \_TIME} + 7 + \left\lceil \frac{2 \cdot \left( T_0 - \frac{1.5}{f_{XOSC}} \right) \cdot B_{W_{channel}}}{f_{XOSC}} \right\rceil}{2 \cdot B_{W_{channel}}} - T_0 + \frac{2.5}{f_{XOSC}}
\]

\[
T_{L,n} \leq \frac{8 \cdot (\text{WAIT \_TIME} + 1)}{2 \cdot B_{W_{channel}}} + \frac{1}{f_{XOSC}}, n = \{2, 3, 4, \ldots\}
\]

\[
T_2 \leq \frac{8 \cdot 2^{AGCCTRL0.FILTER\_LENGTH}}{2 \cdot B_{W_{channel}}} + T_{GAIN\_ADJUST\_MAX}
\]
Spectrum measurements

Spectrum from 868 MHz to 950 MHz

Spectrum from 932.5 MHz to 950 MHz
Spectrum measurements

Spectrum from 2.441 to 2.483 GHz

Spectrum from 2.441 to 2.483 GHz + Microwave
Conclusion

The VSN can be used as a low cost CR platform:

- It can act as secondary user and can adapt to primary spectrum usage.
- Spectrum sensing is performed locally, by each secondary device, so relying solely on this information may give rise to the well known hidden node problem.
- The solution is to introduce a cognitive channel and make the network centrally coordinated.

If we know the locations of the VSN nodes a spatio-temporal spectrum occupancy map can be built. This can be done during the idle time intervals.

Based on the RSSI the spatial relationship of the nodes can be analysed.
Questions?

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