Software Defined Radio Implementation for Maritime Cognitive Radio Communications

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Outline

• 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**

<table>
<thead>
<tr>
<th>System</th>
<th>Band</th>
<th>Throughput</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAVTEX</td>
<td>HF, MF</td>
<td>100 b/s</td>
<td>Information / Distress</td>
</tr>
<tr>
<td>DSC</td>
<td>VHF MF/HF</td>
<td>1.2 kb/s 100 b/s</td>
<td>Short messaging / Distress</td>
</tr>
<tr>
<td>AIS</td>
<td>VHF</td>
<td>9.6 kb/s - 2 ch.</td>
<td>Automatic vessel tracking</td>
</tr>
<tr>
<td>SATCOM</td>
<td>SHF</td>
<td>&lt; 4 Mb/s</td>
<td>IP data / Telephony</td>
</tr>
</tbody>
</table>

Terrestrial networks: GSM, UMTS, LTE…
Introduction and Motivation

• New Demands

Sensor Networks

e-Navigation

Personal Communications

Source: Times of Malta
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
Introduction and Motivation

- Radio Resources Overview – The VHF Band
Introduction and Motivation

- Radio Resources Overview – The VHF Band
Introduction and Motivation

- Solutions

Spectrum refarming?

New spectrum allocations?
Opportunistic Systems (Smart Solutions)

Source: IEEE 802.22 Working Group
Introduction and Motivation

• Opportunistic Systems (Smart Solutions)

Source: Bolas et. al. 2012
Objectives

Broadband VHF Communication System

Opportunistic Use of Maritime VHF Spectrum

Spectrum Sensing, Transceiver Techniques, Network Synchronization → Cognitive Radio

Software Defined Radio Implementation for Maritime Cognitive Radio Communications
Contributions

• 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
Background

- Spectrum Shaping with a Multicarrier Modulation:
  - Orthogonal Frequency Division Multiplexing (OFDM)
• OFDM
  – It’s awesome, but…

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

Out Of Band (OOB) Radiation

Non Contiguous (NC) Radiation
Proposed Solution

- Opportunistic Use of Radio Spectrum in the Maritime context

- Most Common Primary Users

Analogue Telephony

DSC

AIS
Proposed Solution

- Multiuser Scenario – Multichannel Detector

Diagram:
1. Setup
   - Estimate noise power
   - Define decision threshold
   - Set RX frequency
   - Estimate PSD
   - Compute power for each channel
   - Test hypothesis
   - Define spectrum constraint
Proposed Solution

- Reconfigurable radio transceiver
  - Software Defined Radio
Proposed Solution

- Radio Architecture – Master Station

![Diagram of the proposed solution showing the architecture of a cognitive radio system with components such as COGNITIVE ENGINE, SYNC MANAGER, CSMA ENGINE, SPECTRUM WATCHER, DATABASE INTERFACE, OS INTERFACE, PHY (SOFTWARE) layers, and PHY (HARDWARE) layers including USRP TX and USRP RX.]
Proposed Solution

- Network Synchronization
Proposed Solution

• Cognitive Engine and Network Synchronization
Tests And Results

- Spectrum Sensing - Results

![Graph showing PSD Estimate using Welch's method, Power by Channel, and Decision over frequency range 1.560 to 1.575 Hz.](image)
Tests And Results

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

![Graphs showing simulation results for different values of k (Rice factor). The graphs depict the percentage of successful transmissions (ok(sent)) and received transmissions (rcvd(sent)) for varying Signal-to-Noise Ratios (SNR) in dB. The graphs illustrate the impact of the Rice factor on the performance of the transceiver.]
Tests And Results

• Transceiver Analysis – OOB and NC Radiation

Transmitted

Received w/ AWGN (simulation)
Tests And Results

- Transceiver Analysis – OOB and NC Radiation

Received by the USRP
(over the air)
Tests And Results

- Subjective Coexistence Analysis
Tests And Results

- Subjective Coexistence Analysis
Tests And Results

- Subjective Coexistence Analysis

In Band

OOB

NC
Tests And Results

- Subjective Coexistence Analysis

![In Band Graph](image1)

![OOB Graph](image2)

![NC Graph](image3)
Tests And Results

• Subjective Coexistence Analysis

In Band

OOB

NC

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Tests And Results

- Subjective Coexistence Analysis

In Band

OOB

NC
Tests And Results

- Tunneling IP Data – Packet Analysis
Conclusions

- 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.
Future Work

- Network and Radio Architecture;
- Transceiver and Sensing Techniques;
- Network Synchronization;
- Coexistence Analysis and Evaluation.
Thank you for your attention!

Q&A

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