



**TÉCNICO**  
LISBOA



instituto de  
telecomunicações



# Software Defined Radio Implementation for Maritime Cognitive Radio Communications

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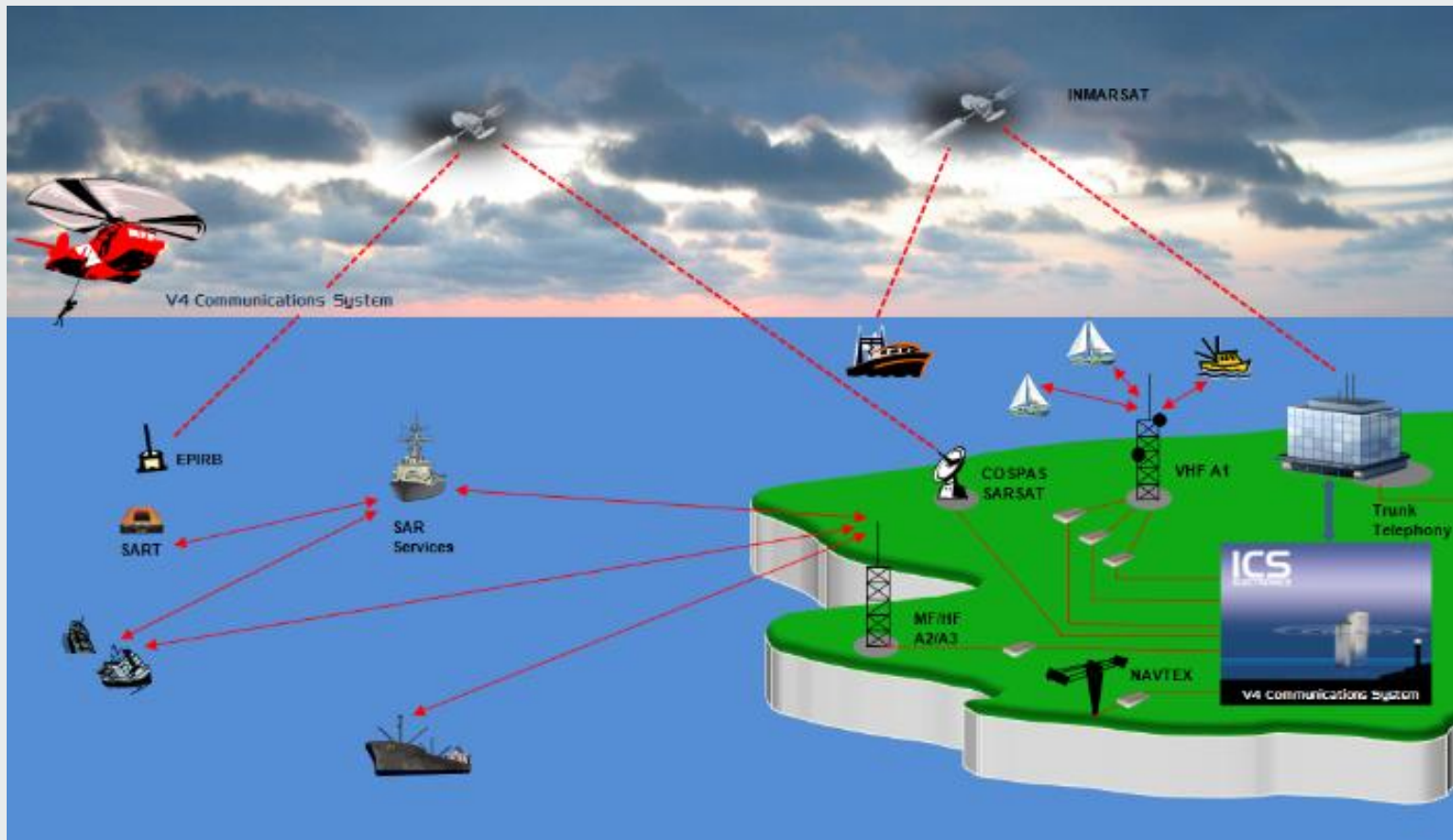
8<sup>th</sup> Congress of the Portuguese Committee of URSI - "Drones and autonomous vehicles: present and future challenges"

November 28<sup>th</sup>, 2014

- Introduction and Motivation
- Objectives / Contributions
- Background
- Proposed Solution
- Tests and Results
- Conclusions
- Future work
- Q&A

# Introduction and Motivation

- Maritime Communications Overview



Source: ICS Electronics

# Introduction and Motivation

- Maritime Communications Overview

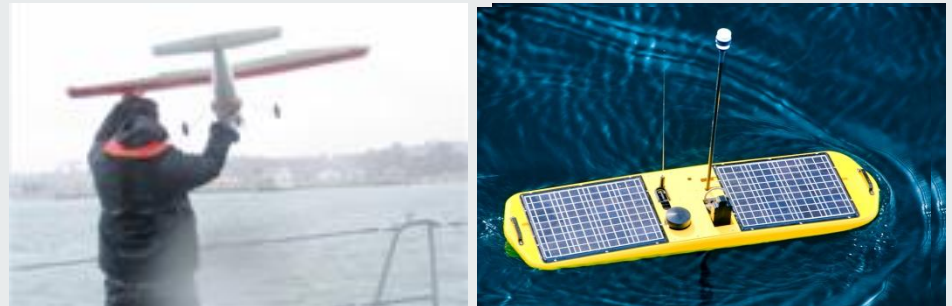
System	Band	Throughput	Application
NAVTEX	HF, MF	100 b/s	Information / Distress
DSC	VHF MF/HF	1.2 kb/s 100 b/s	Short messaging / Distress
AIS	VHF	9,6 kb/s - 2 ch.	Automatic vessel tracking
SATCOM	SHF	< 4 Mb/s	IP data / Telephony

Terrestrial networks: GSM, UMTS, LTE...

# Introduction and Motivation

- New Demands

## Sensor Networks



## e-Navigation

eNavigation Implementation



Source: Times of Malta

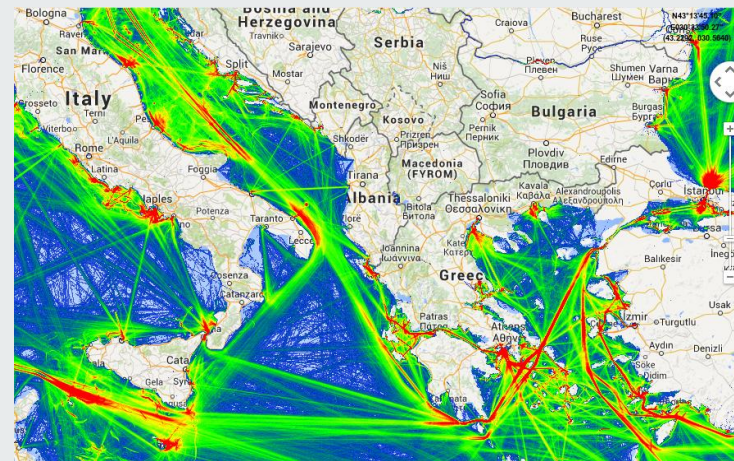
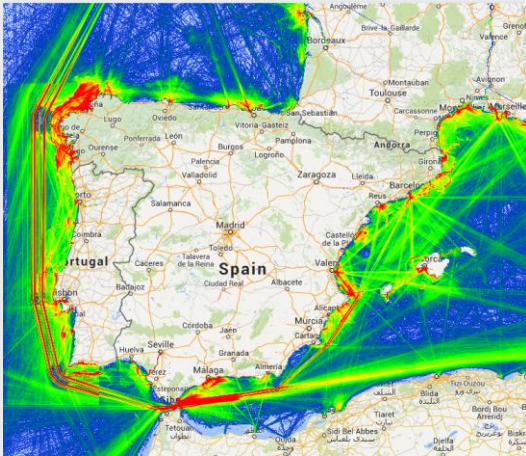
## Personal Communications



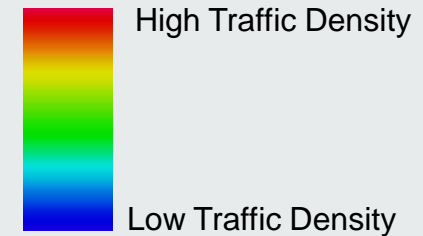
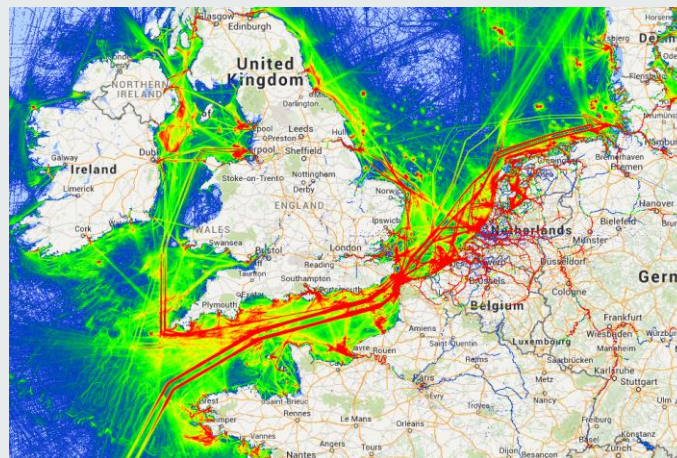


# Introduction and Motivation

- What about coverage?

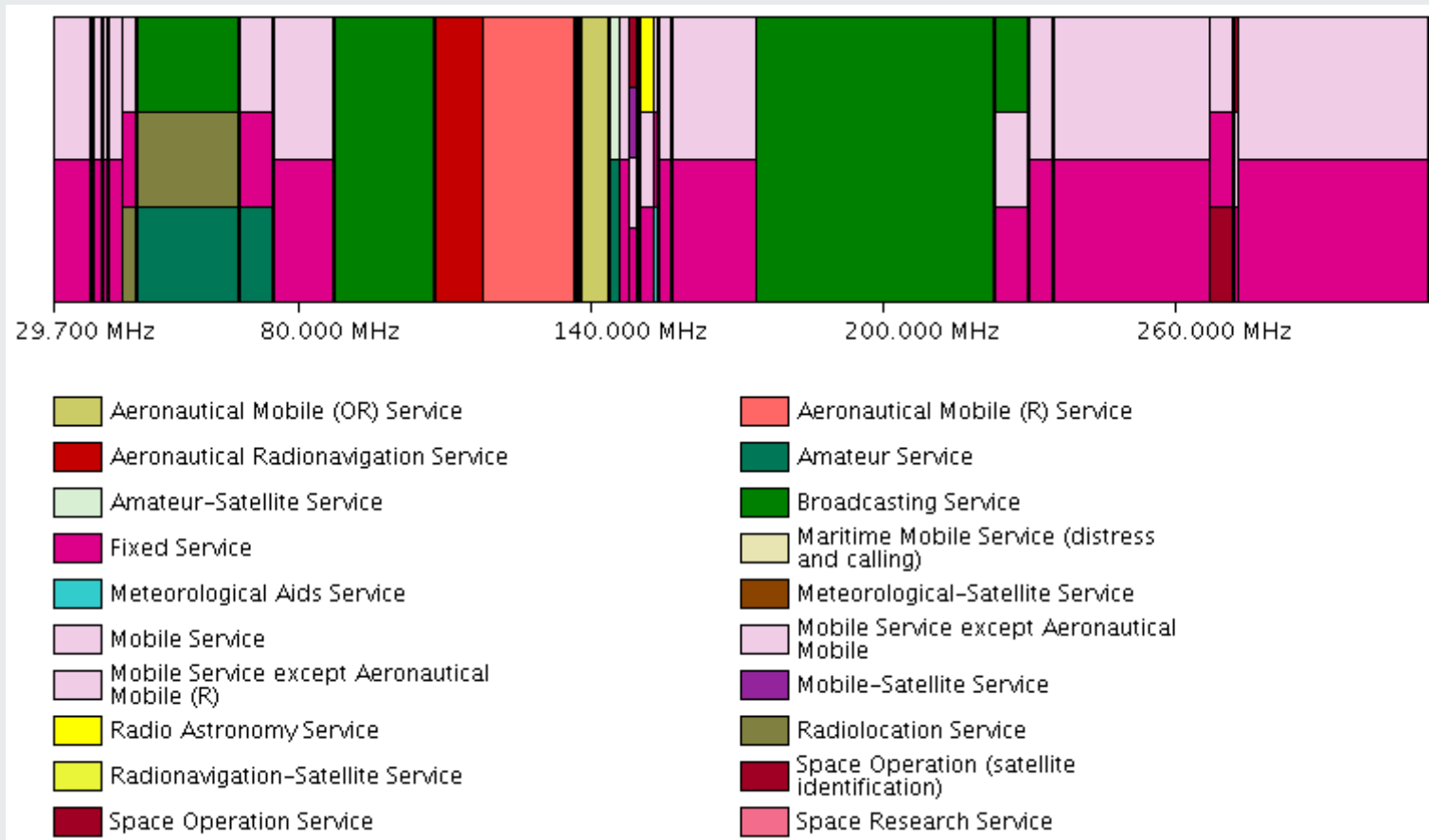


Most ship-to-ship  
and ship-to-shore  
communications  
use the VHF Band  
~ 30 nautical miles



“Traffic Density”. Source: Marine Traffic

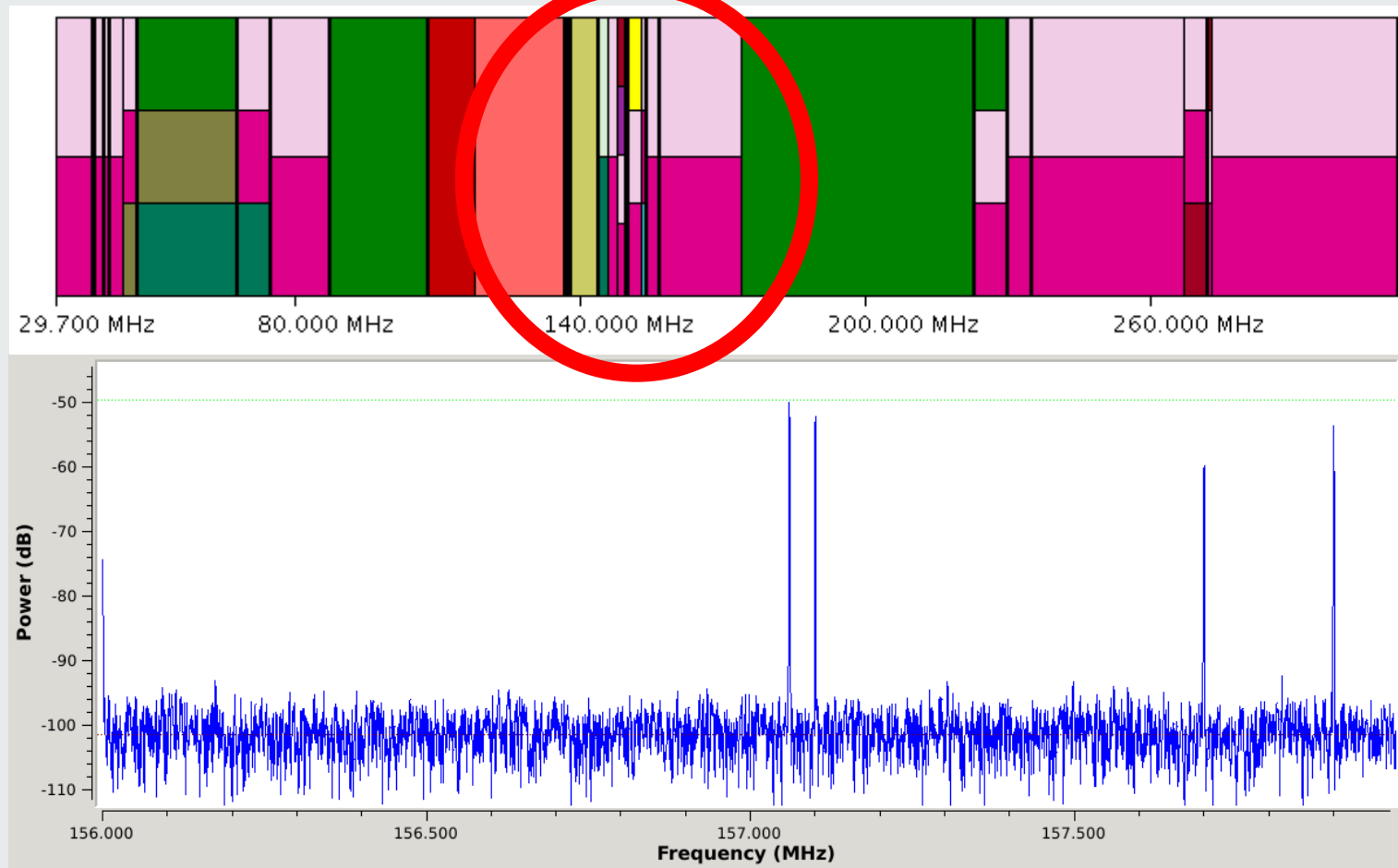
- Radio Resources Overview – The VHF Band



Source: ANACOM

# Introduction and Motivation

- Radio Resources Overview – The VHF Band





# Introduction and Motivation

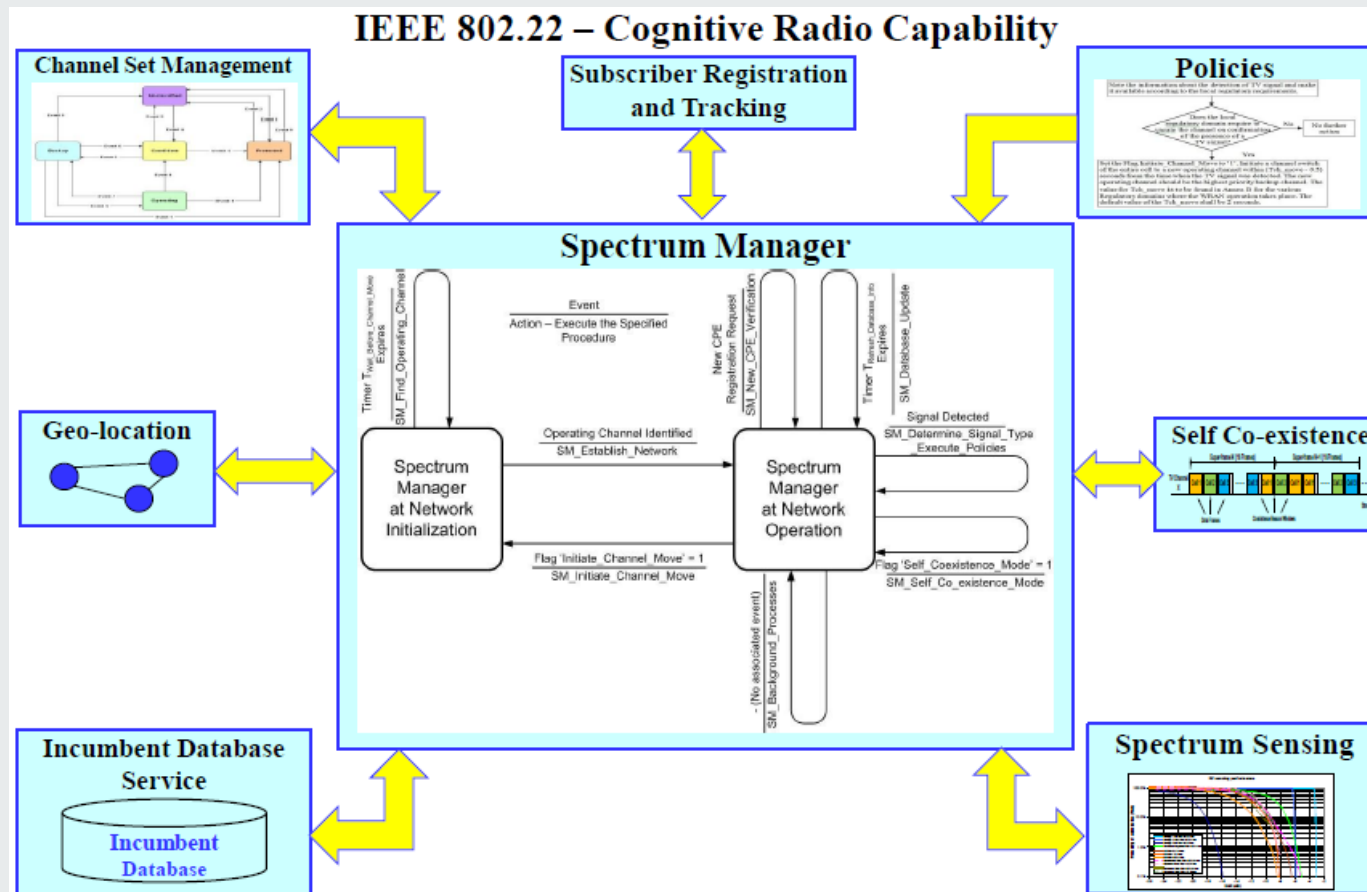
- Solutions

Spectrum refarming?

New spectrum allocations?

# Introduction and Motivation

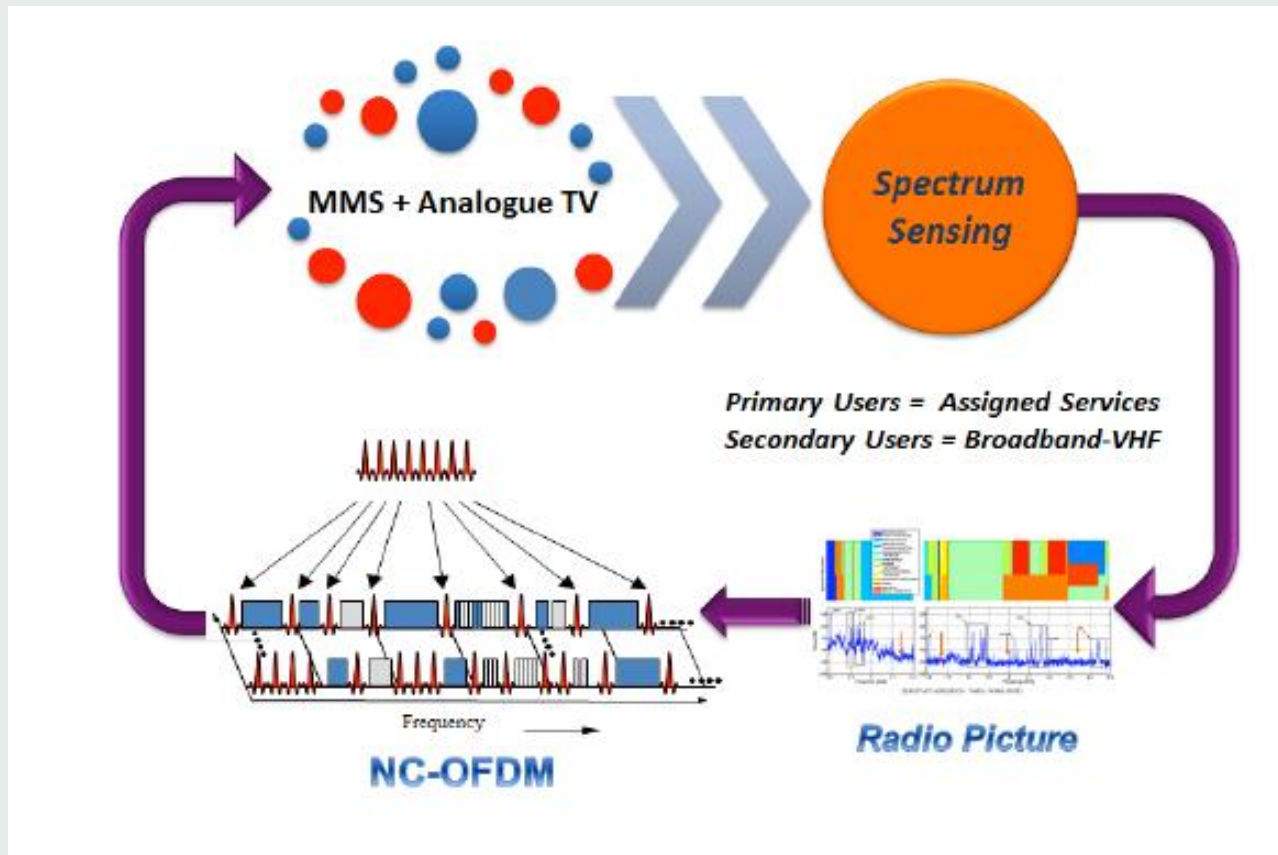
- Opportunistic Systems (Smart Solutions)



Source: IEEE 802.22 Working Group

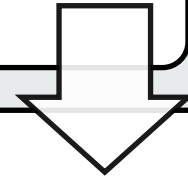
# Introduction and Motivation

- Opportunistic Systems (Smart Solutions)

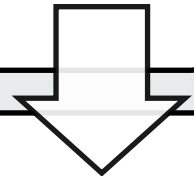


Source: Bolas et. al. 2012

Broadband VHF Communication System



Opportunistic Use of Maritime VHF Spectrum

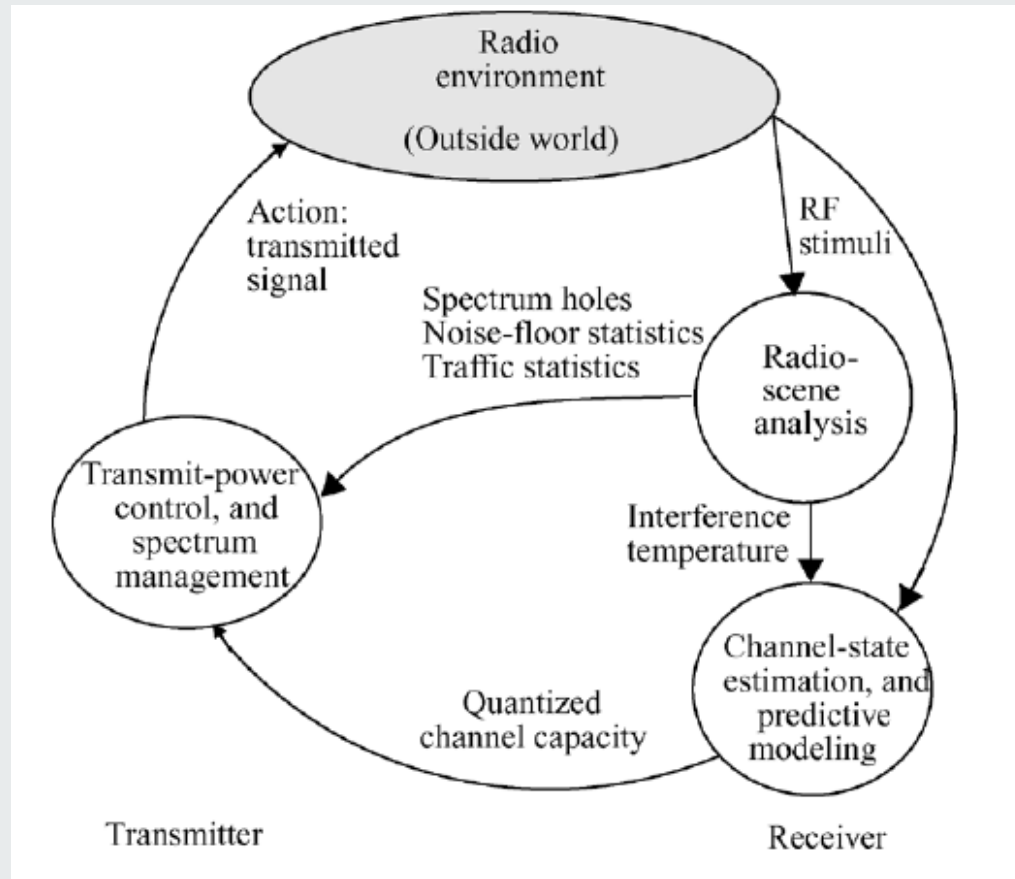


Spectrum Sensing, Transceiver Techniques,  
Network Synchronization → Cognitive Radio

- Implementation of a custom system for the VHF maritime band;
- Implementation and integration of the major components of a cognitive radio;
- Development and implementation of a cognitive engine, as well as a network synchronization protocol;
- Coexistence evaluation between opportunistic and primary users.

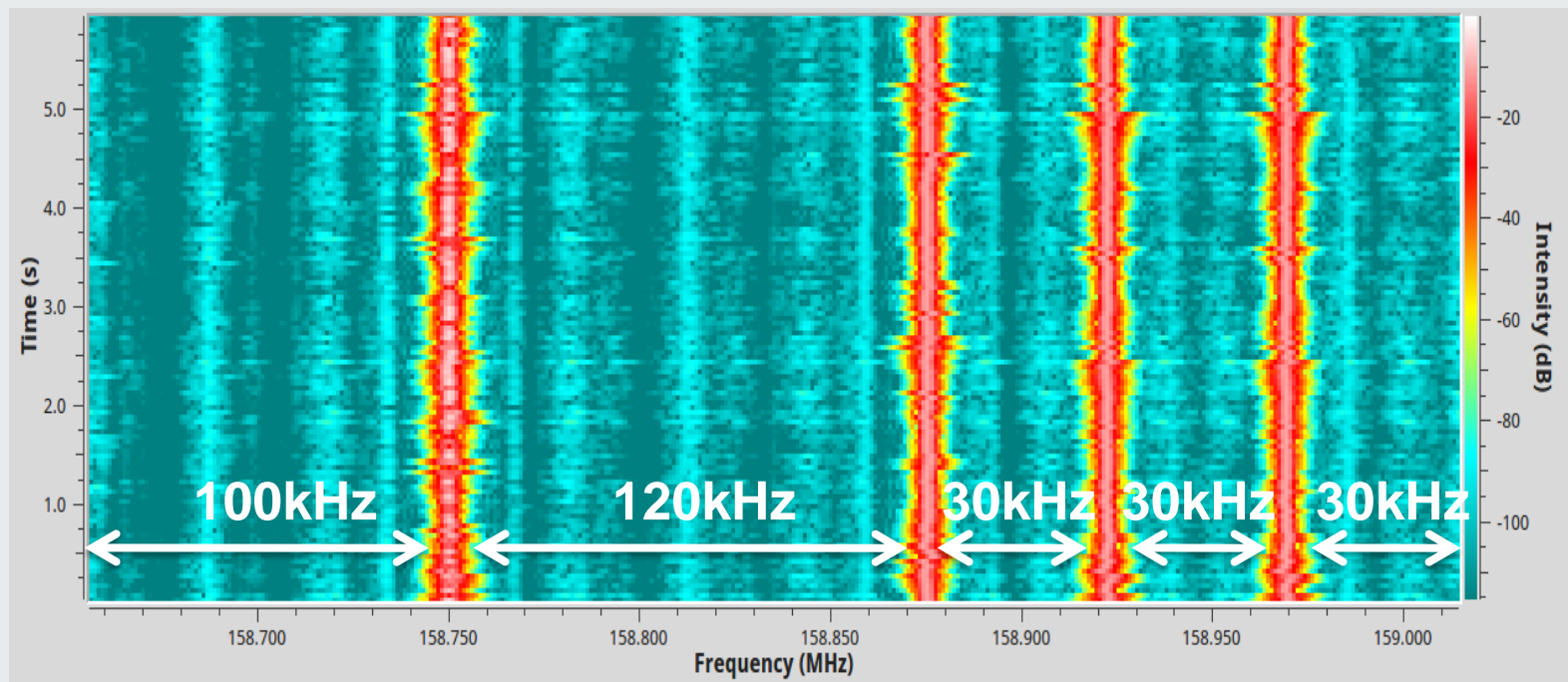


- Cognitive Radios

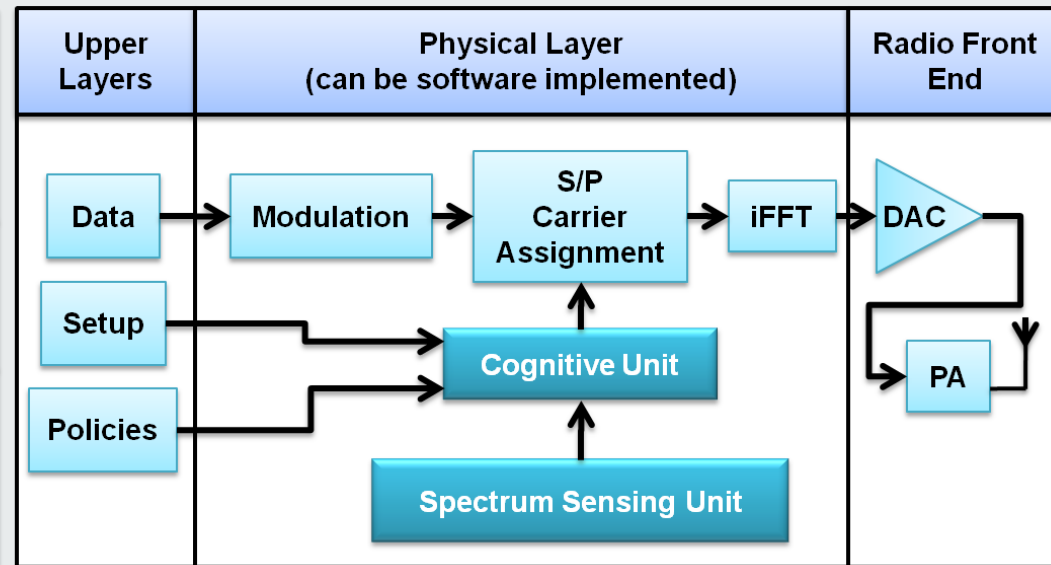
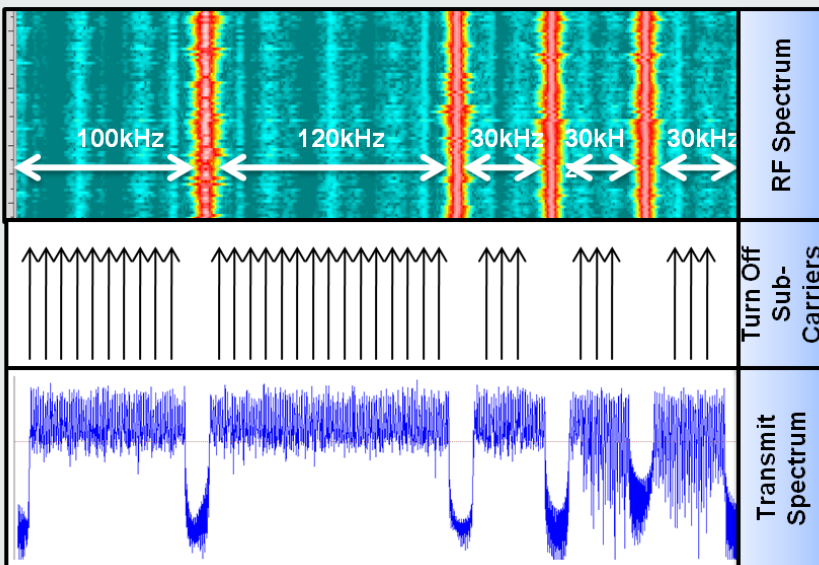


Source: Haykin 2005

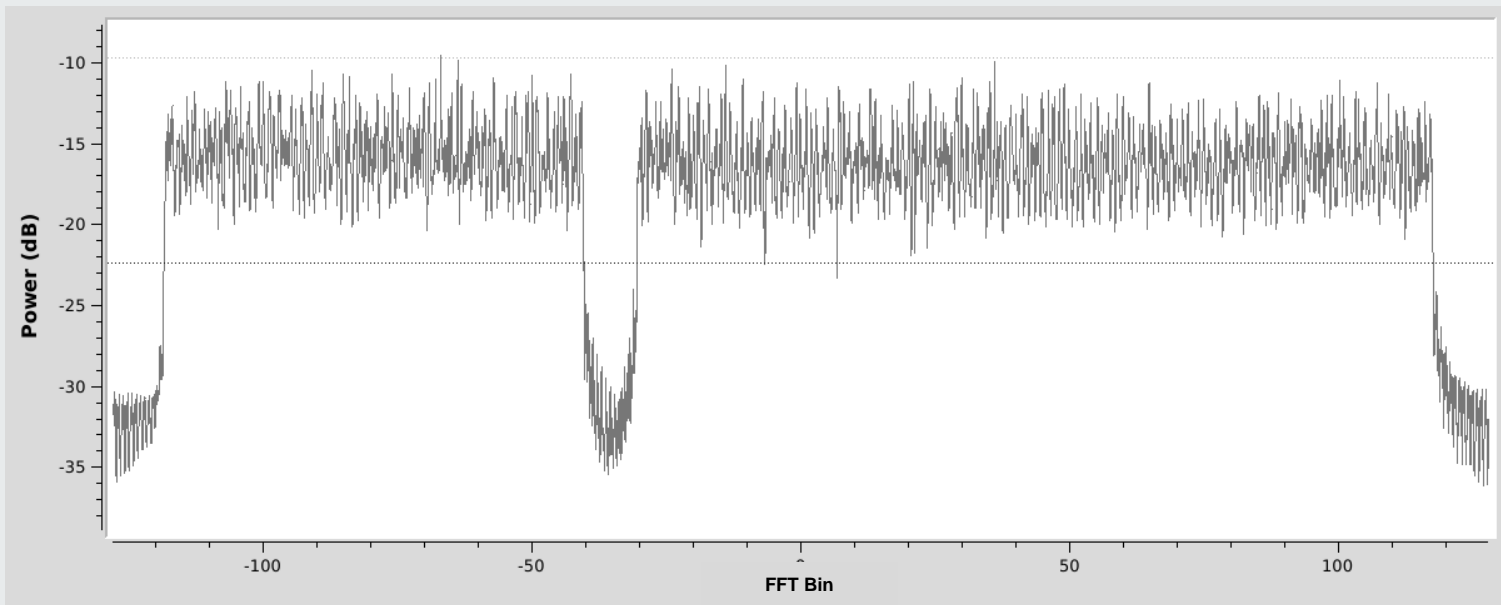
- Spectrum Sensing
  - Detection of Primary User Activity in a Multichannel Scenario



- Spectrum Shaping with a Multicarrier Modulation:
  - Orthogonal Frequency Division Multiplexing (OFDM)



- OFDM
  - It's awesome, but...



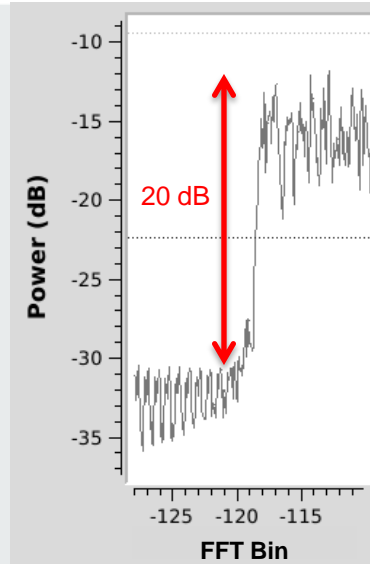
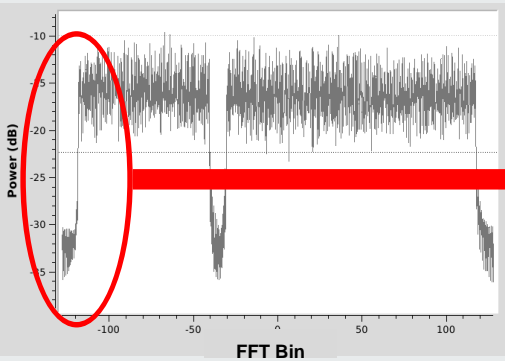
256 bin  
OFDM Signal

10 + 10 OOB  
disabled sub-  
carriers

10 NC  
disabled sub-  
carriers

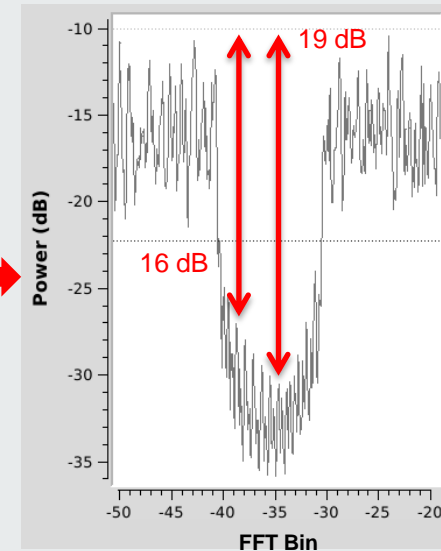
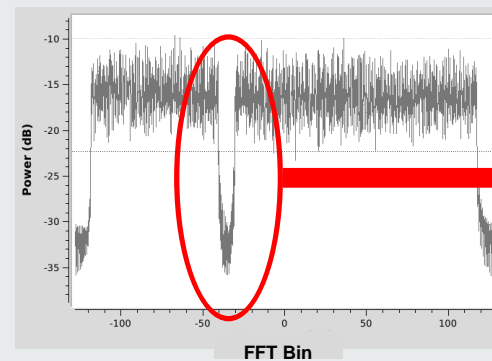
- Radiation leakage
- Relatively high Peak-to-Average Power Ratio (PAPR)

# Background



Out Of Band (OOB) Radiation

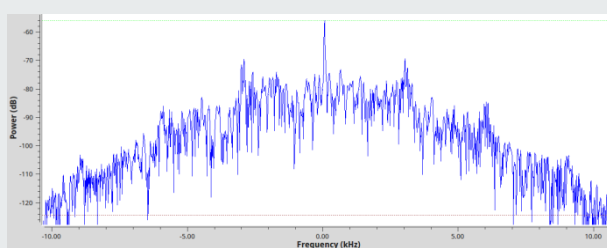
Non Contiguous (NC) Radiation



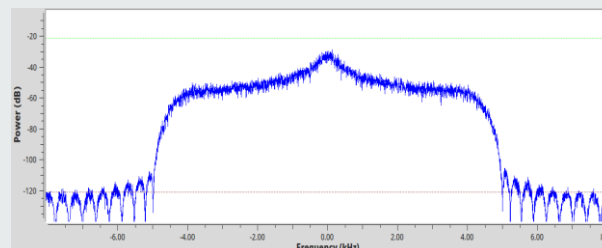


# Proposed Solution

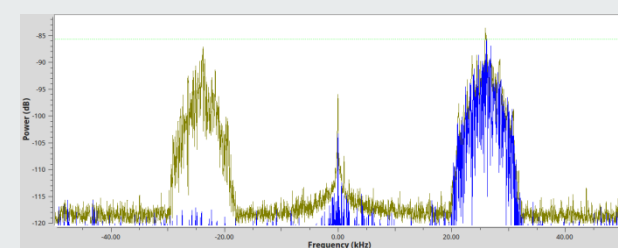
- Opportunist Use of Radio Spectrum in the Maritime context
- Most Common Primary Users



**Analogue Telephony**



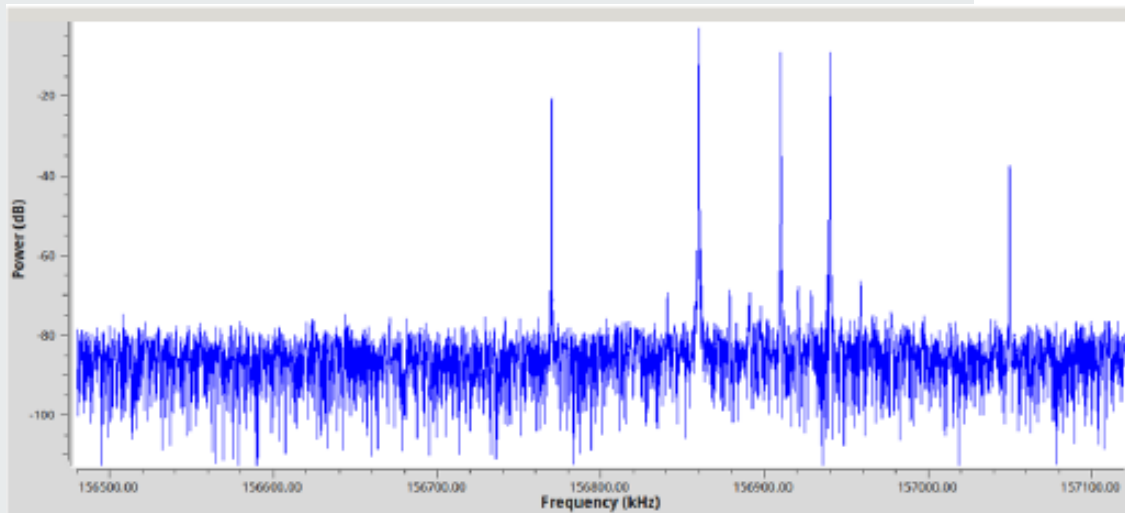
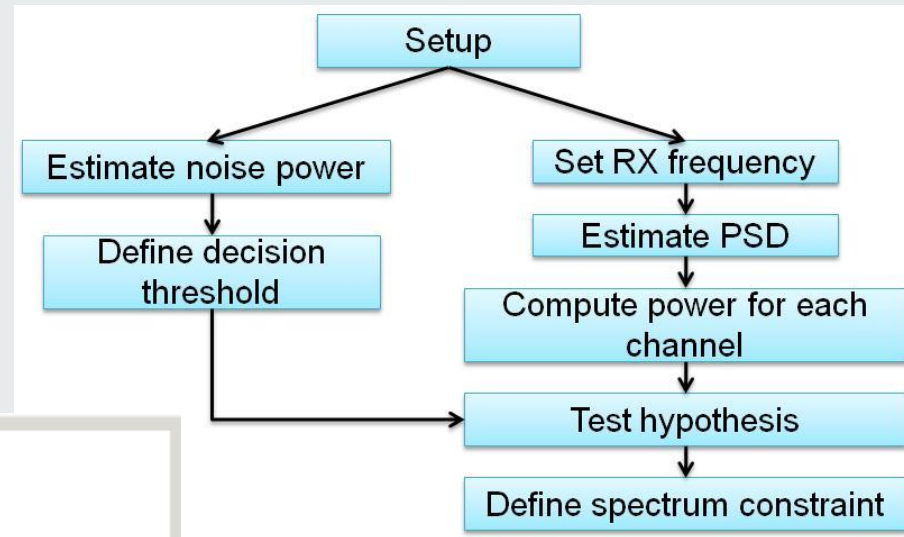
**DSC**



**AIS**

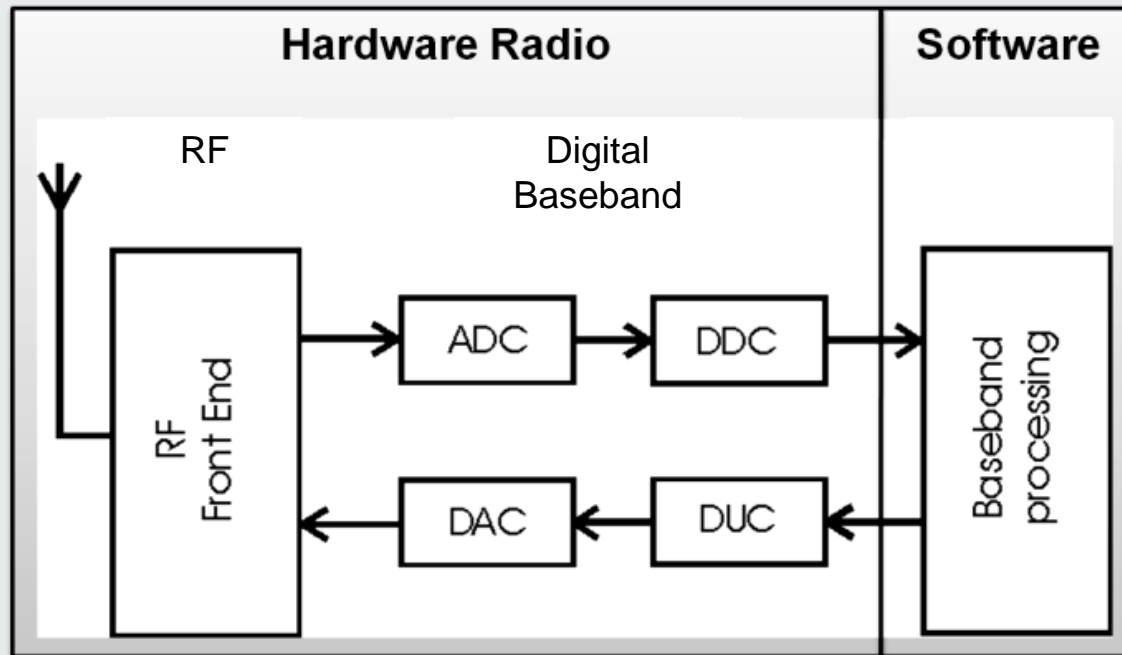
# Proposed Solution

- Multiuser Scenario – Multichannel Detector



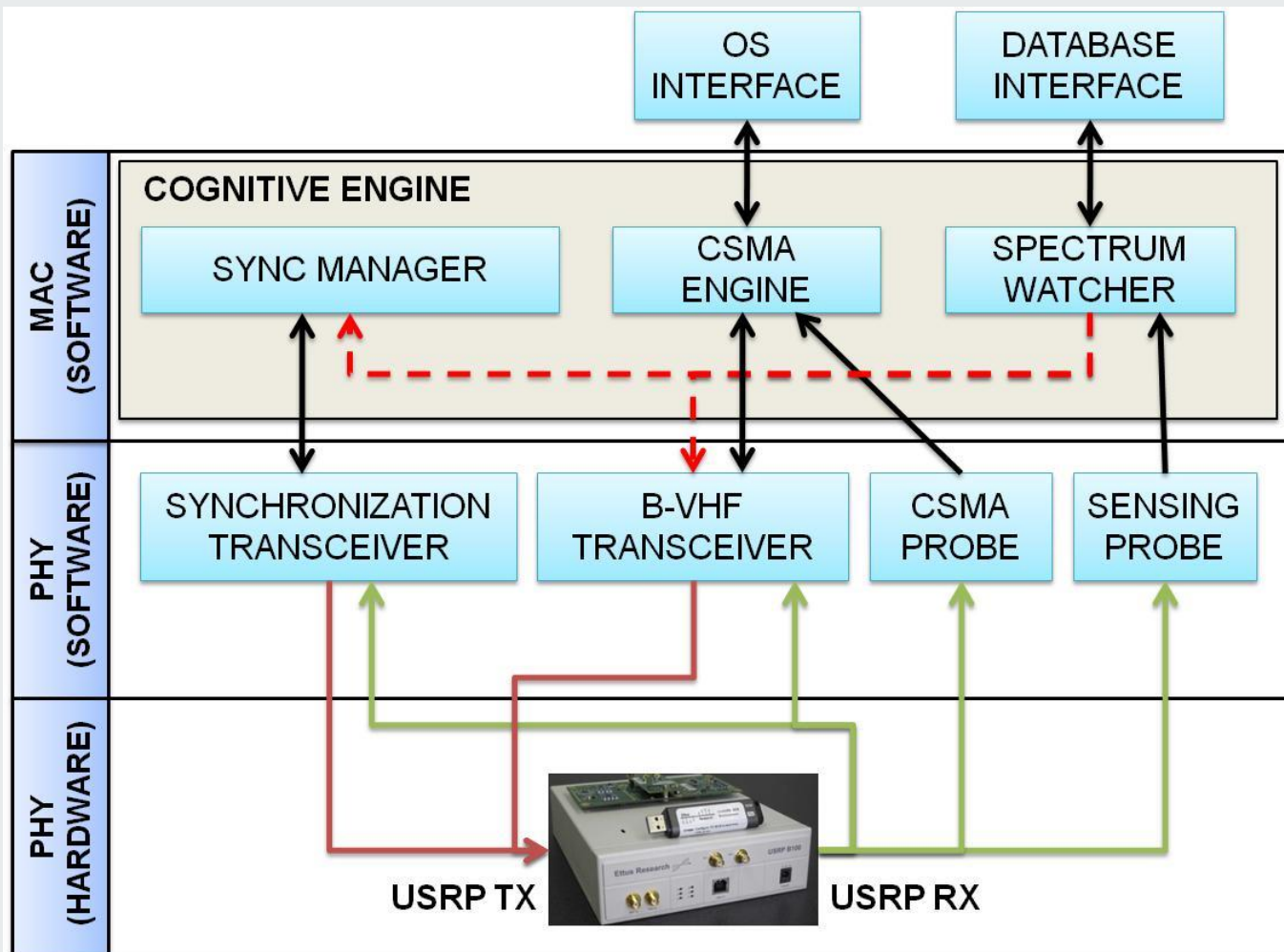
# Proposed Solution

- Reconfigurable radio transceiver
  - Software Defined Radio

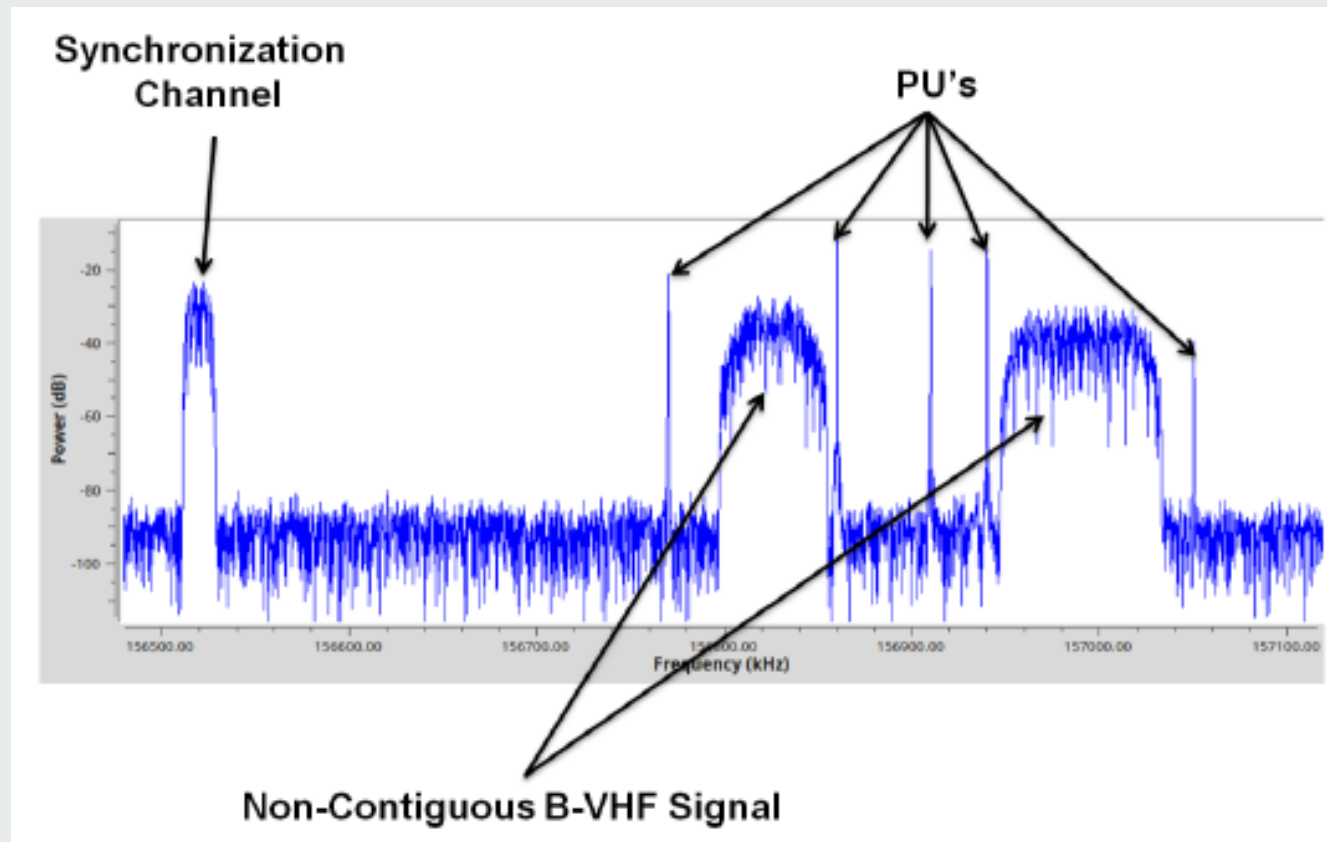


# Proposed Solution

- Radio Architecture – Master Station



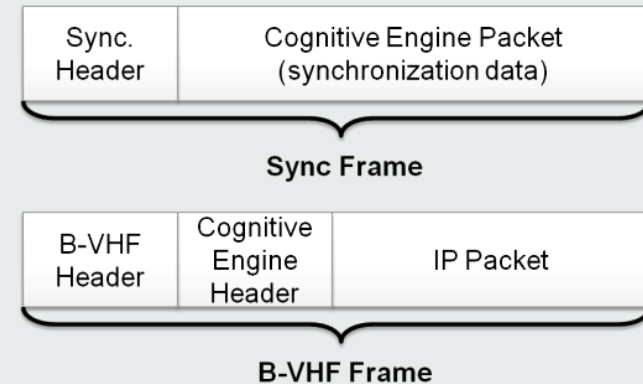
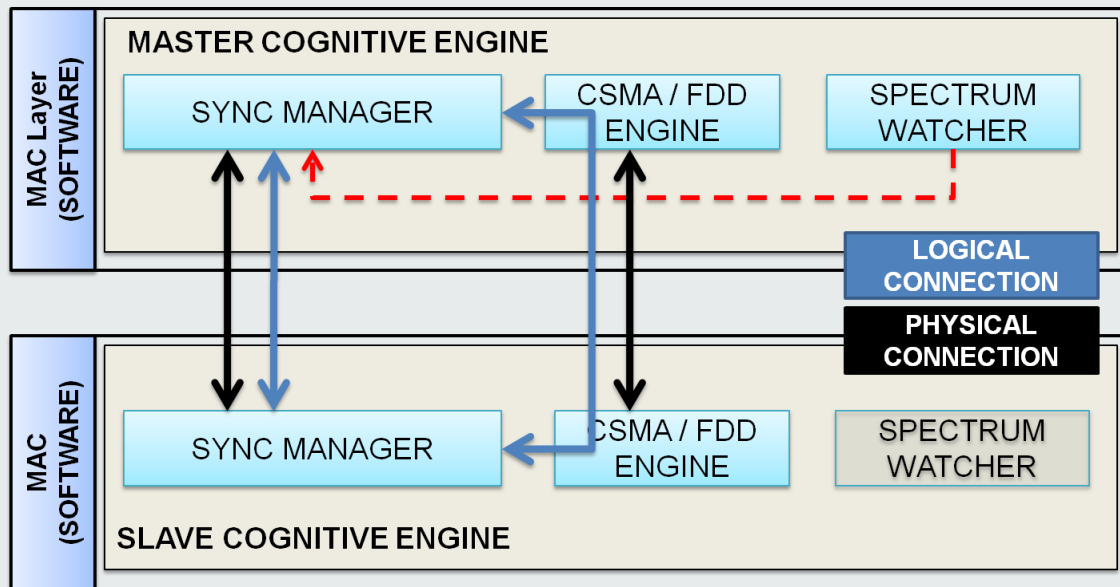
- Network Synchronization



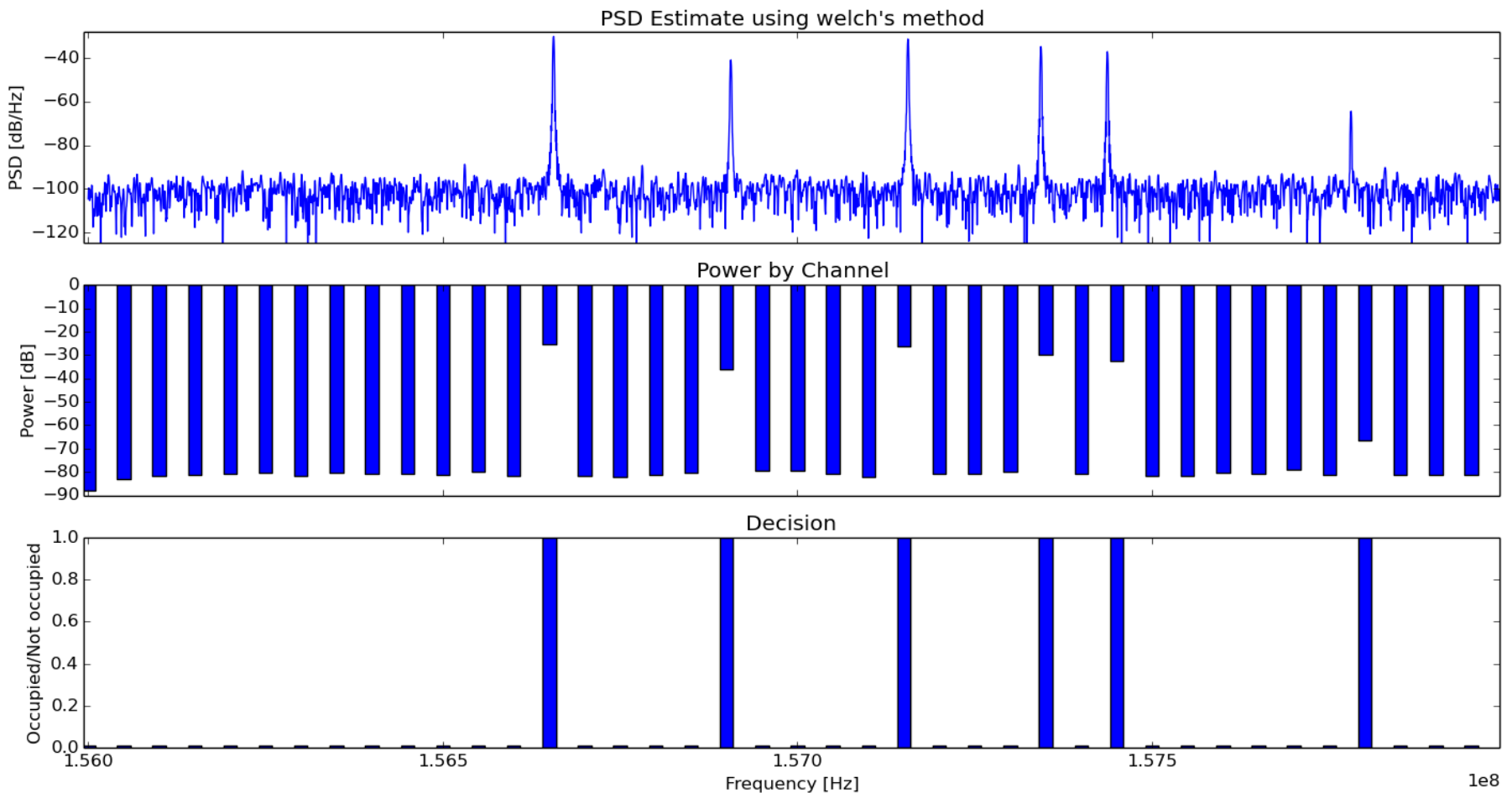


# Proposed Solution

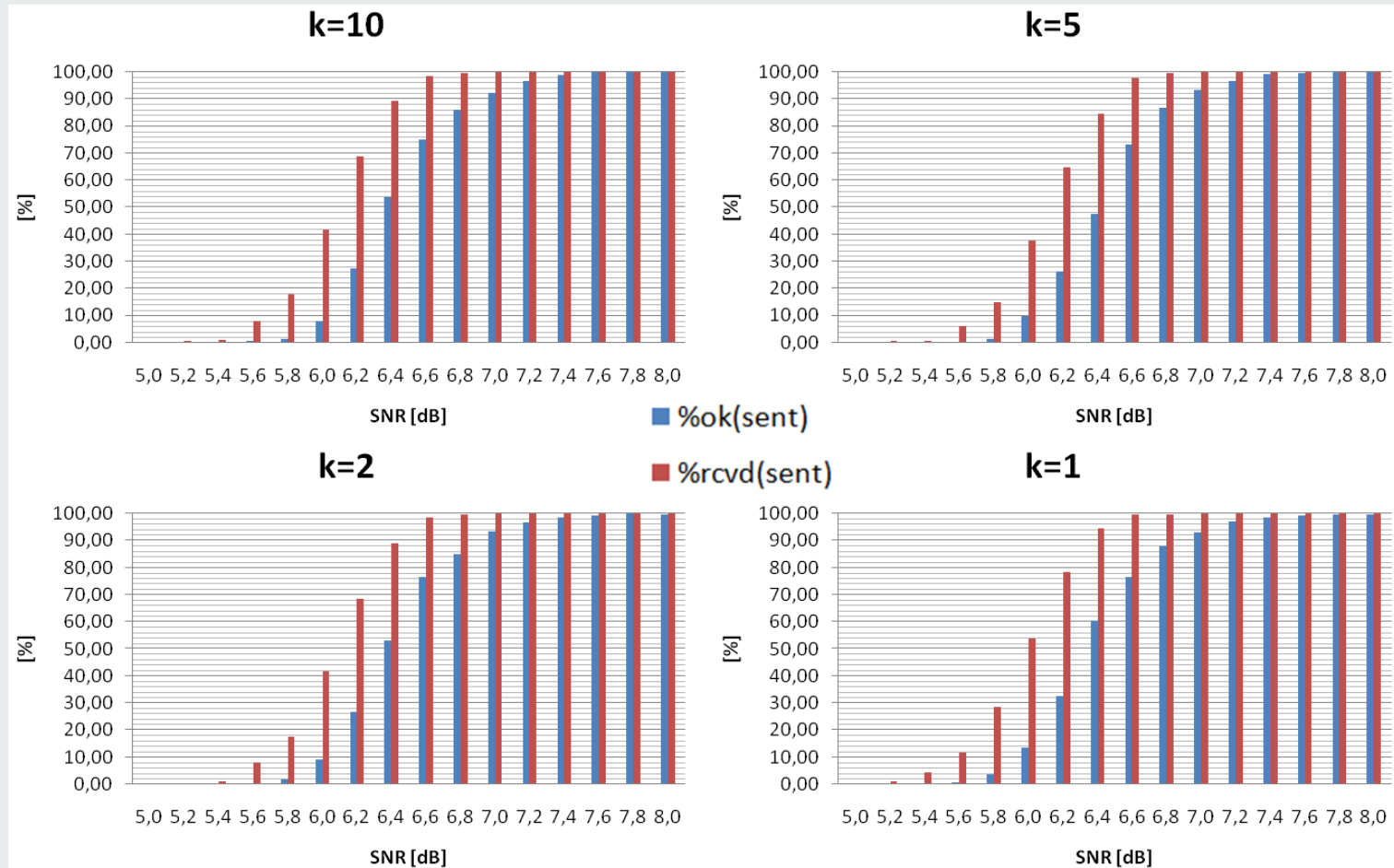
- Cognitive Engine and Network Synchronization



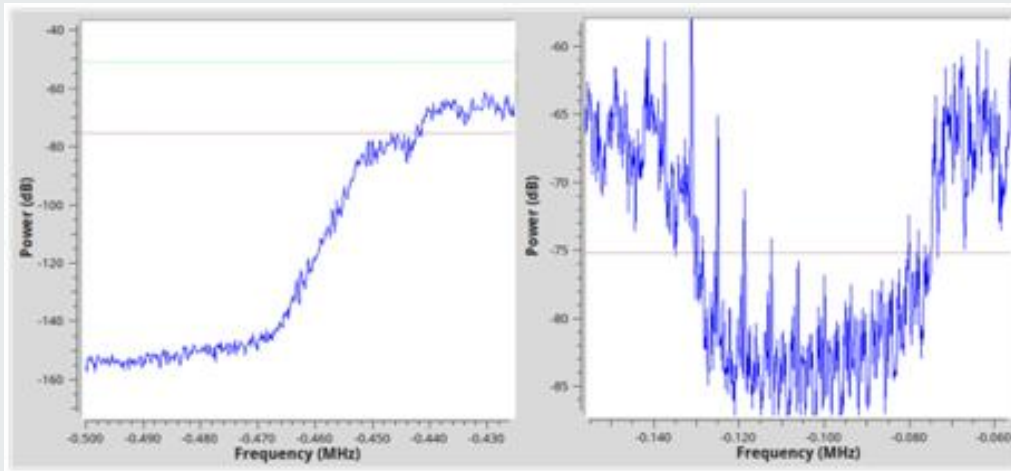
- Spectrum Sensing - Results



- Transceiver Analysis – Simulation Results (k – Rice Factor)

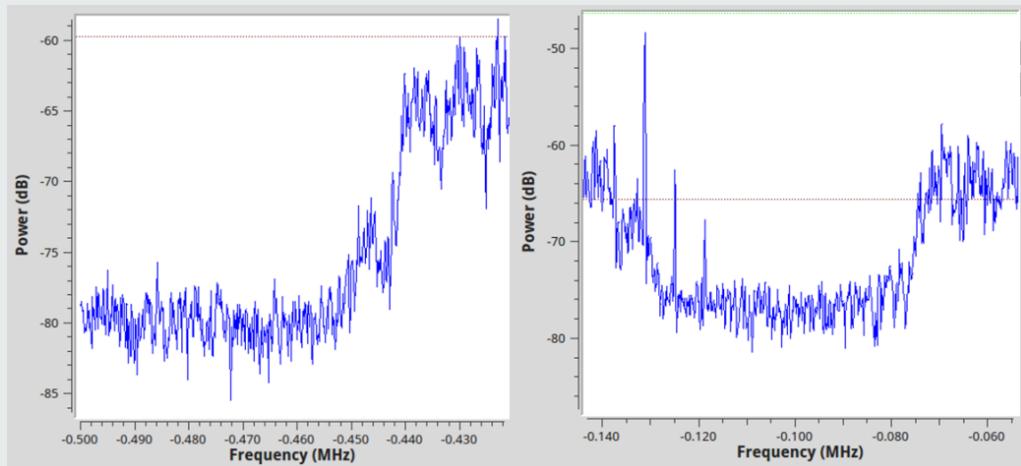


- Transceiver Analysis – OOB and NC Radiation

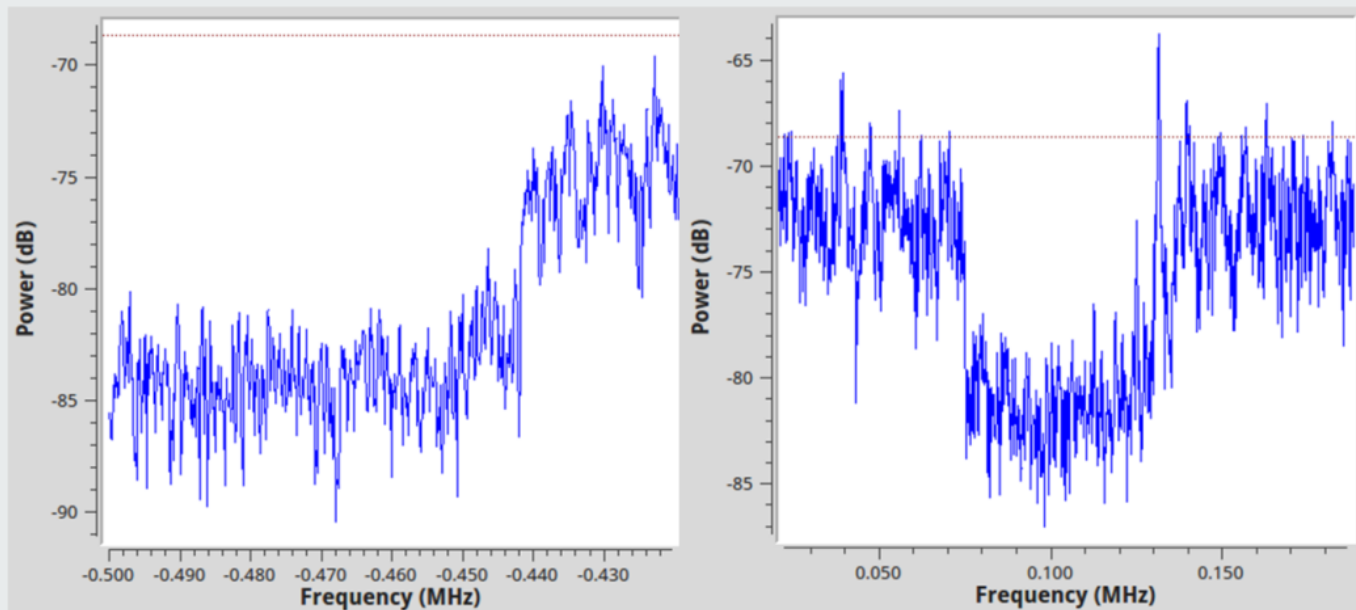


Transmitted

Received  
w/ AWGN  
(simulation)



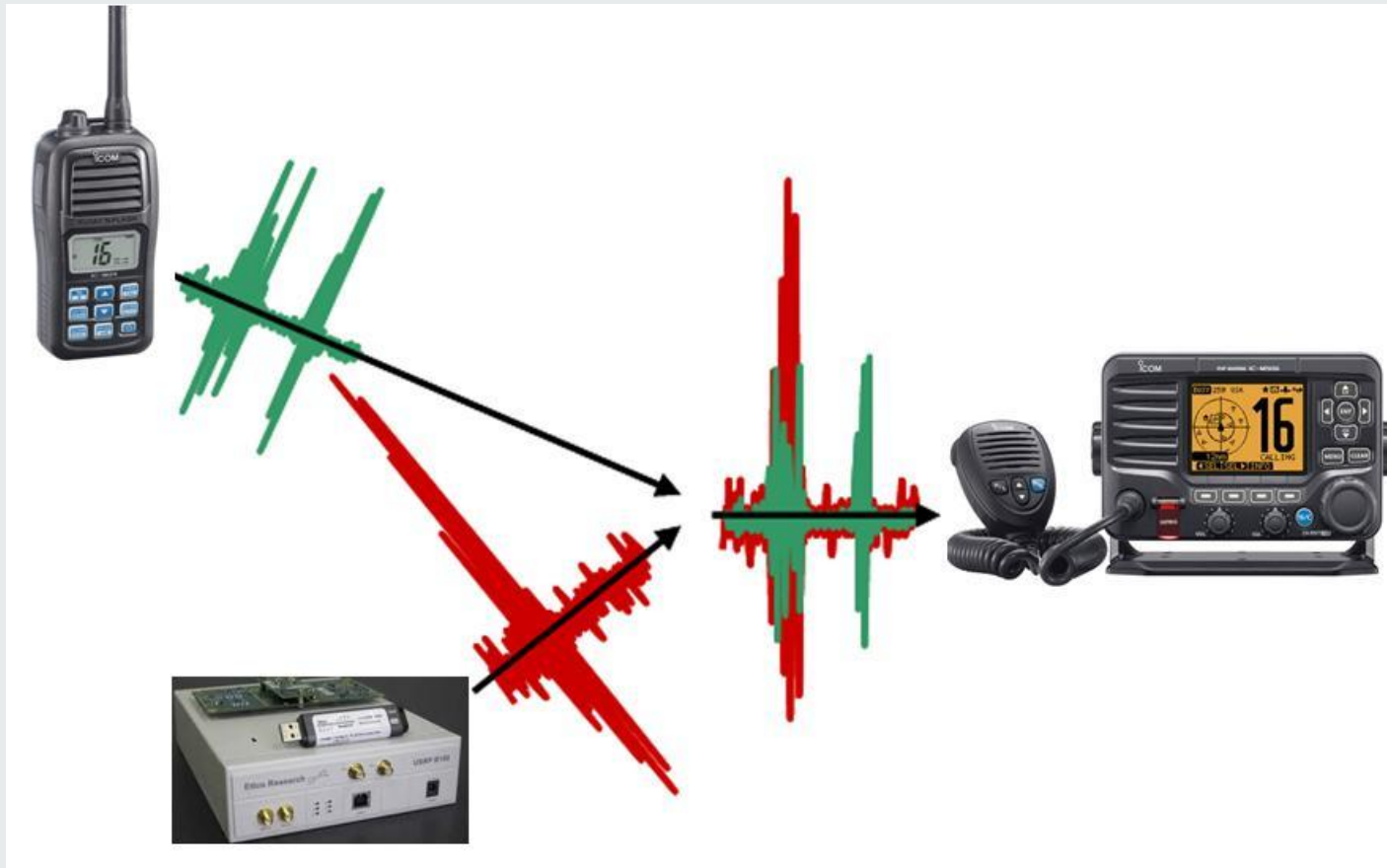
- Transceiver Analysis – OOB and NC Radiation



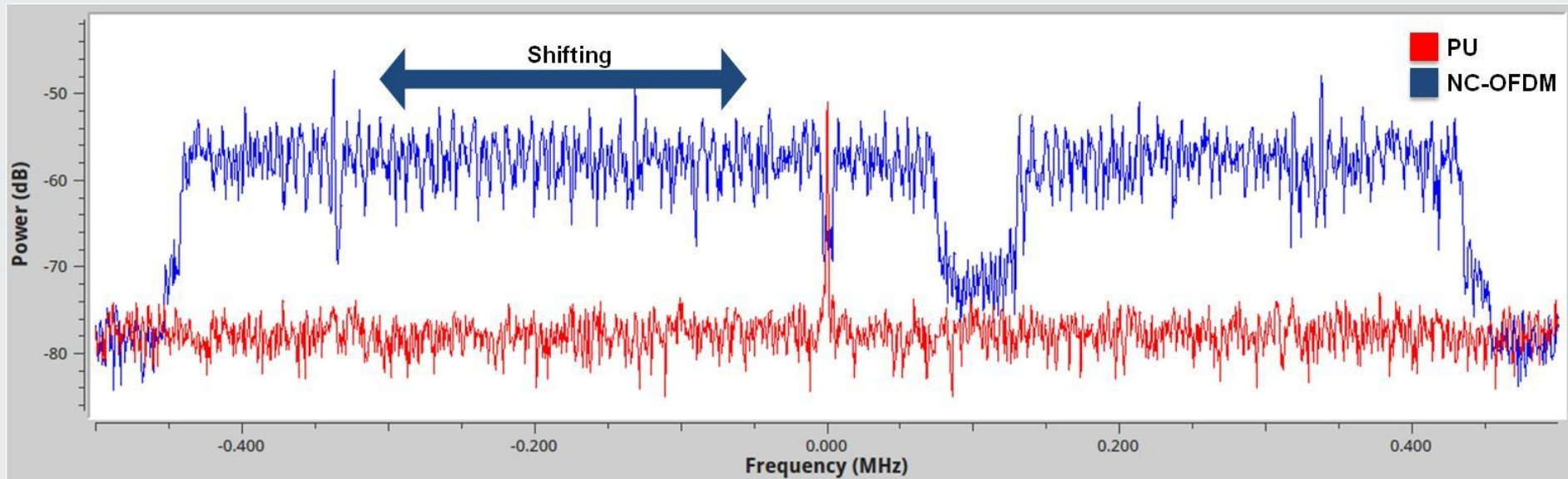
Received by the USRP  
(over the air)



- Subjective Coexistence Analysis

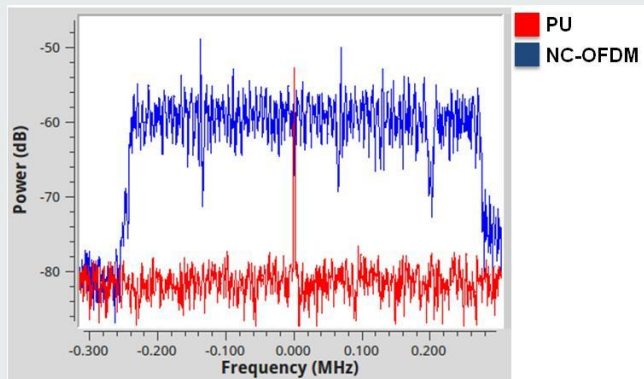


- Subjective Coexistence Analysis

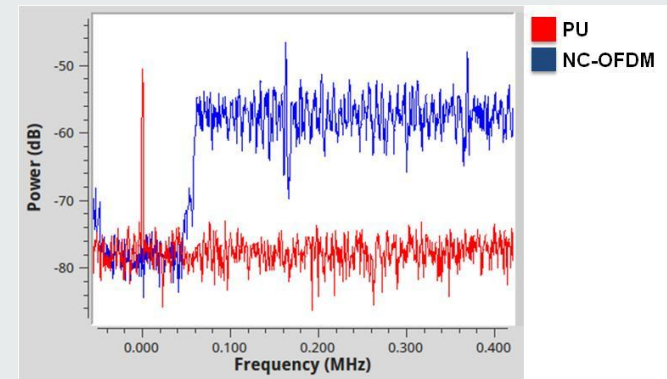


- Subjective Coexistence Analysis

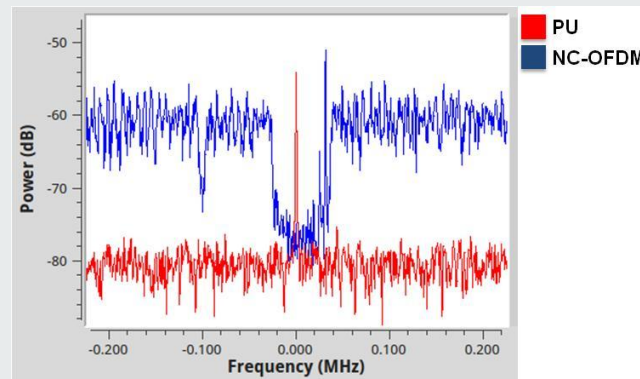
In  
Band



OOB

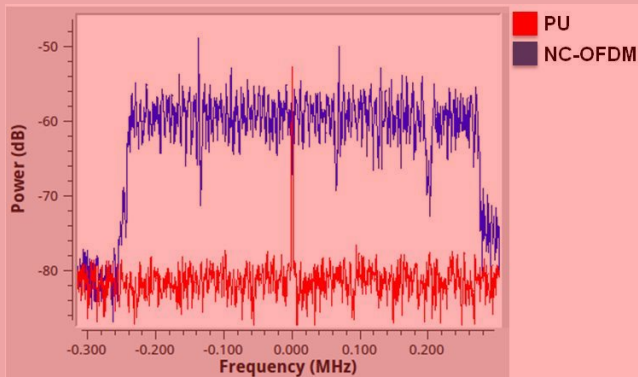


NC

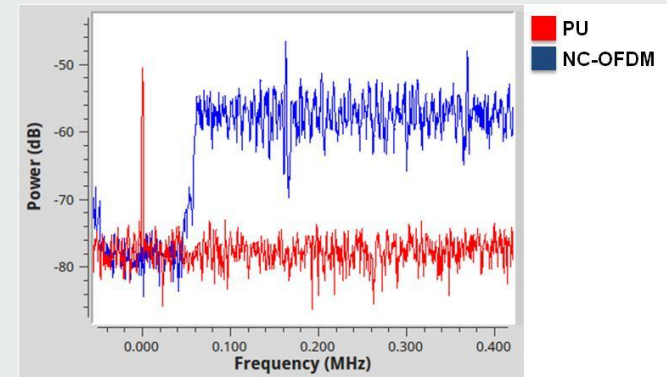


- Subjective Coexistence Analysis

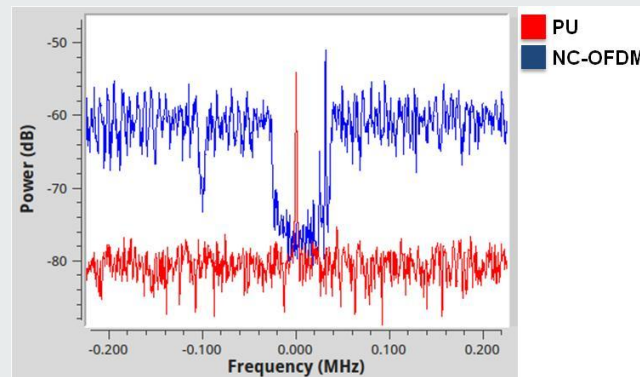
In  
Band



OOB

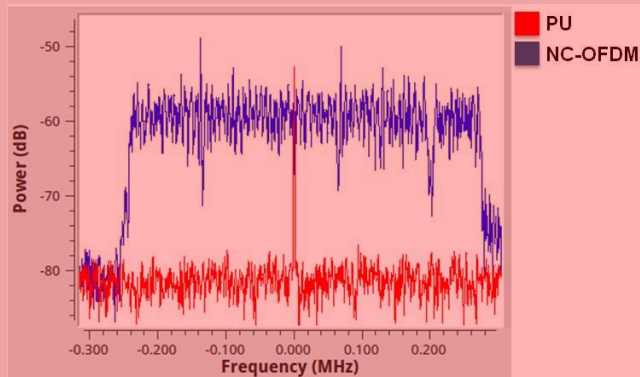


NC

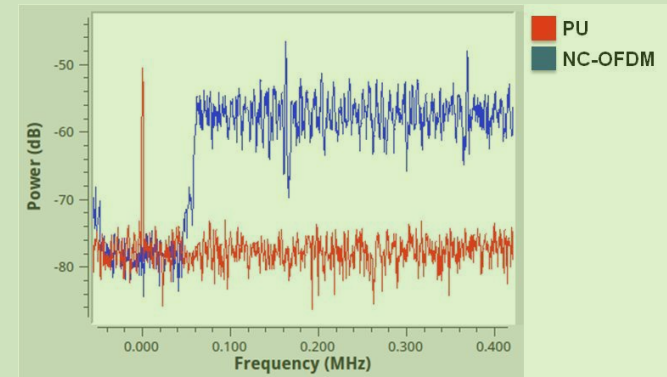


- Subjective Coexistence Analysis

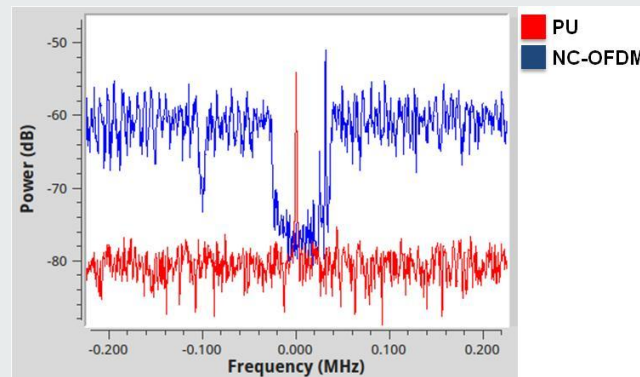
In  
Band



OoB

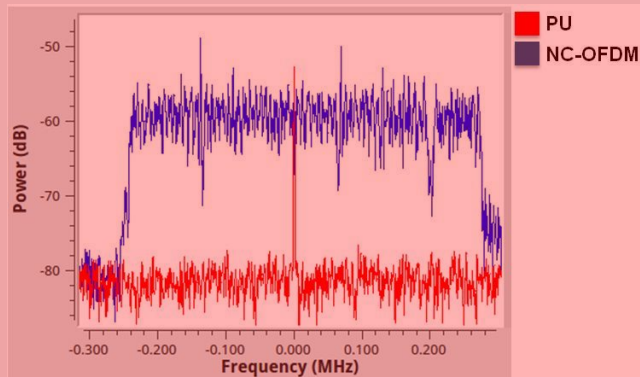


NC

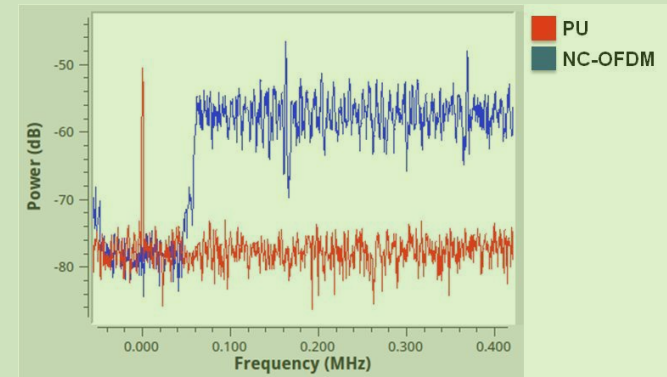


- Subjective Coexistence Analysis

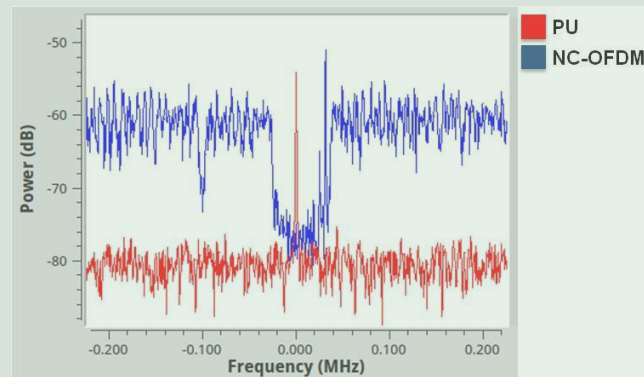
In  
Band



OOB



NC





- Tunneling IP Data – Packet Analysis

Total rcvd: 27 total OK: 26 0 A 98 True Total rcvd: 28 total OK: 27 0 A 98 True Total rcvd: 29 total OK: 28 Tx: len(payload) = 42 0 A 42 True Total rcvd: 30 total OK: 29 Tx: len(payload) = 98 0 A 98 True Total rcvd: 31 total OK: 30 Tx: len(payload) = 98 0 A 42 True Total rcvd: 32 total OK: 31 0 A 98 True Total rcvd: 33 total OK: 32 Tx: len(payload) = 98 0 A 42 True Total rcvd: 34 total OK: 33 0 A 42 True Total rcvd: 35 total OK: 34 0 A 98 True Total rcvd: 36 total OK: 35 Tx: len(payload) = 98 0 A 98 True Total rcvd: 37 total OK: 36 Tx: len(payload) = 98 0 A 98 True Total rcvd: 38 total OK: 37 Tx: len(payload) = 98 0 A 98 True	<table><tr><th>No.</th><th>Time</th><th>Source</th><th>Destination</th><th>Protocol</th><th>Length</th><th>Info</th></tr><tr><td>44</td><td>21.050287000</td><td>192.168.200.10</td><td>192.168.200.30</td><td>ICMP</td><td>98</td><td>Echo (ping) request</td></tr><tr><td>45</td><td>21.541427000</td><td>192.168.200.30</td><td>192.168.200.10</td><td>ICMP</td><td>98</td><td>Echo (ping) reply</td></tr><tr><td>46</td><td>22.050180000</td><td>192.168.200.10</td><td>192.168.200.30</td><td>ICMP</td><td>98</td><td>Echo (ping) request</td></tr><tr><td>47</td><td>22.608066000</td><td>192.168.200.30</td><td>192.168.200.10</td><td>ICMP</td><td>98</td><td>Echo (ping) reply</td></tr><tr><td>48</td><td>22.614704000</td><td>192.168.200.30</td><td>192.168.200.10</td><td>ICMP</td><td>98</td><td>Echo (ping) reply</td></tr><tr><td>49</td><td>23.050441000</td><td>192.168.200.10</td><td>192.168.200.30</td><td>ICMP</td><td>98</td><td>Echo (ping) request</td></tr><tr><td>50</td><td>23.473901000</td><td>192.168.200.30</td><td>192.168.200.10</td><td>ICMP</td><td>98</td><td>Echo (ping) reply</td></tr><tr><td>51</td><td>24.050320000</td><td>192.168.200.10</td><td>192.168.200.30</td><td>ICMP</td><td>98</td><td>Echo (ping) request</td></tr><tr><td>52</td><td>24.589827000</td><td>192.168.200.30</td><td>192.168.200.10</td><td>ICMP</td><td>98</td><td>Echo (ping) reply</td></tr><tr><td>53</td><td>25.050381000</td><td>192.168.200.10</td><td>192.168.200.30</td><td>ICMP</td><td>98</td><td>Echo (ping) request</td></tr><tr><td>54</td><td>25.490405000</td><td>192.168.200.30</td><td>192.168.200.10</td><td>ICMP</td><td>98</td><td>Echo (ping) reply</td></tr></table> <p>Frame 45: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 0</p> <p>Ethernet II, Src: ae:07:e9:0d:a9:09 (ae:07:e9:0d:a9:09), Dst: 0a:ee:3c:00:07:94 (0a:ee:3c:00:07:94)</p> <p>Internet Protocol Version 4, Src: 192.168.200.30 (192.168.200.30), Dst: 192.168.200.10 (192.168.200.10)</p> <p>Internet Control Message Protocol</p> <p>0000 0a ee 3c 00 07 94 ae 07 e9 0d a9 09 08 00 45 00 ..&lt;.....E. 0010 00 54 ec 3c 00 00 40 01 7c f2 c0 a8 c8 1e c0 a8 .T.&lt;..@.  ..... 0020 c8 0a 00 00 e6 b7 23 c4 00 13 02 03 09 54 00 00 .....#. ....T.. 0030 00 00 1f 47 0c 00 00 00 00 00 10 11 12 13 14 15 ...G.....</p>	No.	Time	Source	Destination	Protocol	Length	Info	44	21.050287000	192.168.200.10	192.168.200.30	ICMP	98	Echo (ping) request	45	21.541427000	192.168.200.30	192.168.200.10	ICMP	98	Echo (ping) reply	46	22.050180000	192.168.200.10	192.168.200.30	ICMP	98	Echo (ping) request	47	22.608066000	192.168.200.30	192.168.200.10	ICMP	98	Echo (ping) reply	48	22.614704000	192.168.200.30	192.168.200.10	ICMP	98	Echo (ping) reply	49	23.050441000	192.168.200.10	192.168.200.30	ICMP	98	Echo (ping) request	50	23.473901000	192.168.200.30	192.168.200.10	ICMP	98	Echo (ping) reply	51	24.050320000	192.168.200.10	192.168.200.30	ICMP	98	Echo (ping) request	52	24.589827000	192.168.200.30	192.168.200.10	ICMP	98	Echo (ping) reply	53	25.050381000	192.168.200.10	192.168.200.30	ICMP	98	Echo (ping) request	54	25.490405000	192.168.200.30	192.168.200.10	ICMP	98	Echo (ping) reply	Tx: len(payload) = 98 1 A 42 True Total rcvd: Tx: len(payload) = 42 50 total OK: 50 Tx: len(payload) = 98 1 A 42 True Total rcvd: 51 total OK: 51 Tx: len(payload) = 42 Tx: len(payload) = 98 1 A 42 True Total rcvd: Tx: len(payload) = 42 52 total OK: 52 1 A 42 True Total rcvd: 53 total OK: 53 Tx: len(payload) = 42 Tx: len(payload) = 98 1 A 98 True Total rcvd: 54 total OK: 54 Tx: len(payload) = 98 1 A 98 True Total rcvd: 55 total OK: 55 1 A 98 True Total rcvd: 56 total OK: 56 Tx: len(payload) = 98 1 A 98 True Total rcvd: 57 total OK: 57 Tx: len(payload) = 98 1 A 98 True Total rcvd: 58 total OK: 58 Tx: len(payload) = 98 1 A 98 True
No.	Time	Source	Destination	Protocol	Length	Info																																																																																
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- Prototype, fully functional broadband cognitive radio system;
- Innovative aspects concerning cognitive radio implementations;
- Results demonstrate the ability to detect multiple primary users
- Acceptable behavior for a digital communication system in terms of packet performance and radiation profile;
- Regulatory and coexistence issues;
- Transport of IP data.

- Network and Radio Architecture;
- Transceiver and Sensing Techniques
- Network Synchronization;
- Coexistence Analysis and Evaluation.

# Thank you for your attention!



## Q&A

Software Defined Radio Implementation for Maritime Cognitive Radio Communications



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