Evaluation of Fast Frequency Hopping Modem Using An Emulation-Based Test Framework

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Overview

- Motivation
- Research Goals
- Fast Frequency Hopping (FFH) Modem
- Proposed Test Framework
- Methodology
- Results
- Conclusions
- Future Work

Motivation

- Cognitive Radio (CR) is proposed as a solution to the spectrum congestion and utilization problem

- Two significant problems when testing CRs:

1. **How to validate a CR device to show it will not cause unnecessary interference under varying known or unknown conditions.**

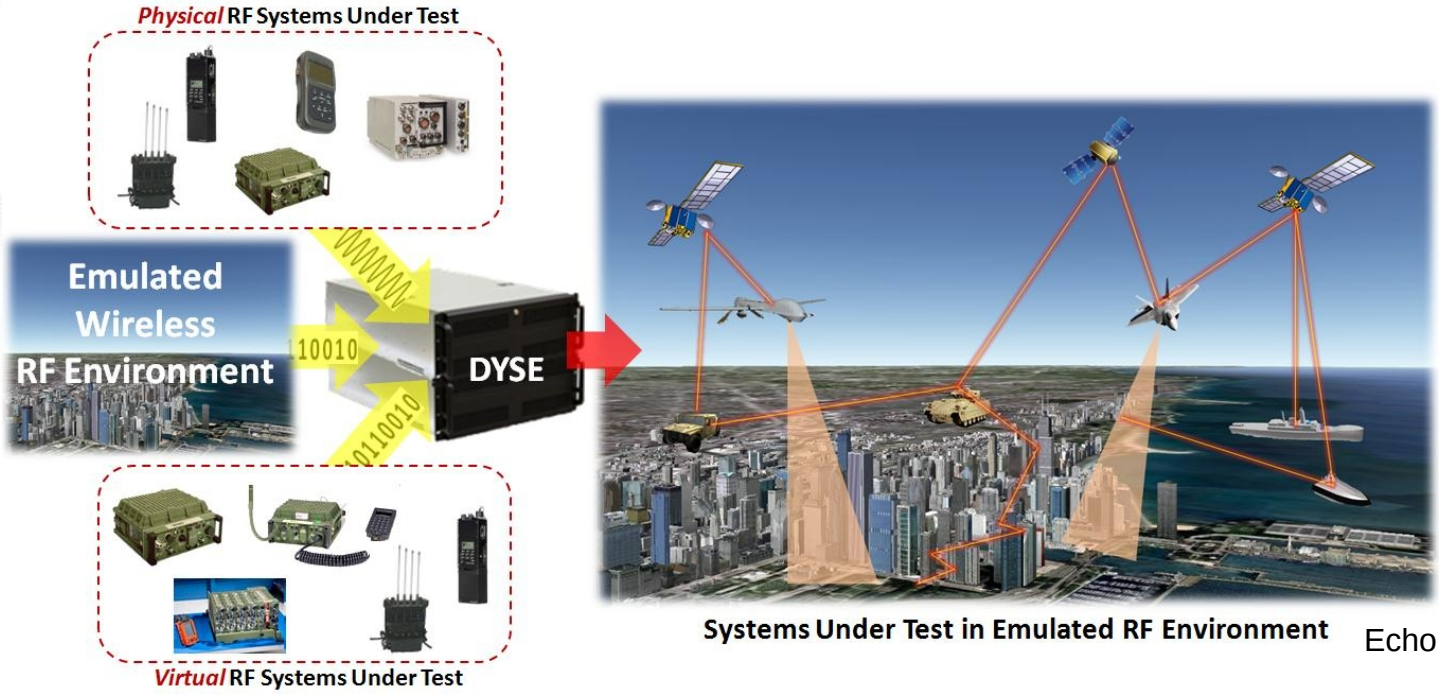
2. **There is a lack of standardization and commonality between CR researchers.**

Research Goals

- **Research Questions:**
  - Can a framework to test and evaluate CRs as a complete system be developed?
- **Assumptions:**
  - The CR is a physical device with RF capabilities
  - Testing from perspective of end-user
- **Approach:**
  - Develop prototype DSA/CR using FFH modem and use as initial case study

Environment Emulator

- Work underway to utilize DYnamic Spectrum Environment Emulator (DYSE)

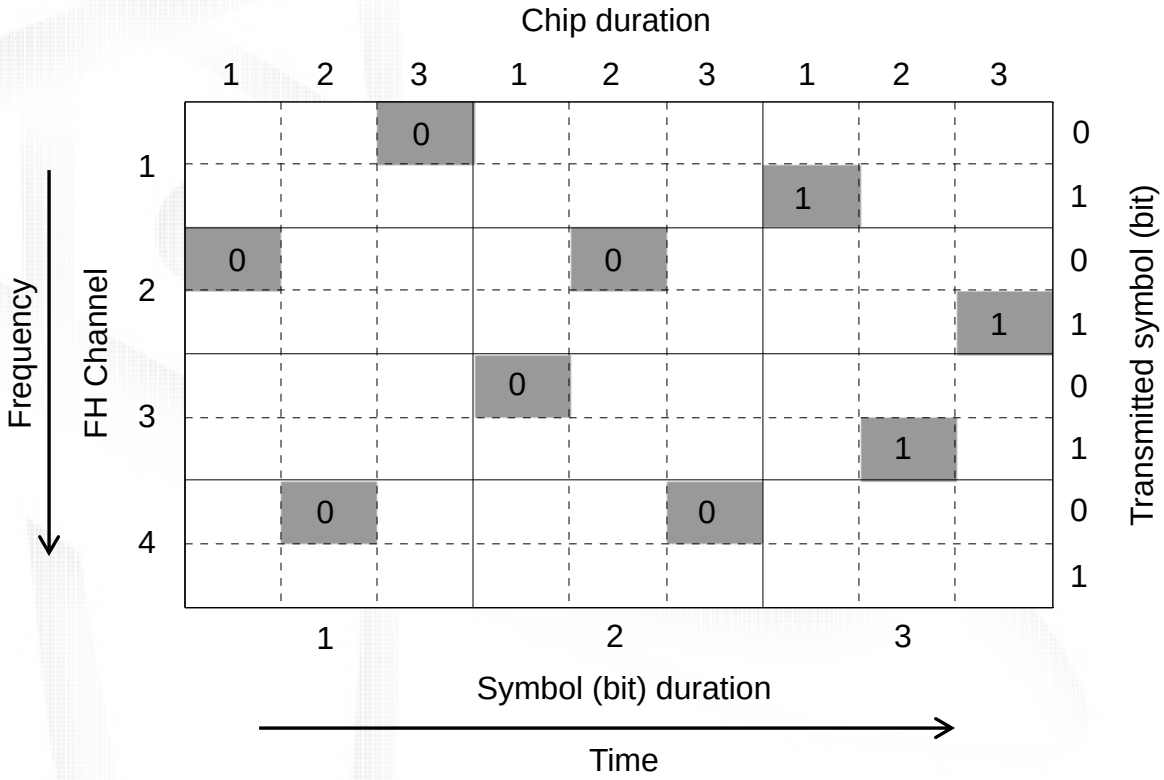


Echo Ridge LLC, 2014

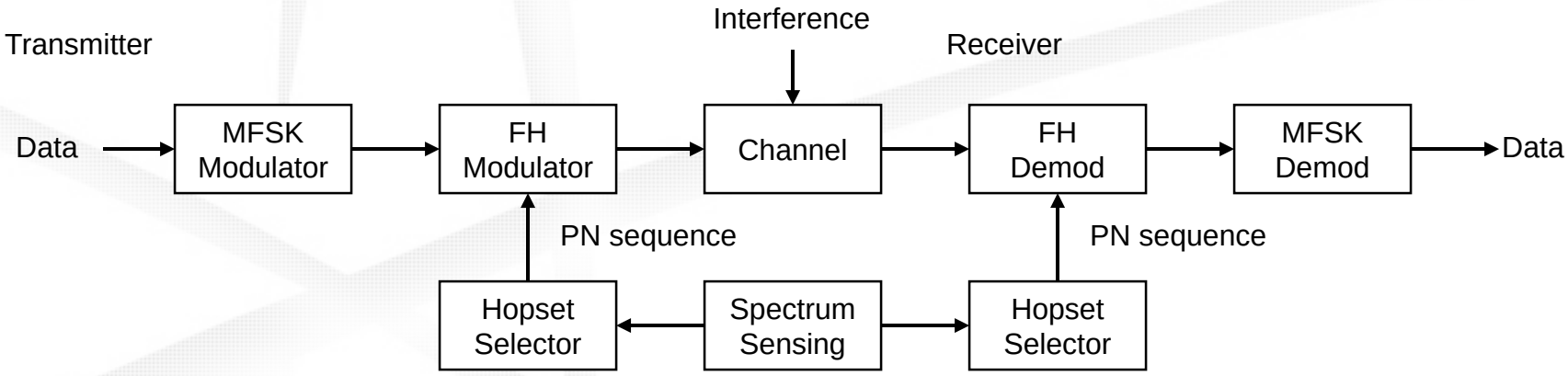
Research is still on-going to integrate FFH modem into prototype to use in the test framework

FFH Modem

- Frequency Hopping (fast)
  - Chip (hop) rate exceeds symbol rate (bit rate for binary signaling)



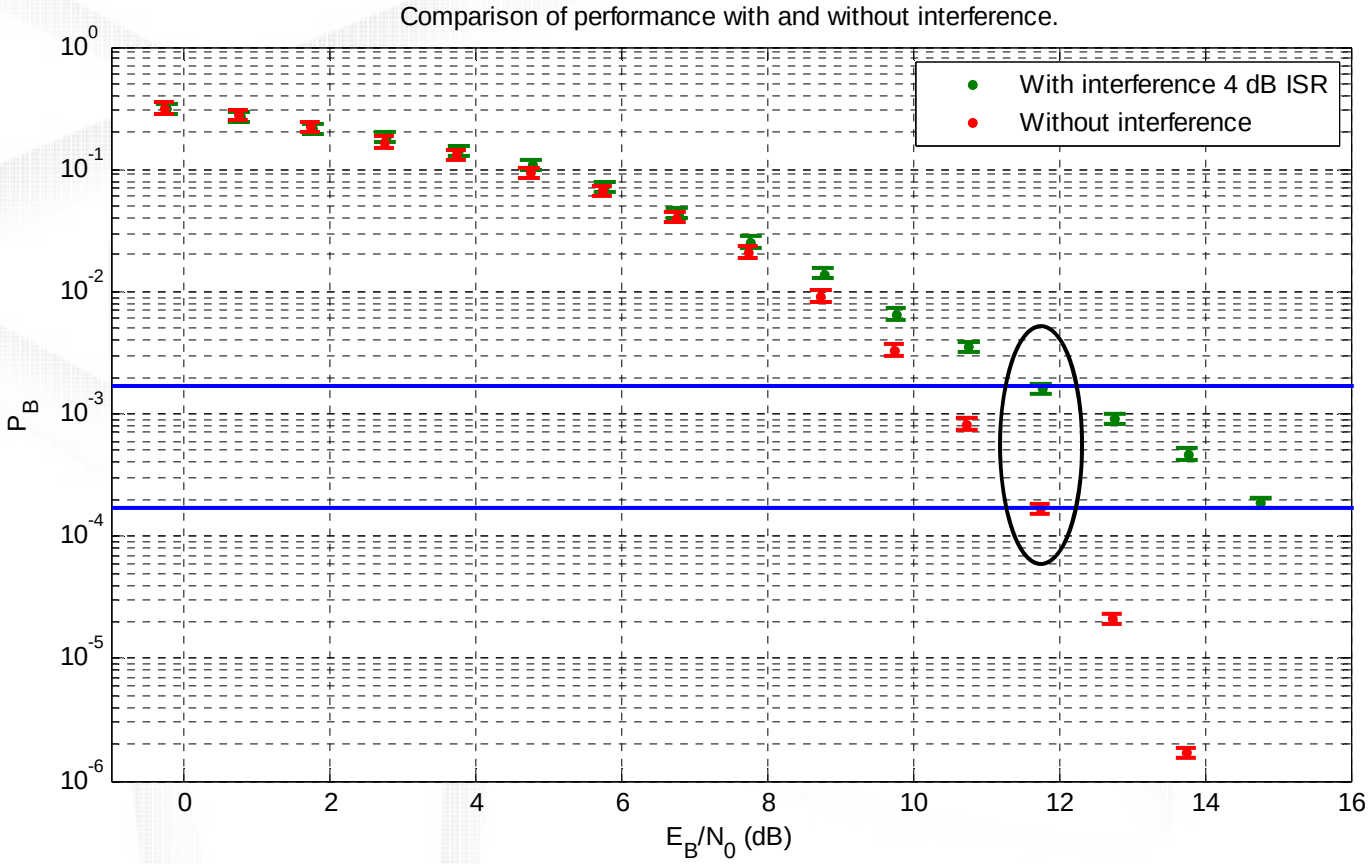
FFH Modem



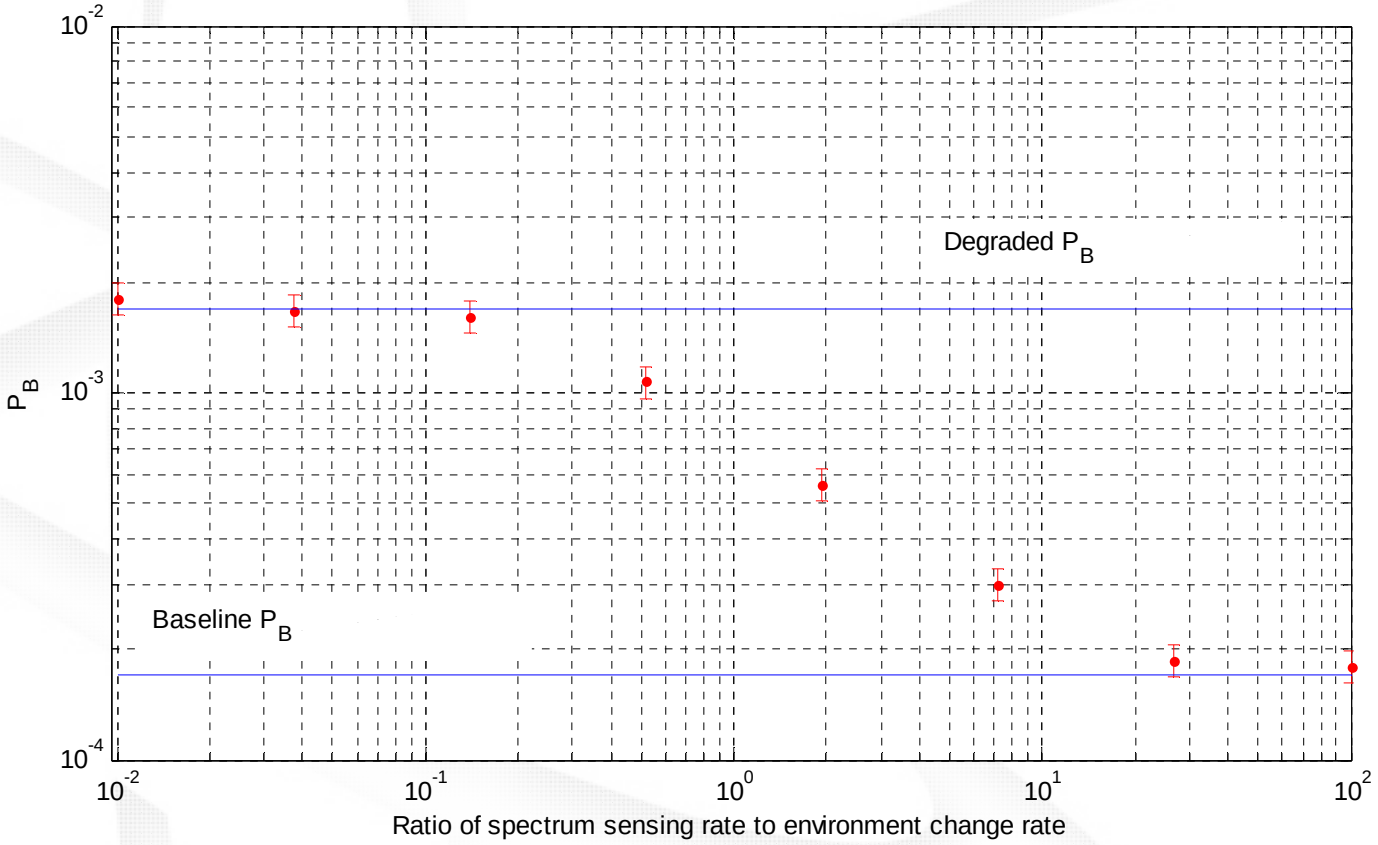
Parameter	Value
Modulation	Binary FSK
Center frequency	10 MHz
Sample frequency	40 Msamp/s
Symbol (bit) rate	78,125 Symbols/s
FSK bandwidth	469 KHz
Number of channels	32
Chips per symbol	3
Spread spectrum bandwidth	15 MHz

Results – FFH Modem

Compare the performance of a non-adaptive receiver with and without interference



Results – FFH Modem



BER is bounded by the case where there is no adaptation on top and by the case where there is no interference on bottom.

Proposed Test Framework

- The PU(s) created environment is the workload
- Measure ***both*** PU and SU response to workloads
- Classify PU workloads into benchmarks for repeatability, reproducibility and flexibility
- Use emulated RF environment
  - Create PUs
  - Control transmission paths
- SU cognition is measured via device behavior

Goal is to create device and architecture independent test framework

Behavior-Based Testing (1/2)

A radio device behaves cognitively if it:

1. *Improves performance* by responding to the environment
2. *Avoids causing interference* to existing users
3. In performing 1 and 2, *implements user policy and goals*

Does the device improve communications while not degrading others' ability to communicate?

Behavior Based Testing (2/2)

- Benefits:
  1. There is no need to test underlying components to characterize overall performance
  2. CR can be evaluated as a complete system
  3. CR definitions become less important
  4. Testing is architecture independent
  5. Enables cognition as a continuum—from autonomous to autonomy

Benchmarks (1/2)

- Benchmarks implemented similar to Standard Performance Evaluation Corporation (SPEC) benchmarks
- Organize into benchmark classes
  - IEEE 802.22 style CRs may be evaluated in one benchmark class
  - Ad hoc style CRs evaluated in different class
  - Avoids requiring strict definitions on what a CR is
  - Focus is on performance

Benchmarks (2/2)

- Benchmarks defined by 11 characteristics

1. Network vs Node
2. Topology
3. RF Environment
4. Test Band
5. Motion
6. Performance Metrics
7. Timeframe/Sampling Intervals
8. Geographical Information
9. Maximum Power Level
10. Primary User Profile
11. Scenario Description

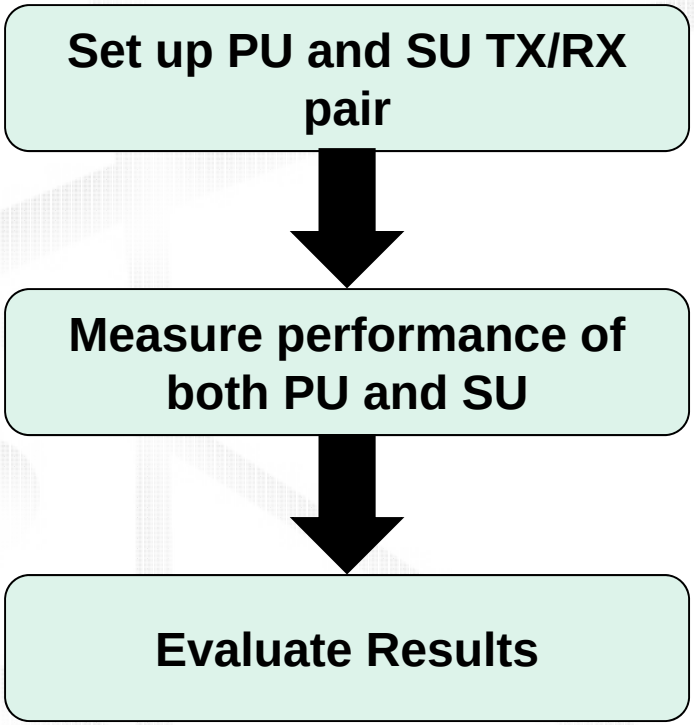
- This list is extensible for research specific goals

Methodology

- **Hypothesis:** *Cognition of cognitive radio systems can be successfully tested by measuring cognitive radio behavior of the entire system, without knowledge of the behavior of the underlying cognitive components.*

Can behavior-based testing be used to evaluate a cognitive radio system?

Approach

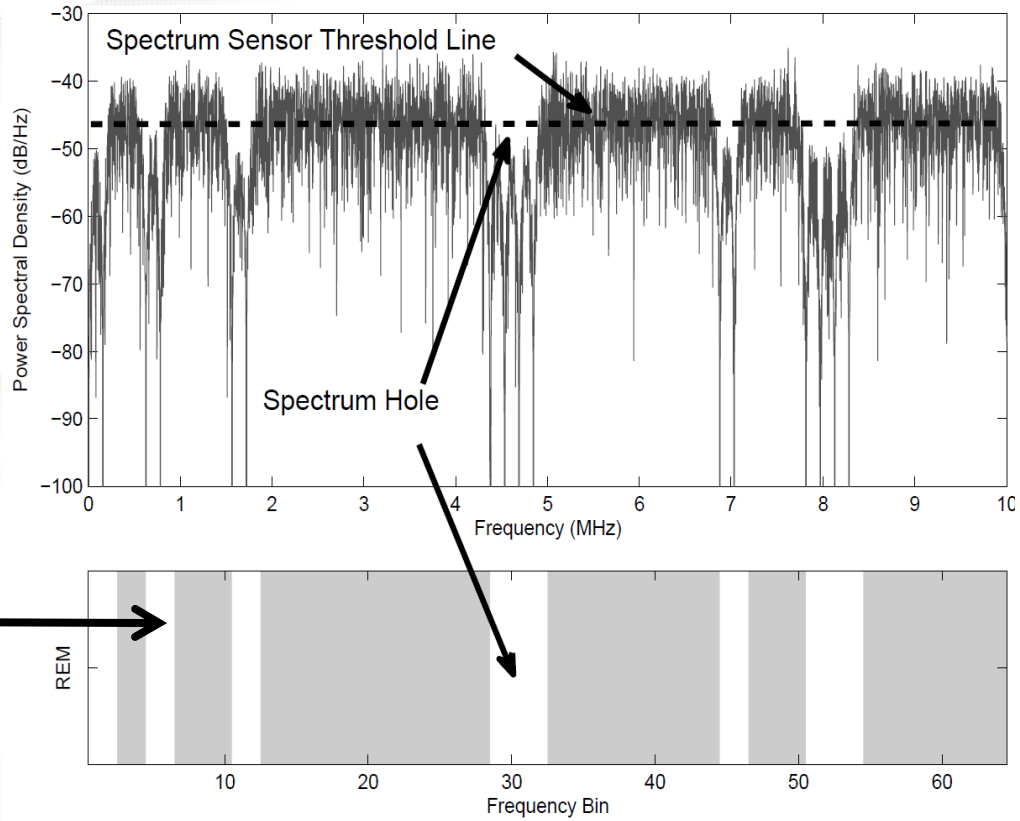


Assumptions:

- Cognition is enabled by utilizing spectrum knowledge through spectrum sensing
- Greater waveform capabilities leads to greater cognitive capabilities

Workload

- Spectrum broken up into 64 channels over 10 MHz of spectrum
- SU may utilize spectrum holes to improve performance



Each channel is referred to as a “Bin”

Workload Factors

- ***PU activity (the RF Environment) is the workload***

- Five different environments
  1. FSK Tone, 8 Bins BW
  2. Hopping FSK Tone, 8 Bins BW
  3. Continuous, Contiguous OFDM, 32 Bins BW
  4. Non-Contiguous OFDM, 48 Bins BW
  5. Randomized, Non-Contiguous OFDM, 16 Bins BW

System Under Test Parameters

- Desired Waveform
  - OFDM (contiguous), OFDM (non-contiguous), FSK
- Cognitive Engine Algorithm
  - The CE Algorithm chooses the best possible waveform subject to upper limit of the desired waveform
  - Order of Preference
    - OFDM (Contiguous): No. Bins Available > 8
    - OFDM (Non-contiguous): No. Bins Available > 8
    - FSK: No Bins Available <= 8

      FSK Bandwidths are 8, 4, 2, 1 and bins

When the CE is off, no spectrum sensing occurs
When the CE is on, a simple energy detection spectrum sensor is used

System Under Test Factors

Factor	Levels
Desired Waveform	FSK-1
	FSK-8
	OFDM-16
	OFDM-48
Cognitive Engine	On
	Off

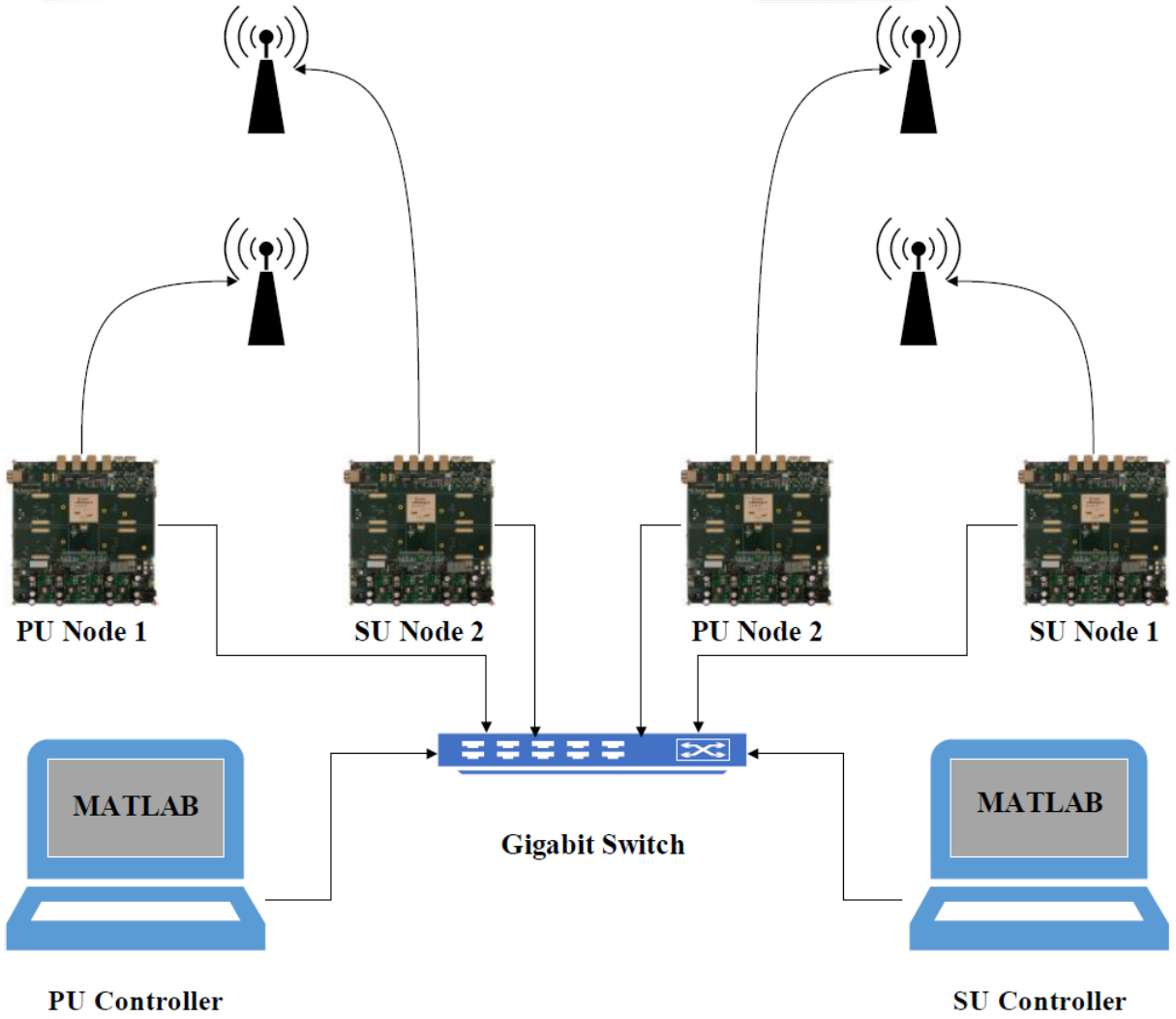
Nomenclature: FSK-1

Waveform Type

No. Bins Bandwidth

Experimental Setup

- WARP v2 boards
- HP Compaq 8510p laptops
- MATLAB R2012b
- WARPLab v7.3
- Gigabit Ethernet Switch
- PU and SU use same code



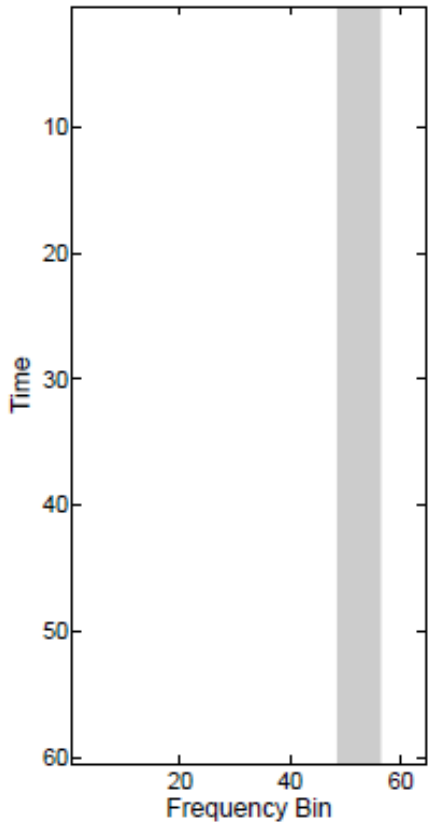
Results

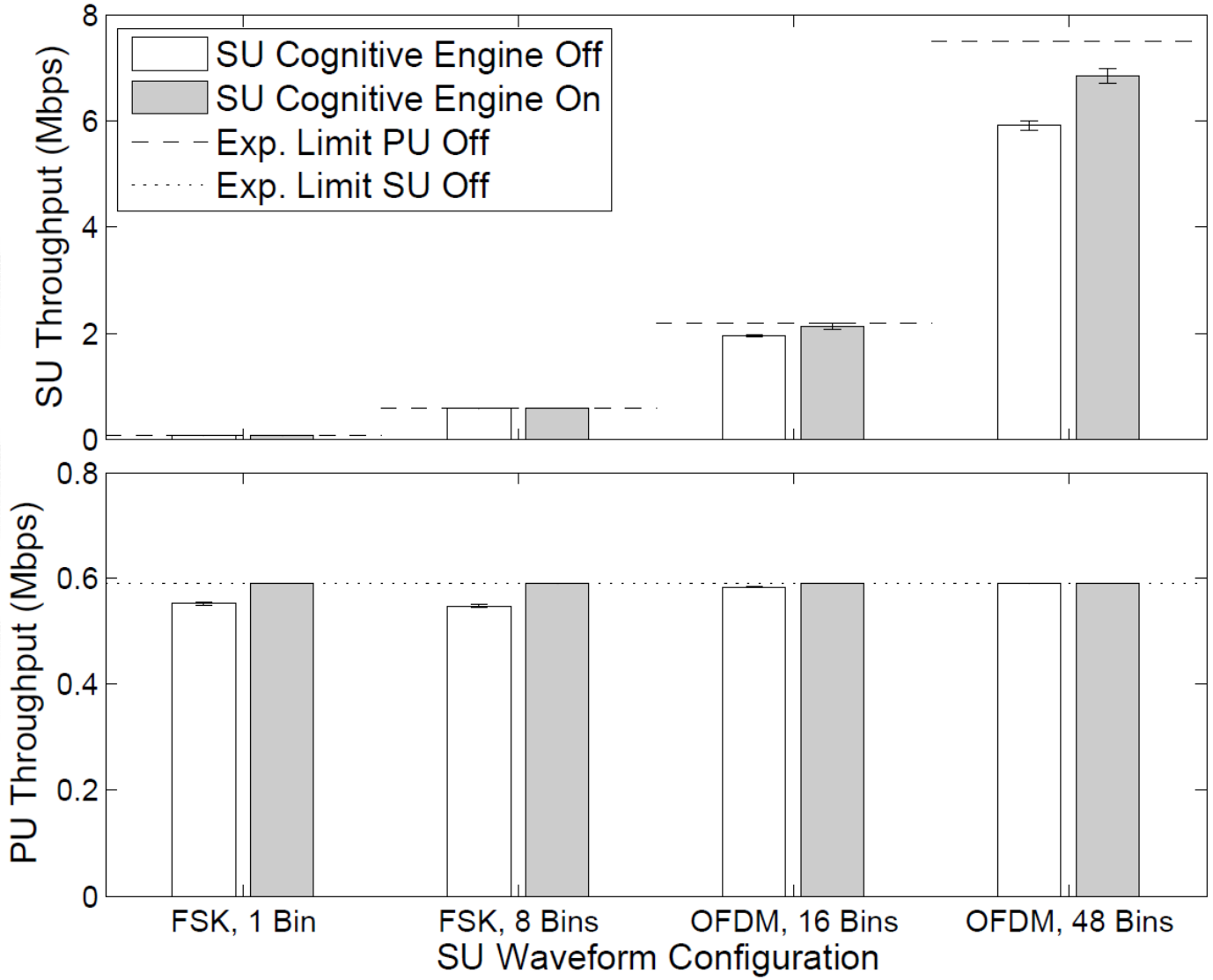
- PU and SU Throughput
- PU and SU BER
- Evaluation to determine if differences are statistically significant
- Results are presented in terms of each presented workload (i.e. each PU Environment)

Results –Throughput

Environment 1

(FSK-8 Constant Tone)

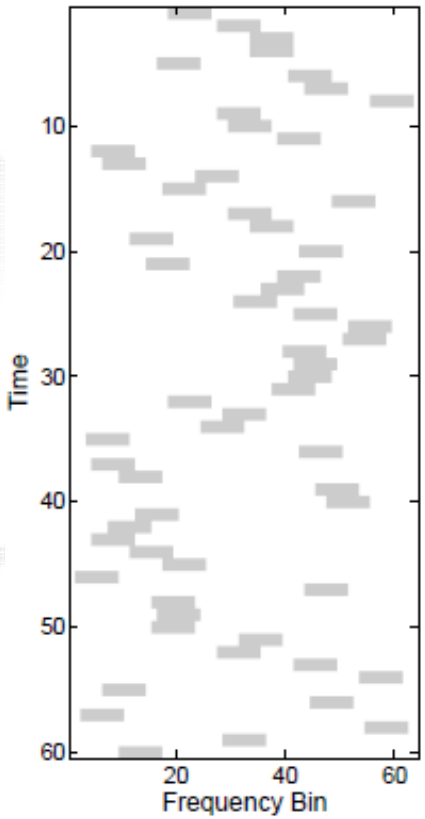


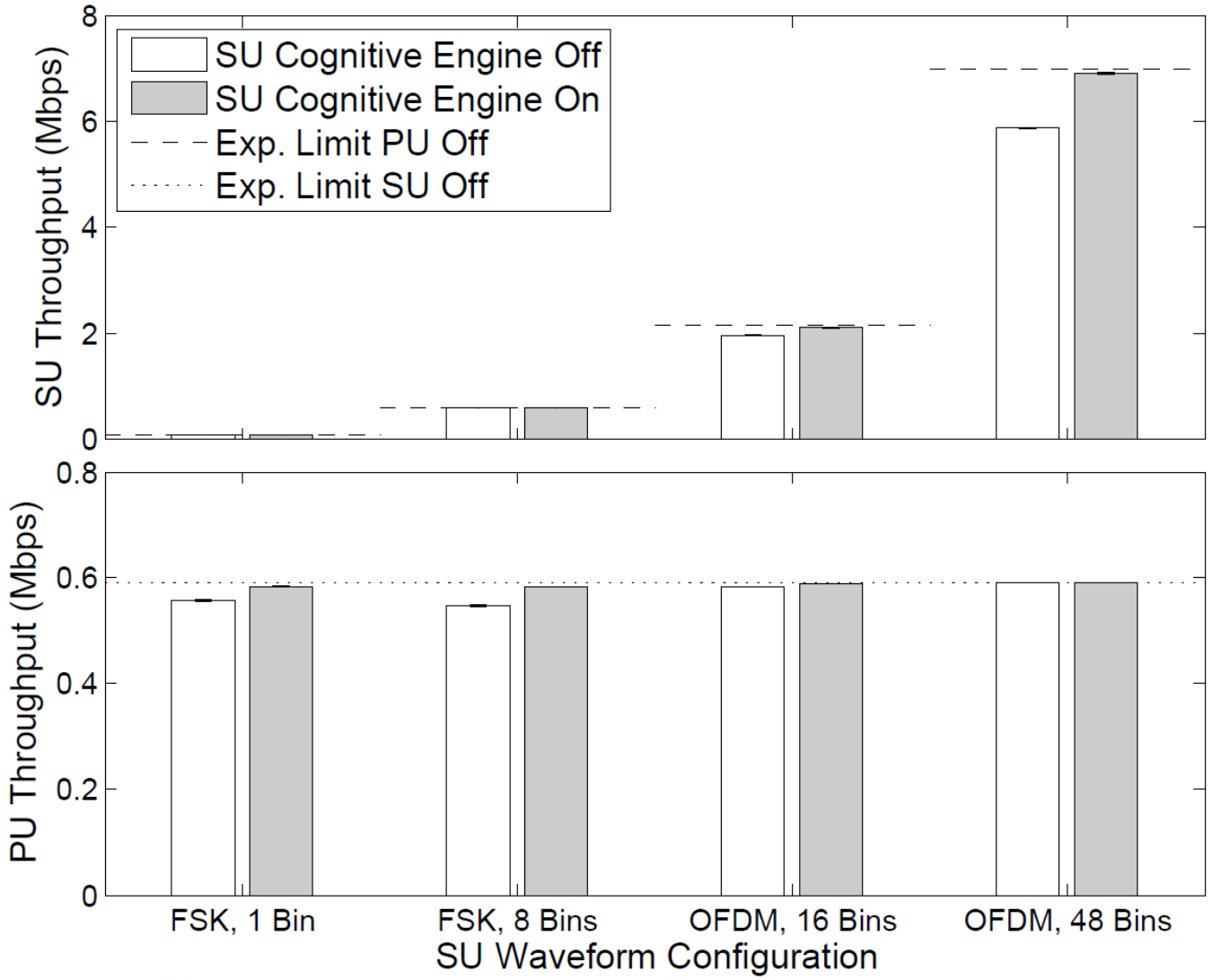


Results – Throughput

Environment 2

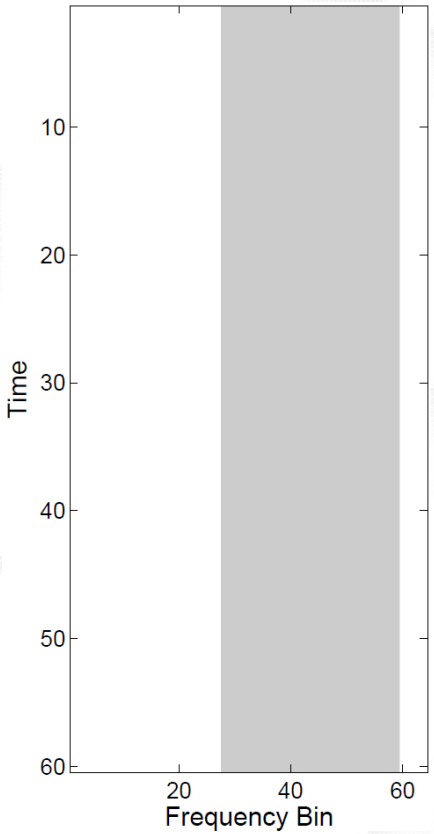
(FSK-8 Hopping Tone)

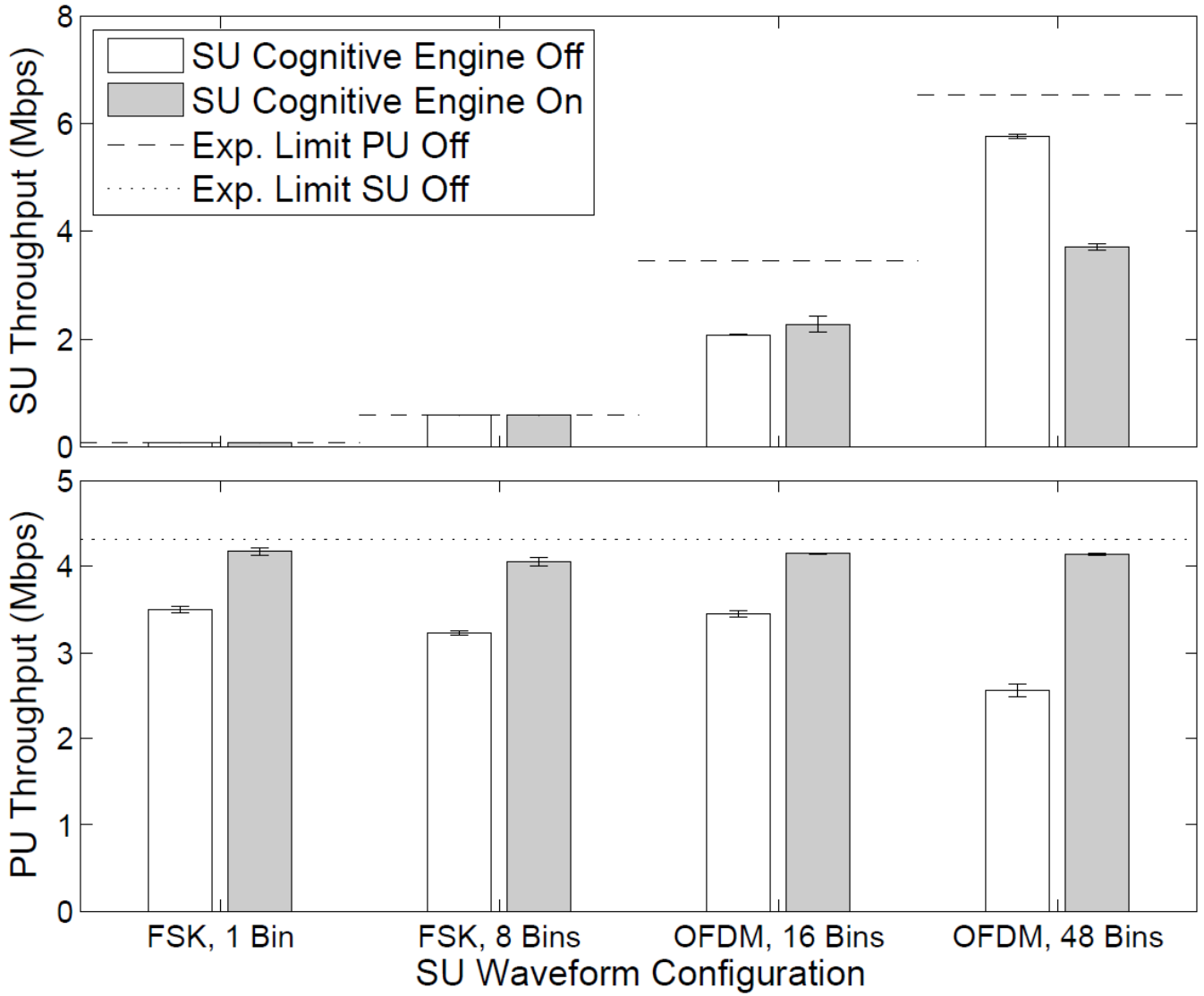




Results – Throughput

Environment 3
(Contiguous OFDM-32)

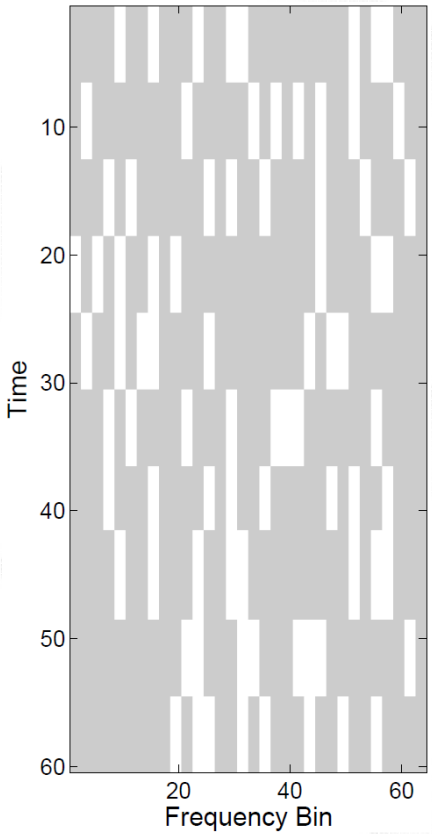


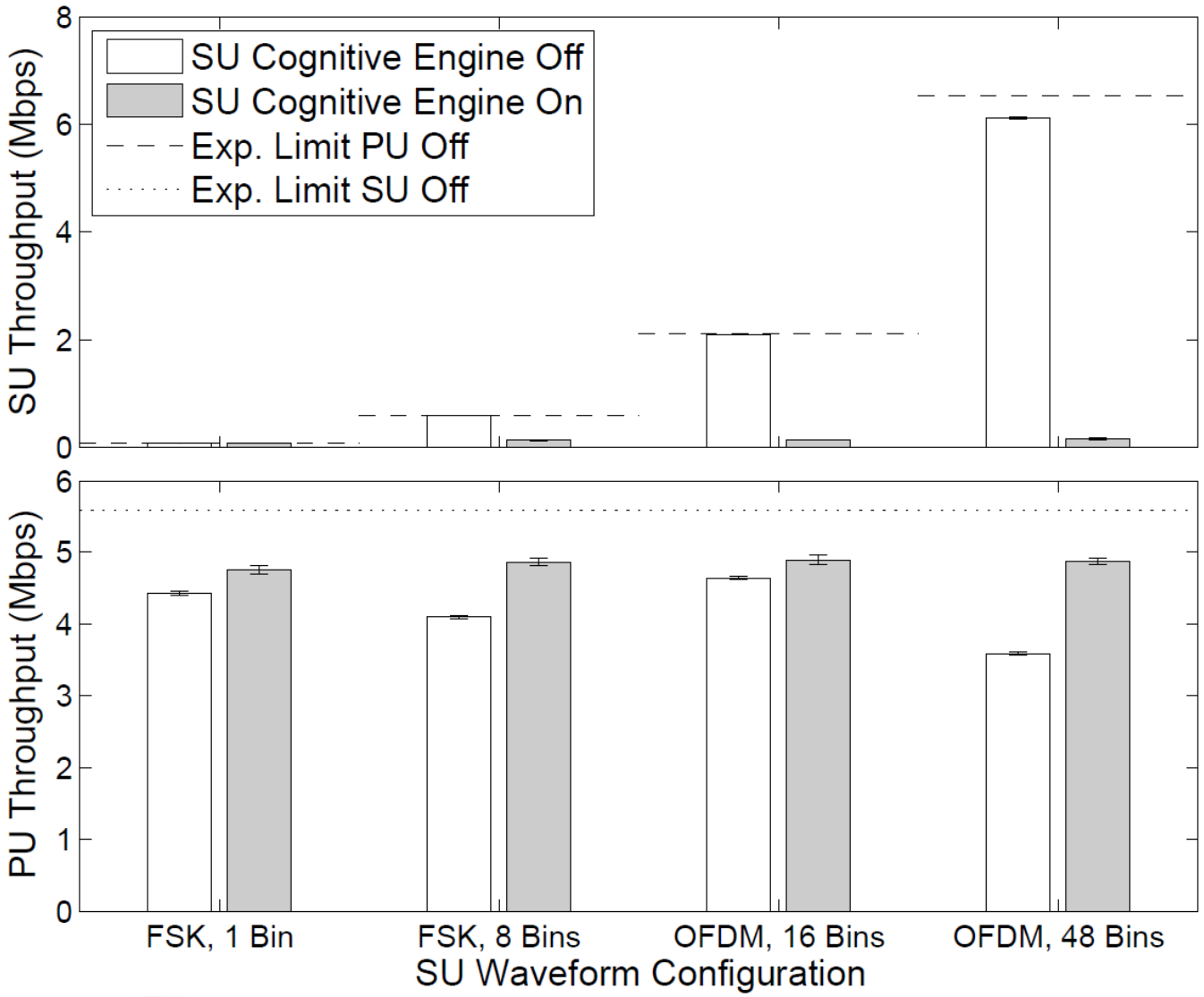


Results – Throughput

Environment 4

(Non-contiguous OFDM-48)

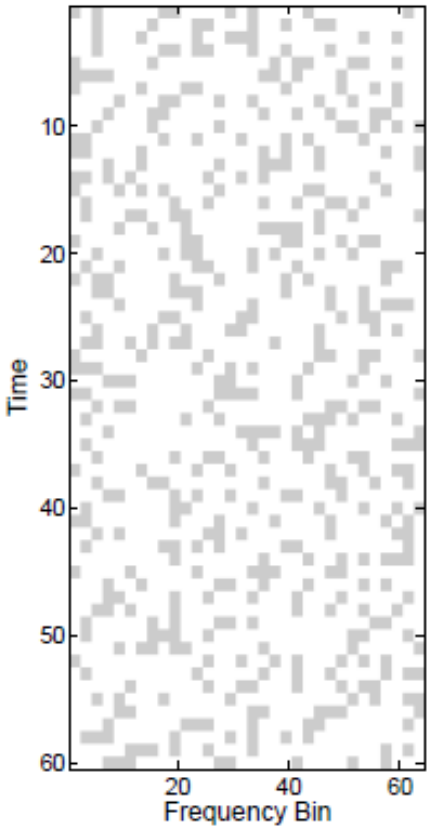


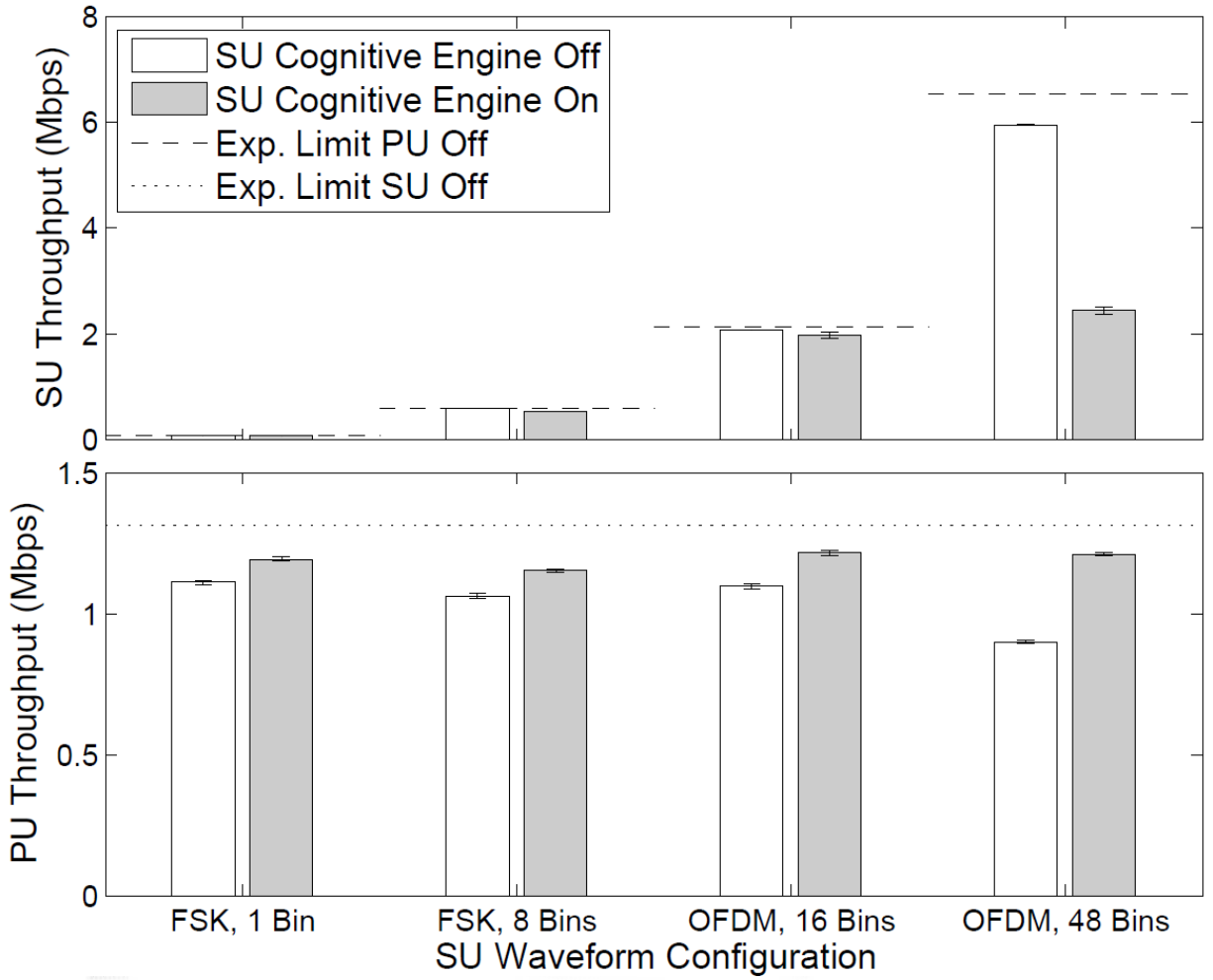


Results – Throughput

Environment 5

(Randomized OFDM-16)





Results – Throughput

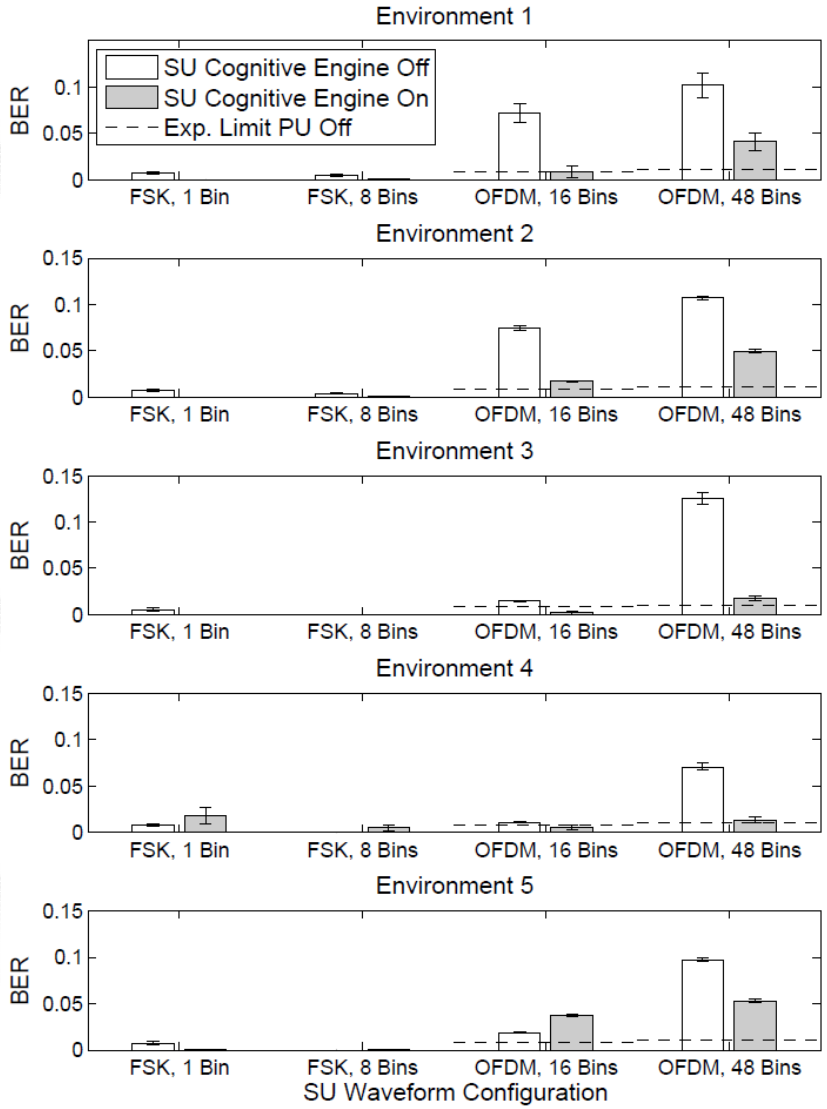
- Evaluated distributions using *t*-test (α=0.05)
  - Compared each SU configuration with CE on vs CE off
  - Compared each SU configuration with CE on against other CE on configurations (relative cognition levels)

Results - Throughput

- ***CE On vs CE Off Case***
  - SU throughput increases in 55% of cases
    - Exception: cases where useable spectrum is small relative to desired waveform bandwidth
  - PU throughput increases in every case except 1
    - PU Environment 2, OFDM-48 is statistically the same as OFDM-16
- ***Relative Cognition Case***
  - SU throughput increases in every case except 1
    - PU Environment 4, OFDM-16 is statistically the same as FSK-8
  - PU throughput improves or stays constant
    - 2 anomalies, likely due to undesired interference from FSK-8

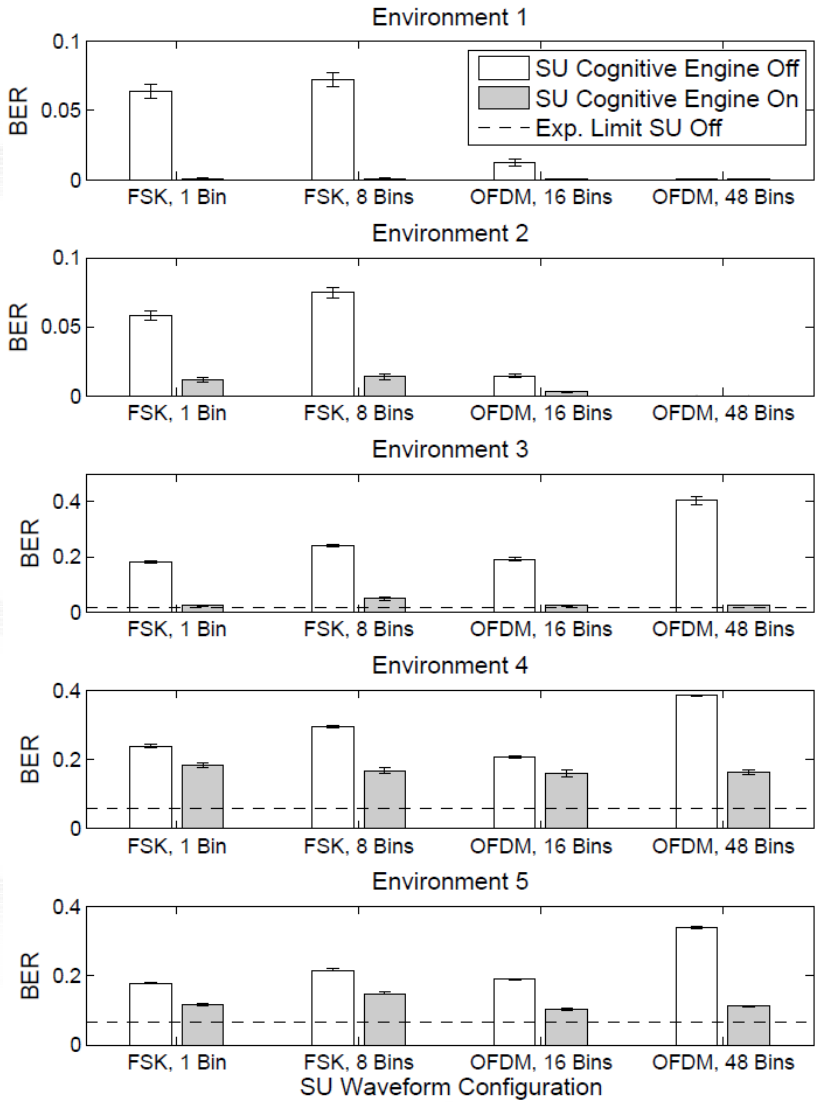
Results - BER

- SU BER
  - Improves in every case when CE is on except when non-contiguous OFDM is utilized by SU
  - Non-contiguous OFDM has higher BER



Results - BER

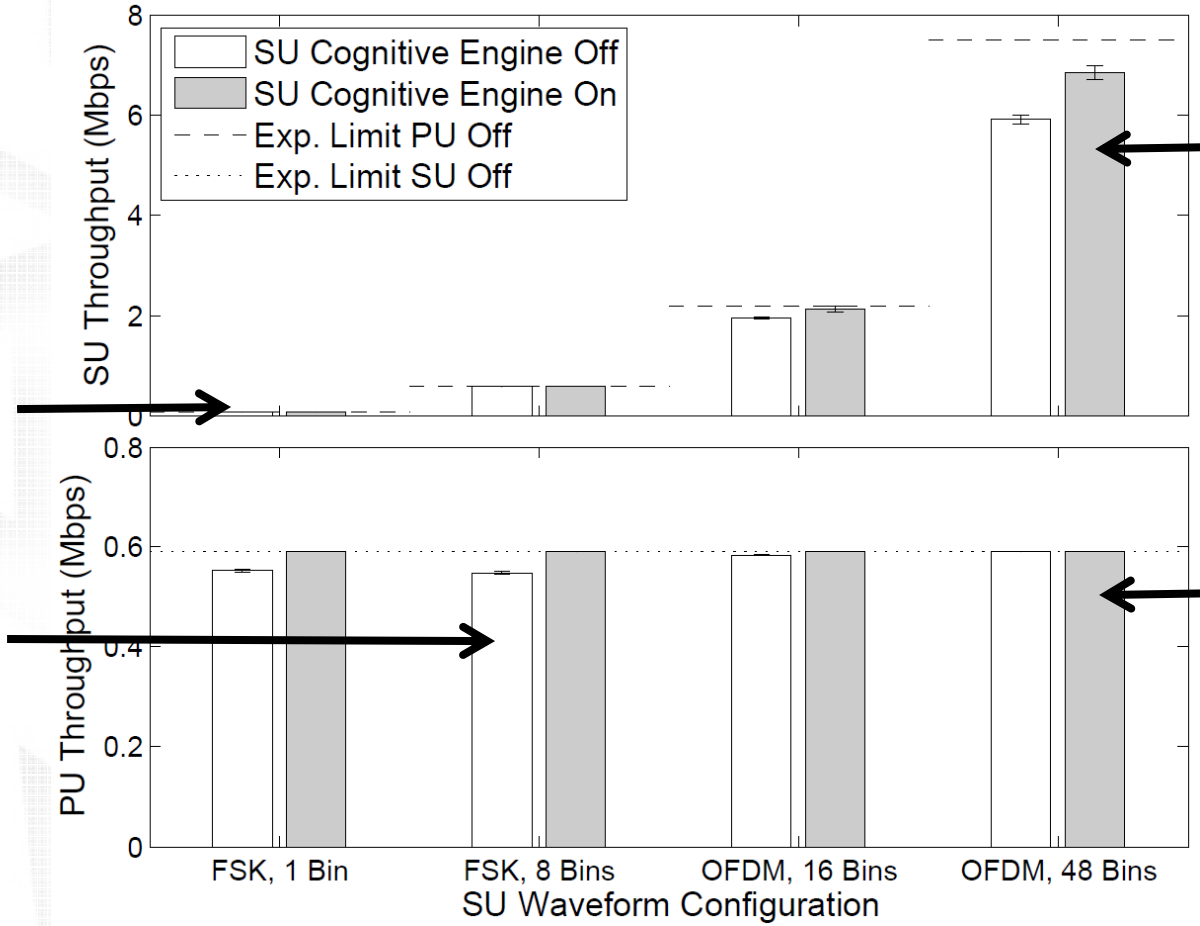
- PU BER
  - Improves in every case when CE is on



Results - Scoring

Receives 0
For SU Throughput

Receives 0
For PU Throughput



Receives 10
For SU Throughput

Receives 10
For PU Throughput

Results - Scoring

SU Weight = 50%, PU Weight = 50%

Environment	FSK 1 CE Off	FSK 8 CE Off	OFDM 16 CE Off	OFDM 48 CE Off	FSK 1 CE On	FSK 8 CE On	OFDM 16 CE On	OFDM 48 CE On
1	0.2	0	5.4	9.3	4.8	5.1	6.4	10
2	0.8	0	5.3	9.2	4	4.3	6.2	10
3	0.7	0	3.5	4.4	4.4	4.6	7.8	10
4	2.6	0	10	7.9	6.3	7.7	8.1	7.9
5	0.8	0	4.6	5.1	4.2	3.6	9.2	10

Expected Most "Cognitive" Waveform

Results - Scoring

SU Weight = 25%, PU Weight = 75%

Environment	FSK 1 CE Off	FSK 8 CE Off	OFDM 16 CE Off	OFDM 48 CE Off	FSK 1 CE On	FSK 8 CE On	OFDM 16 CE On	OFDM 48 CE On
1	0.7	0	6.9	9.6	7.4	7.6	8.2	10
2	1.6	0	6.7	9.6	6.3	6.3	7.9	10
3	2.8	1.3	3.9	0	7.7	7.2	9	10
4	4.7	1.3	8.7	0	8.4	9.6	10	9.8
5	4.3	2.7	5.1	0	7.6	6.3	9.9	10

Expected Most "Cognitive" Waveform

Conclusions

- Preliminary research suggest path forward is feasible
- FFH Modem is suitable for use in developing a prototype CR
- Preliminary data does not disprove hypothesis
  - Suggests greater cognition/adaptability leads to increased SU throughput and PU throughput
  - Suggests greater cognition/adaptability leads to decreased BER
- More data and experimental configurations required to fully validate hypothesis

Conclusions

- Continued development underway
  - Implement FFH Modem in hardware
  - Test CR prototype in the DYSE using the developed test framework

Questions?

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References

[1] Echo Ridge LLC. "DYSE: DYnamic Spectrum Environment Emulator". http://www.echoridgenet.com/echo_dyse.html. Accessed 3 March 2014.