Implementing cognitive radio principles on VSN

Gregor Berke

AgroSense

Outline

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Å ISM Bands and Regulatory

Å Spectrum sensing

Å Versatile Sensor Node Platform

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Introduction

- The wireless medium:
  - Limited resource
  - Shared among many users
  - Requires coordinated usage
- The transmission of radio waves is regulated by international an national regulatory authorities, determinating:
  - Frequency allocation
  - Licesing to difernent technologies and systems

Introduction

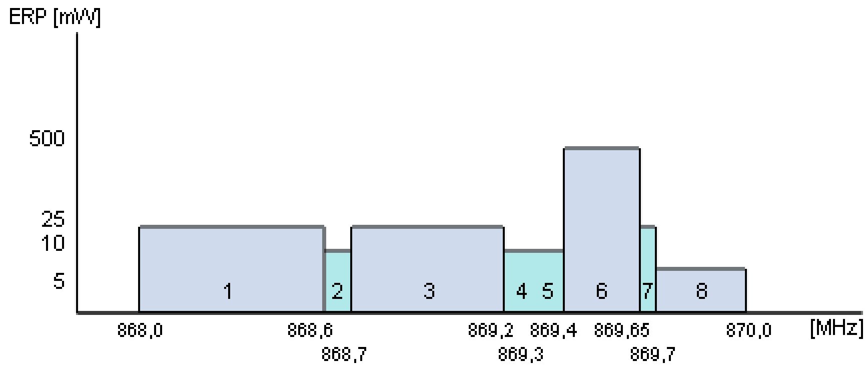
- Licensed spectrum for exlusive use became a scarce resource:
  - New wireless technologies
  - Increasing frequnency demands
- Measurement campaings show that only between 15 % and 85% of the assigned spectrum in frequency bands up to 3GHz is utilized.
- This motivated the concepts of:
  - Dynamic spectrum access
  - Cognitive radio networks

ISM Band Regulatory

- 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



*http://iaf-bs.de/projects/ism-433-868.en.html

ISM Bands

- 2.4 GHz (Worldwide):
  - 10 mW EIRP to 100 mW (EU)
  - 1 mW EIRP to 1 W EIRP (US)
  - High Bandwidth
- 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
  - Propriertary WSN protocols
  - Active RFIDs
  - 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

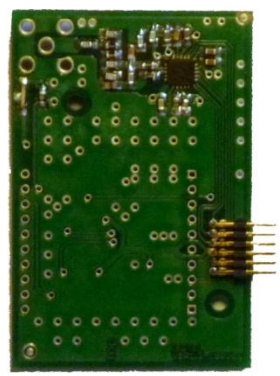
- 72 MHz, 512 kB of FLASH, 64 kB of SRAM
- Interfaces: USB, SD card, SPI, I^2C ,UART, ADC,….

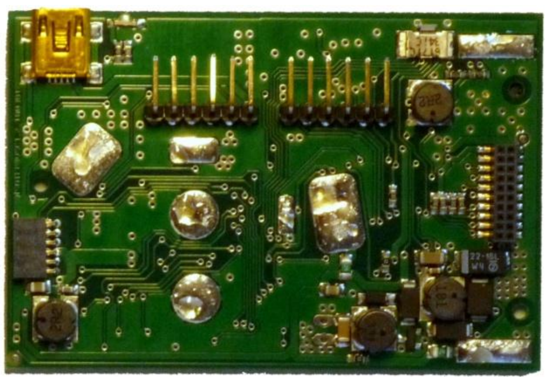
Å **VSR** (Radio) : Chipcon (CC1101,CC2500), XBee

Å **VSE** (Expansion):

- Ethernet,GPRS
- Sensors

Å **VSP** (Power)





CC1101 Transceiver

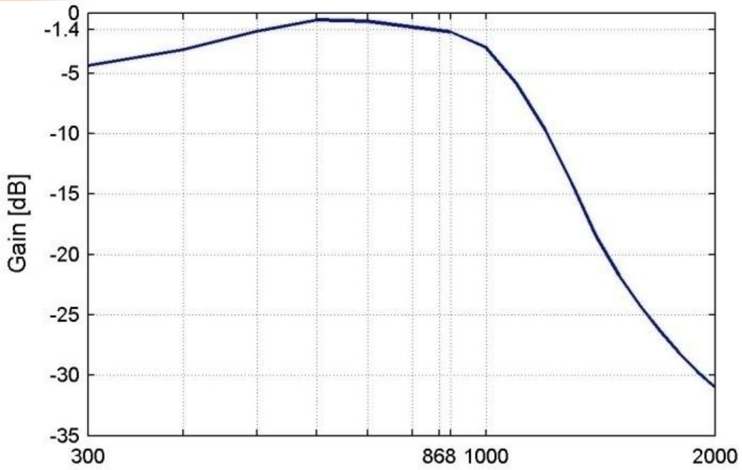
- CC1101 is a low-cost sub-GHz RF transceiver intended for low-power wireless applications in the ISM frequency bands :
  - 315/433 MHz
  - 868/915 MHz
- Excellent receiver sensitivity:
  - -116 dBm @ 433 Mhz
  - -112 dBm @ 868 Mhz
- Programmable output power up to 12 dBm.
- Data rates from 0.6 kbps up to 600 kbps.

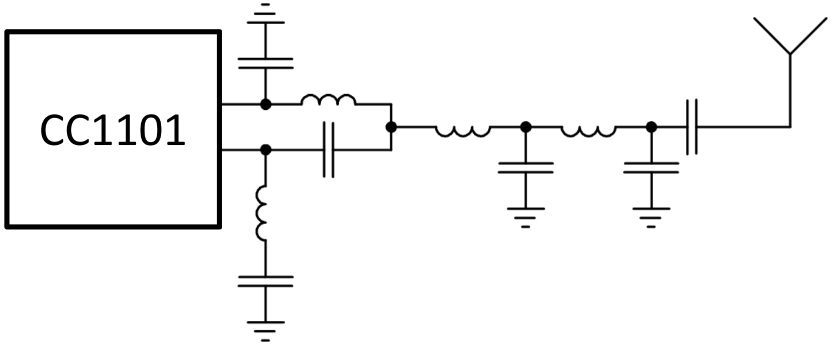
CC2500 Transceiver

- 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.

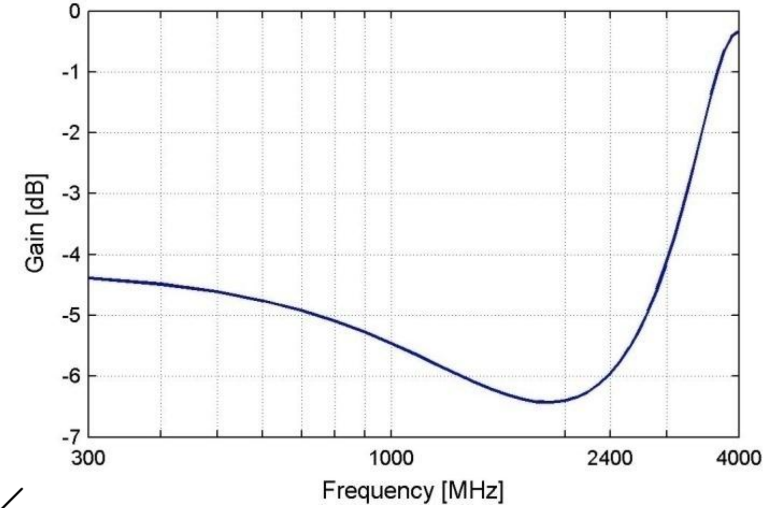
RF Characteristics

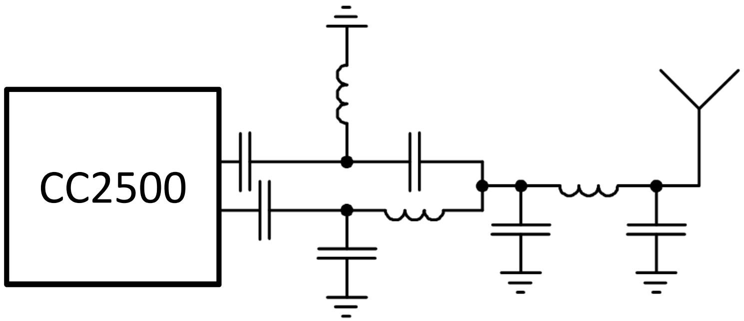
CC1101 Filter (387-928 MHz)





CC2500 Filter (2.4-2.438 GHz)





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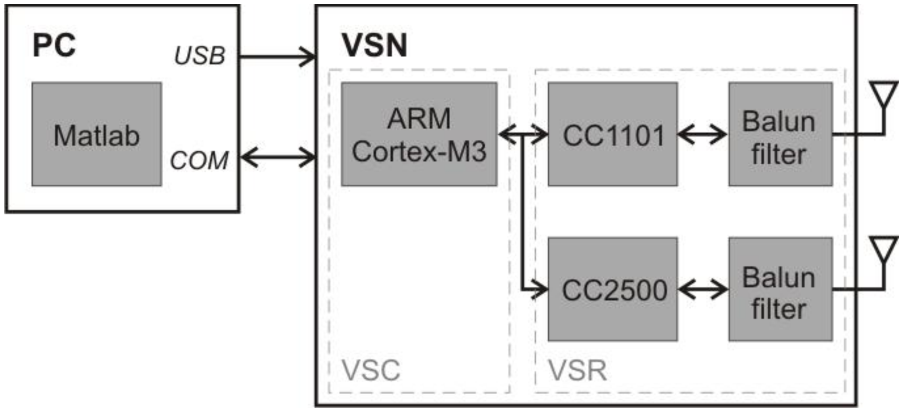
Spectrum Sensing setup

Å PC with MATLAB :

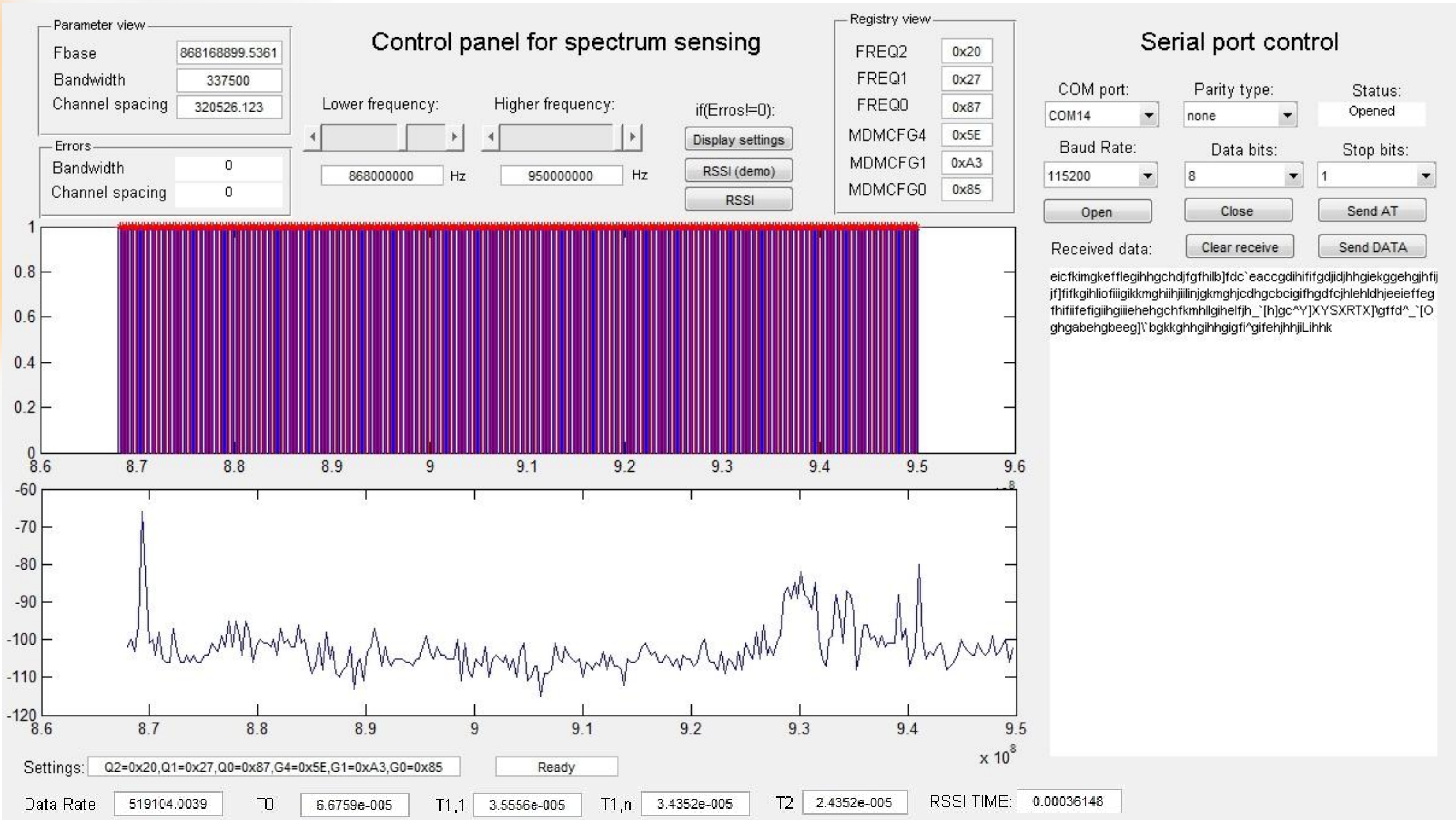
- User Interface for frequency sweep range selection
- CCxxx register settings calculation
- Spectrum display

Å VSN:

- VSC+VSR (CC1101)
- VSC+VSR (CC2500)



MATLAB GUI for Spectrum Sensing



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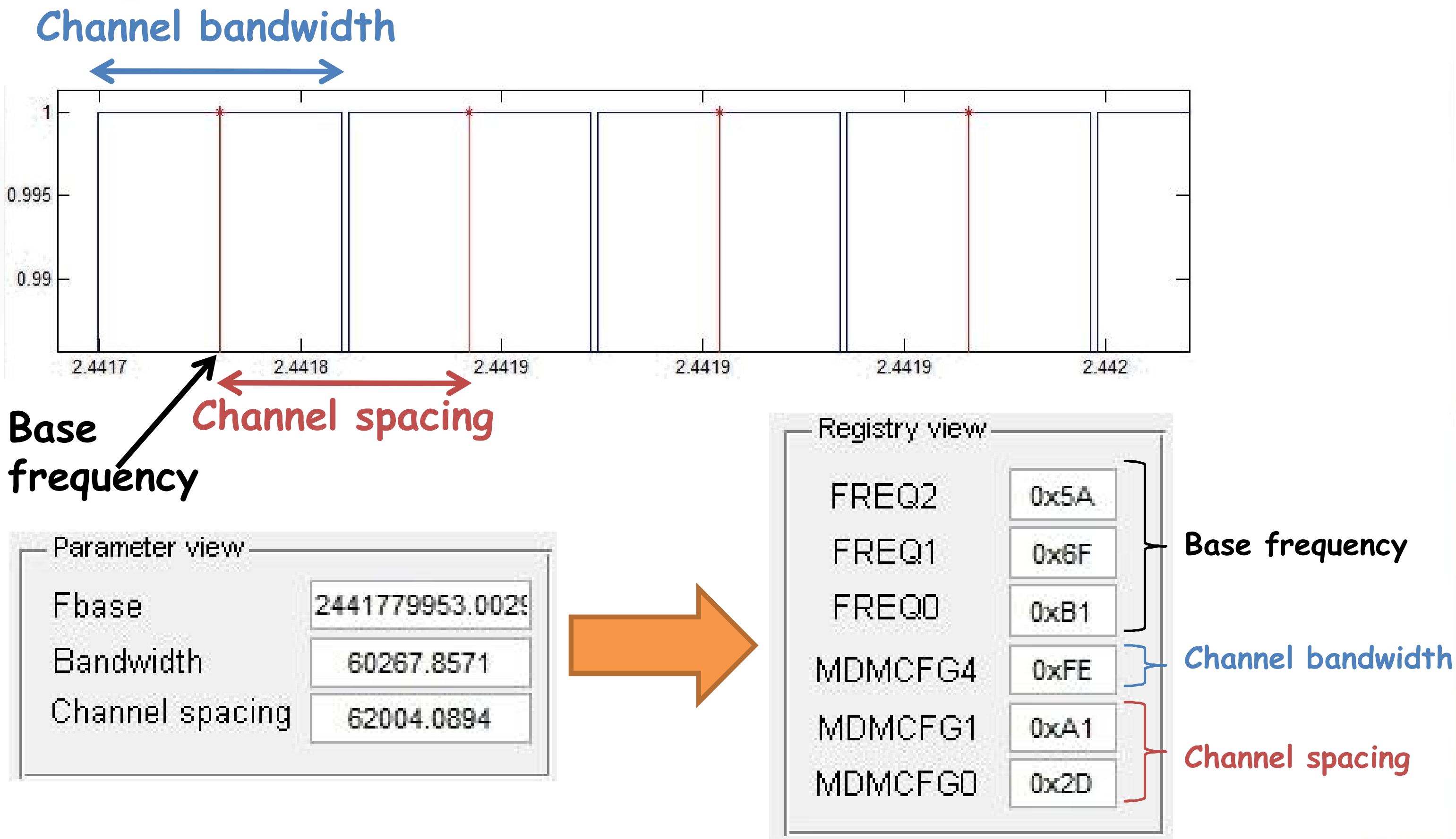
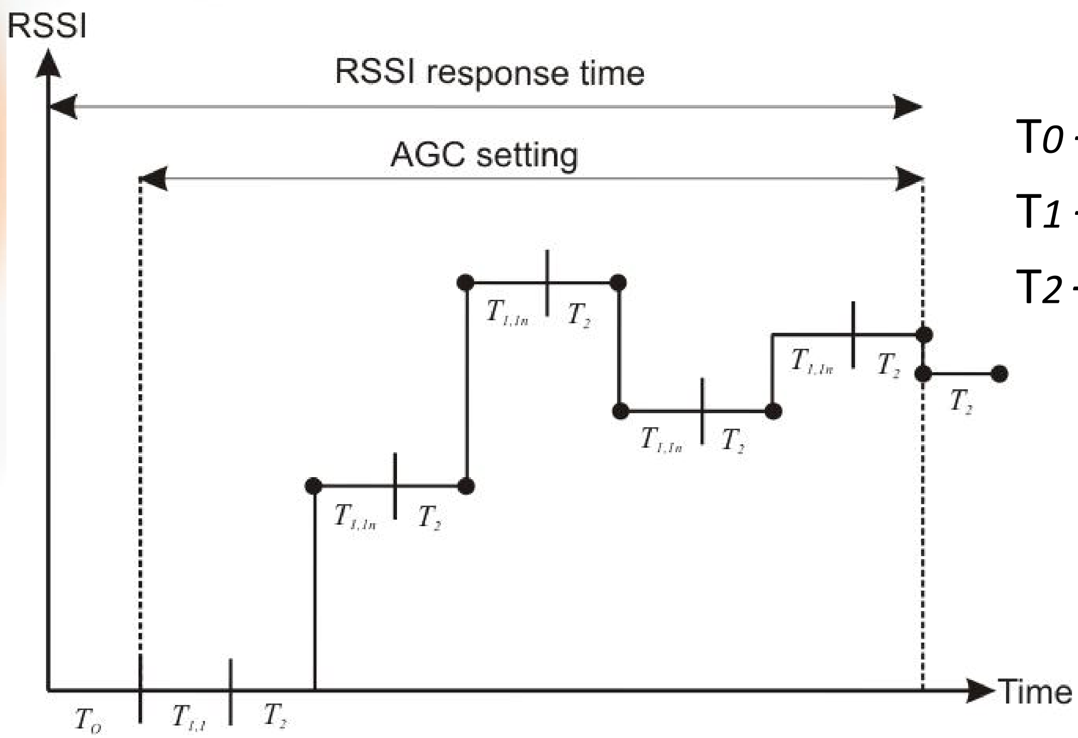
Radio settings for Frequency Sweep



RSSI Response time for CCxxxx Transceivers



T0 – *Demodulation time*

T1 – *AGC gain change time*

T2 – *AGC average time*

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

RSSI Response time Calculation

B_{CHAN}	T_0	$T_{1,1}$	$T_{1,n}$	T_2	T_{RSSI}
420 kHz	66 µs	28 µs	27 µs	20 µs	**300 µs**
70 kHz	177 µs	170 µs	164 µs	114 µs	**1.5 ms**

$$T_0 = MAX\left\{\frac{ceiling\left[\frac{1023\cdot 2\cdot BW_{channel}}{f_{XOSC}};1\right]+19}{2\cdot BW_{channel}}+\frac{2.5}{f_{XOSC}};\frac{ceiling\left[\frac{1022\cdot 8\cdot R_{DATA}}{f_{XOSC}};1\right]+9}{8\cdot R_{DATA}}+\frac{4.5}{f_{XOSC}}\right\}$$

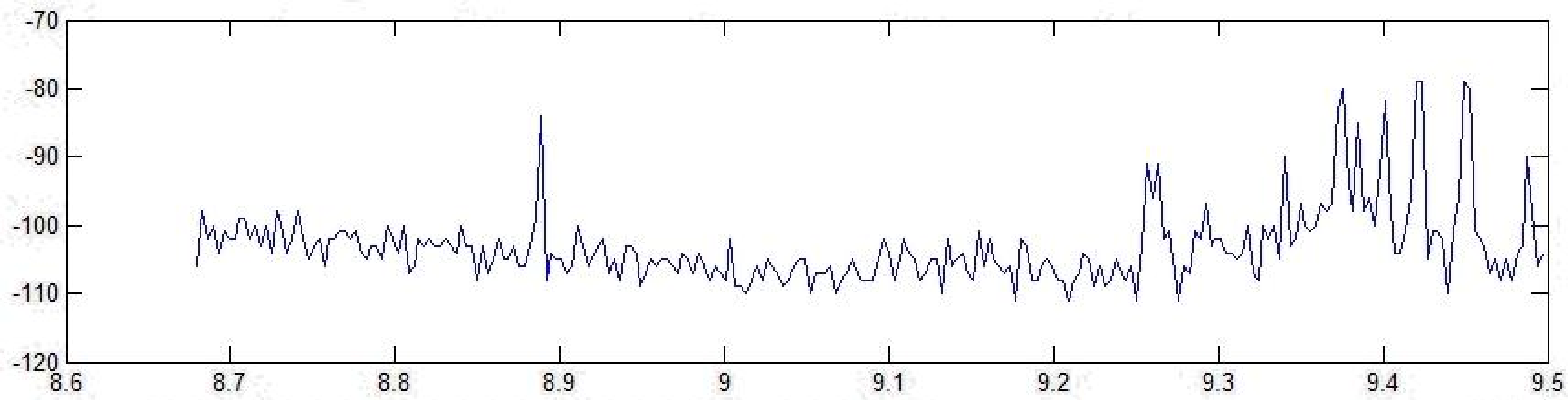
$$T_{1,1} = \frac{8\cdot WAIT\_TIME+7+ceiling\left[2\cdot\left(T_0-\frac{1.5}{f_{XOSC}}\right)\cdot BW_{channel};1\right]}{2\cdot BW_{channel}}-T_0+\frac{2.5}{f_{XOSC}}$$

$$T_{1,n} \le \frac{8\cdot(WAIT\_TIME+1)}{2\cdot BW_{channel}}+\frac{1}{f_{XOSC}}, \text{n} = \{2, 3, 4, \ldots\}$$

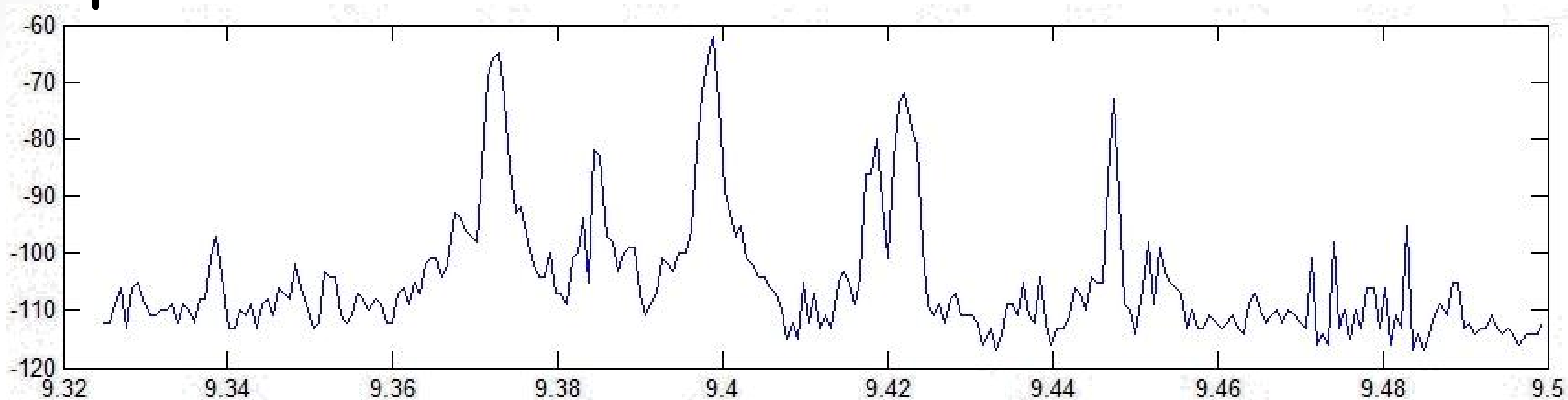
$$T_2 \le \frac{8\cdot 2^{AGCCTRL0.FILTER\_LENGTH}}{2\cdot BW_{channel}}+T_{GAIN\_ADJUST\_MAX}$$

Spectrum measurements

Spectrum from 868 MHz to 950 MHz

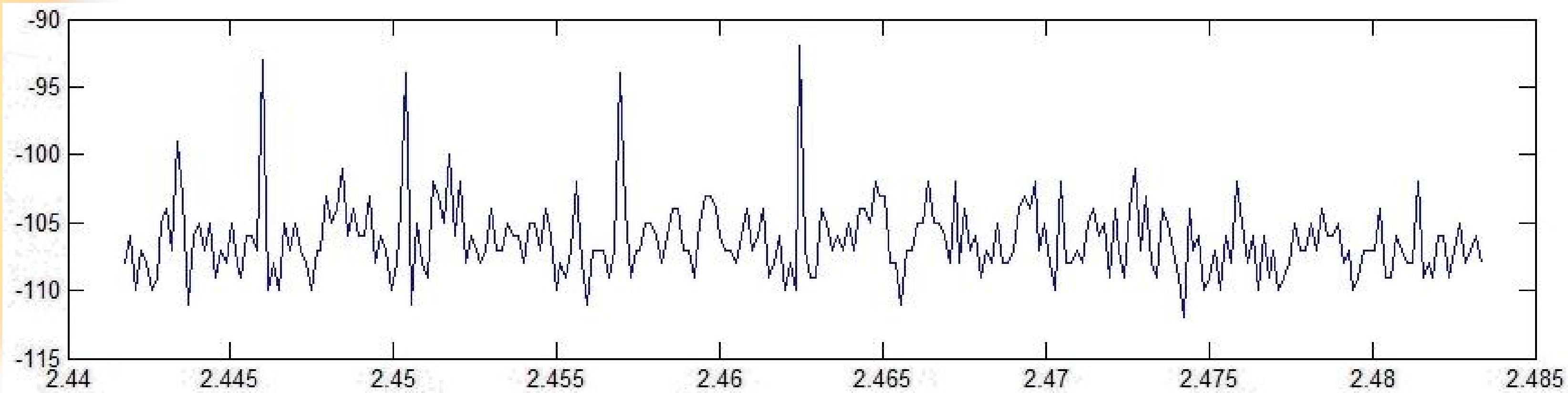


Spectrum from 932.5 MHz to 950 MHz

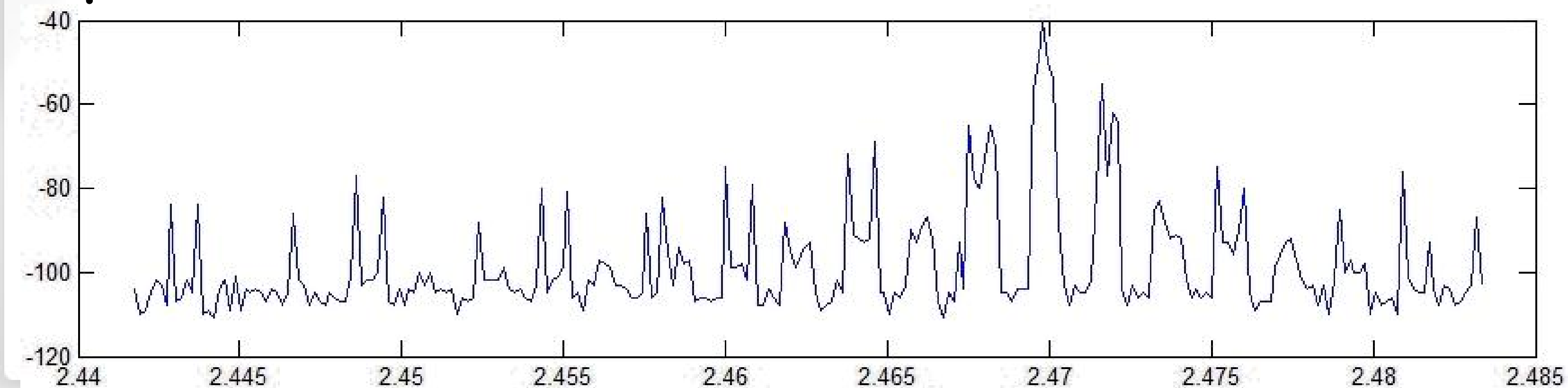


Spectrum measurements

Spectrum from 2.441 to 2.483 GHz



Spectrum from 2.441 to 2.483 GHz + Microwave



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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 sensig 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 build. This can be done during the idle time intervals.
- Based on the RSSI the spatial relationship of the nodes can be analysed.

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Jožef Stefan Institute
Department of
Communication Systems

Questions ?

Gregor.Berke@ijs.si

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