Complexity Analysis of Systematic Spectrum Sensing for Cognitive Radio

Speaker:

Date: 30th Nov. 2010

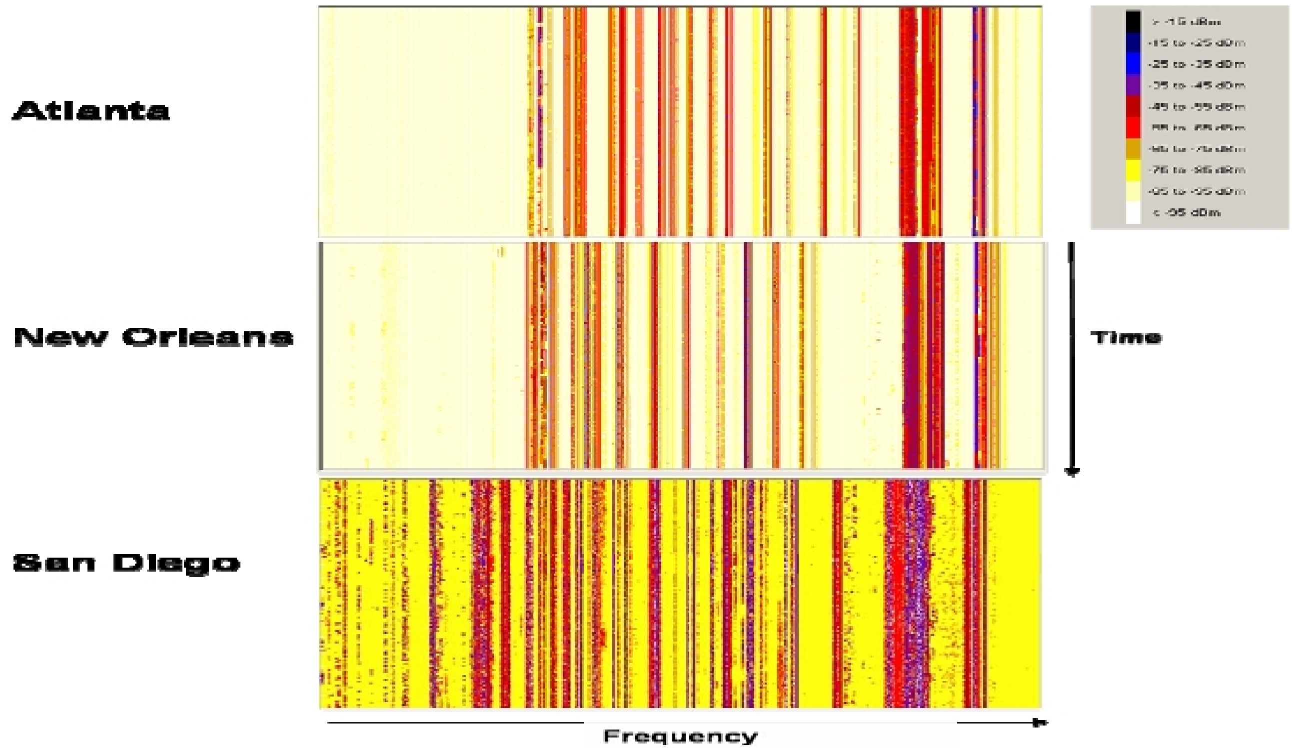
Outline

- Background and Motivation
- Spectrum Sensing Methodology
- Implementation
- Simulation Results
- Conclusion

Outline

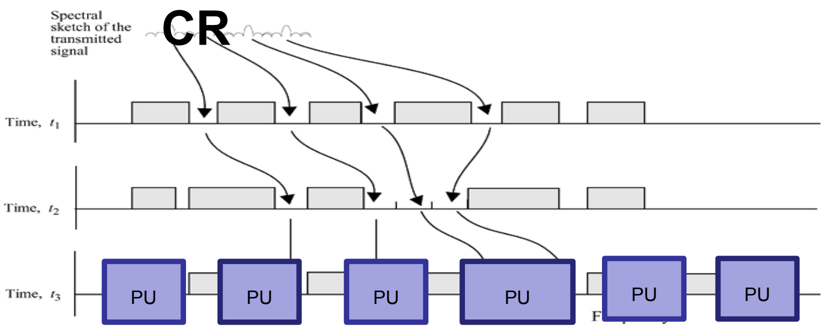
- Background and Motivation
- Spectrum Sensing Methodology
- Implementation
- Simulation Results
- Conclusion

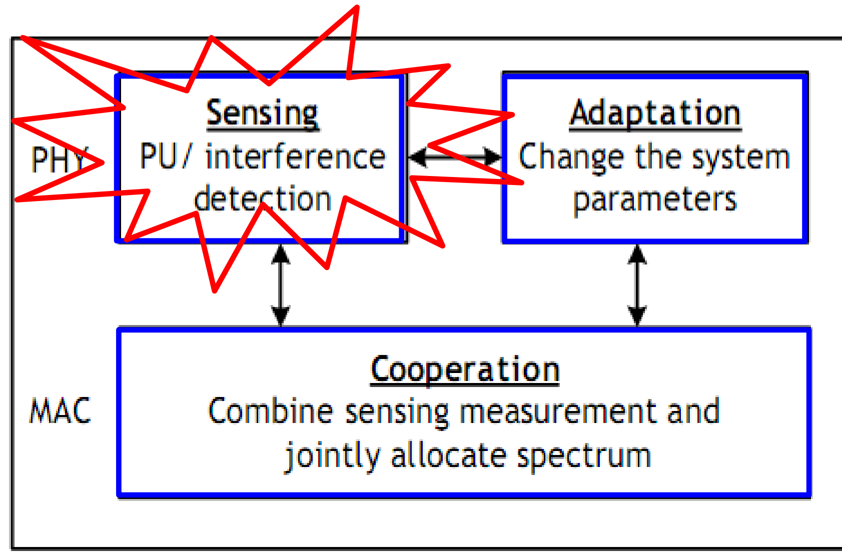
Sparse Spectrum Utilization



Cognitive Radio (CR)

Cognition!!!!!

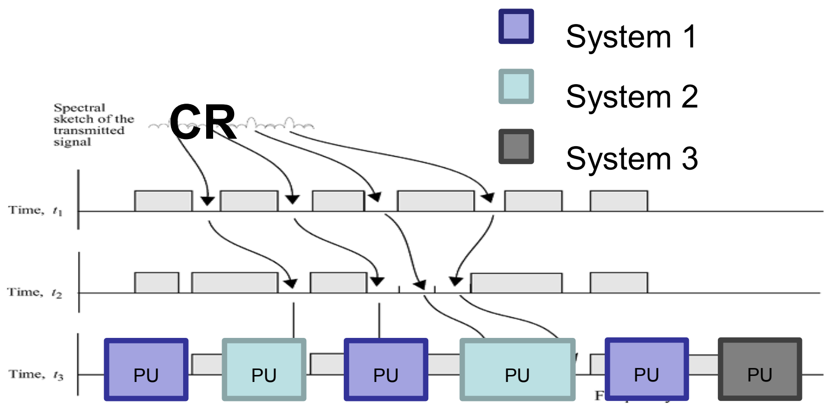




- Received signal strength in dicator (RSSI):

$$M(r) = \frac{1}{L}\sum_{t=0}^{L-1}\left(\sum_{n=0}^{N-1}\left|r(n)\right|^2\right) \underset{H_0}{\overset{H_1}{\gtrless}} \tau_{RSSI}$$

Motivation

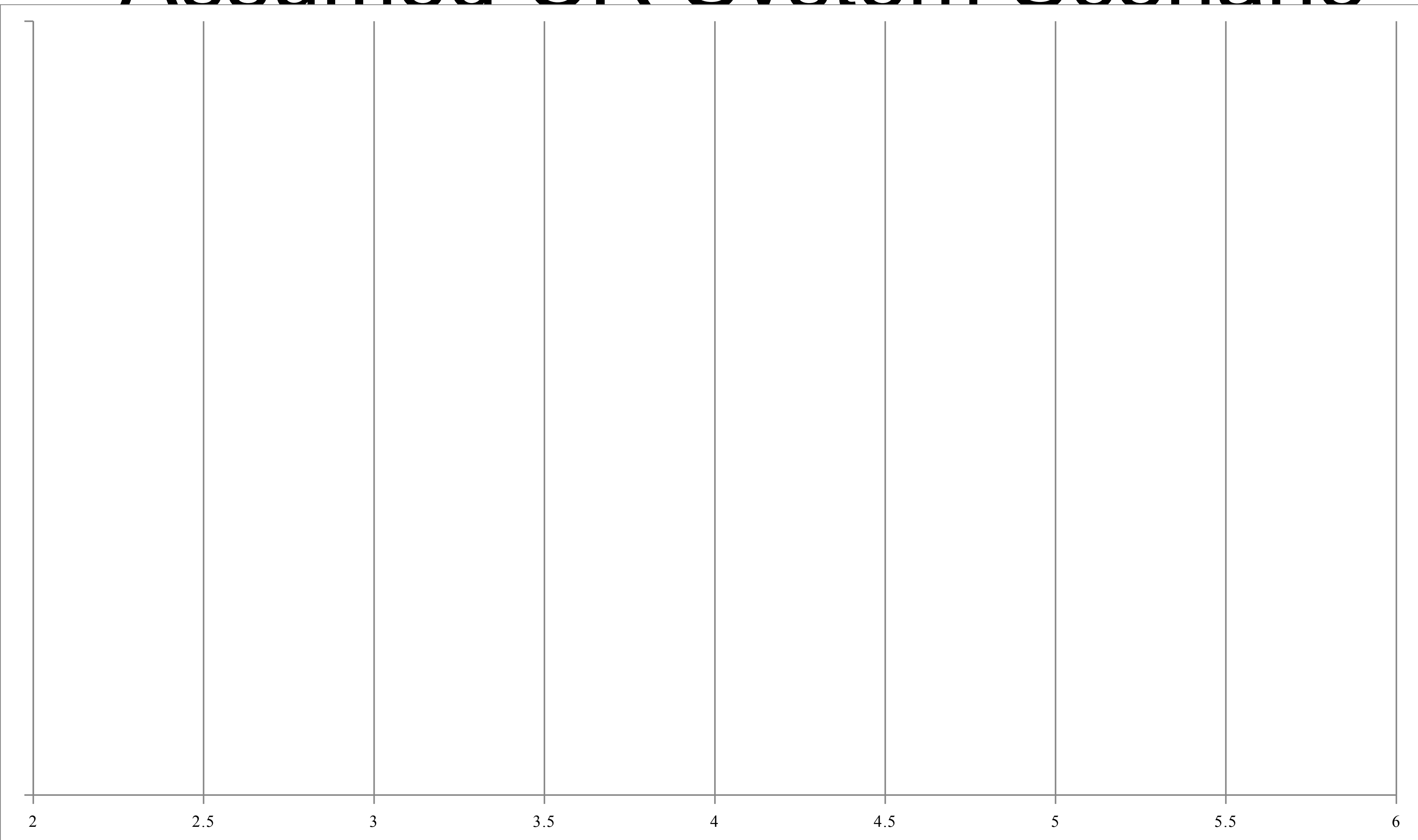


Previous work:
- Ad-hoc standard detection method.
- Need algorithm for complex scenario.

Practical/Implement consideration:
- Hardware/Software implementation?
- Always need complex detection algorithm?

- Issues of multi-standard spectrum sensing:
  - PUs detection & identification. (combine previous detection methods and reduce the system complexity)
  - How many systems we can cover in our scenario?
  - How often to sense? (software implementation performance)

Assumed CR System Scenario



System Parameters

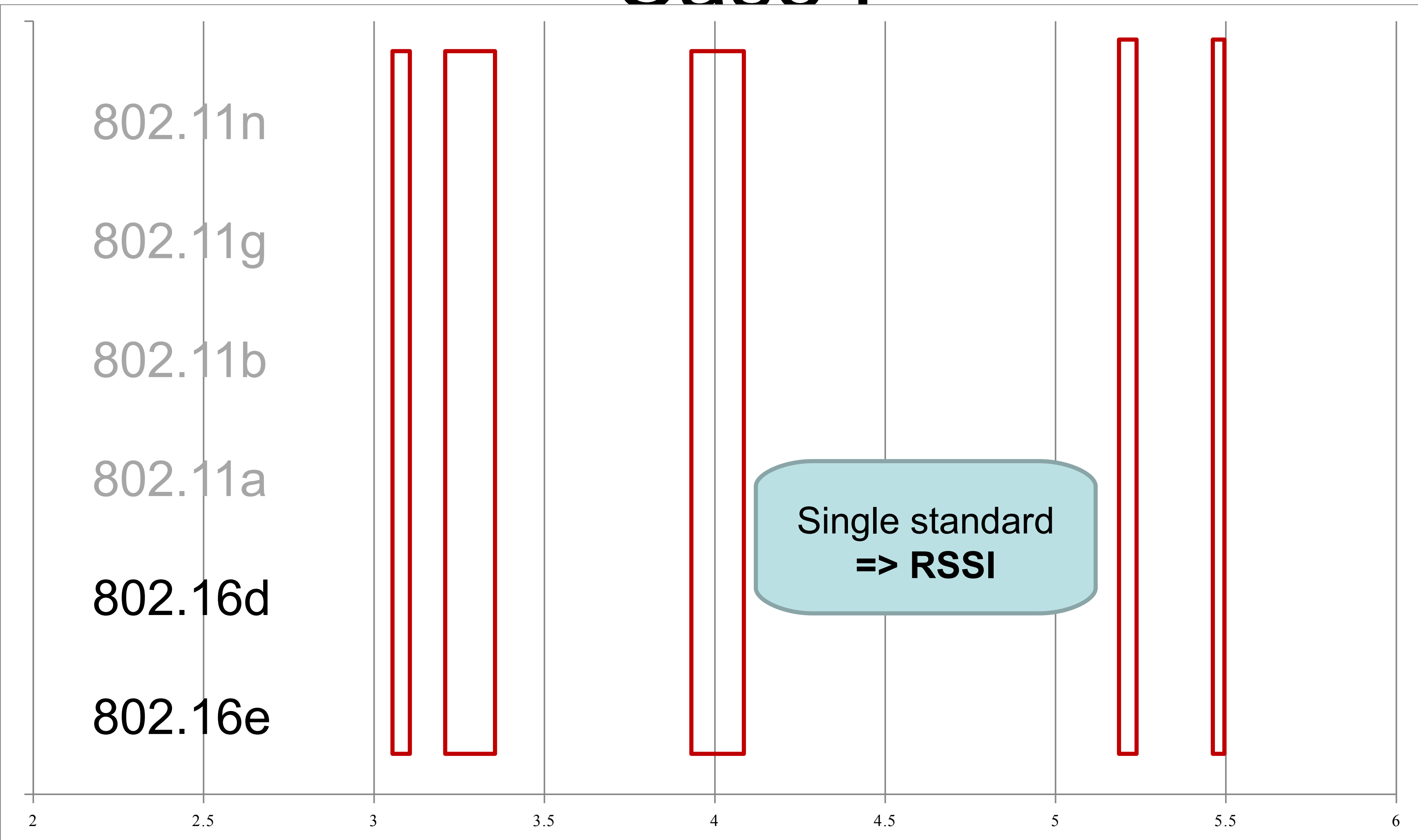
	FFT/data (samples)	CP (ratio/samples)	GI Duration	Symbol Duration
802.11a/g	64/48	1/4 (16)	0.8 us	4 us
802.11n	64/52	1/4 (16)	0.8 us	4 us
		1/8 (8)	0.4 us	3.6 us
	128/108	1/4 (32)	0.8 us	4 us
		1/8 (16)	0.4 us	3.6 us
802.16d	256/192	1/8 (32)	8 us	72 us
802.16e	512/360	1/8 (64)	11.4 us	102.9 us

GI: guard interval
CP: cyclic prefix

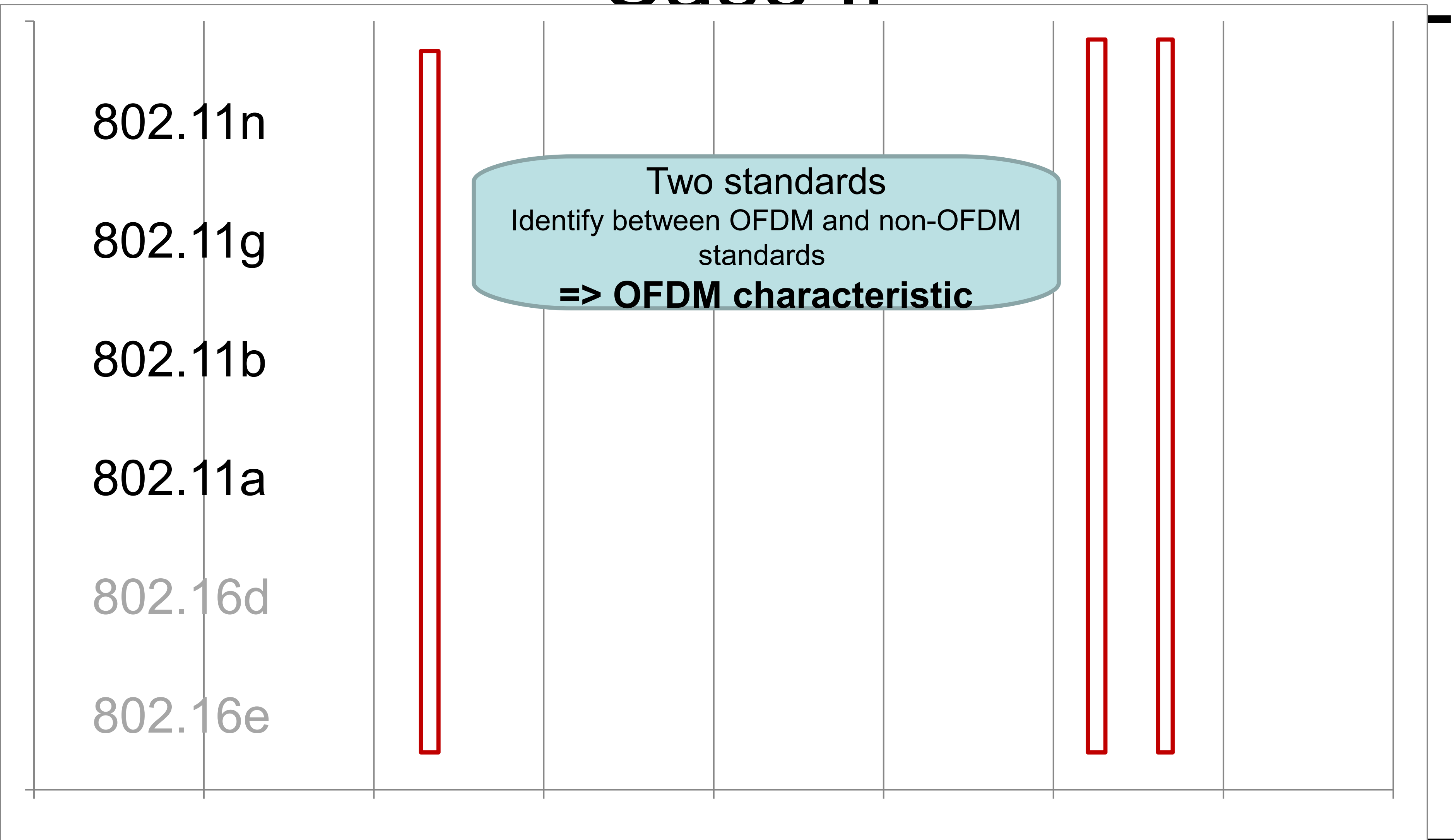
Outline

- Background and Motivation
- Spectrum Sensing Methodology
- Implementation
- Simulation Results
- Conclusion

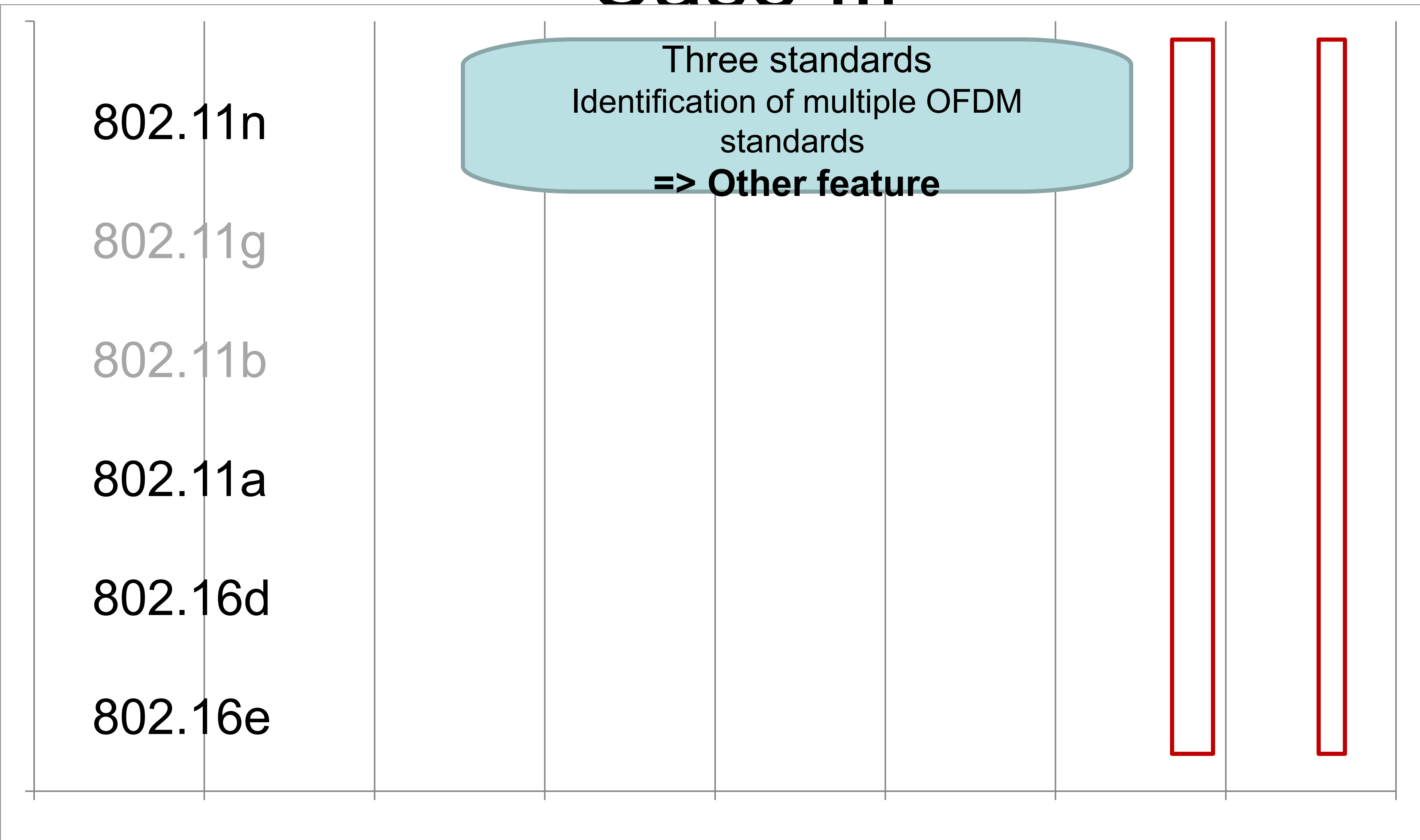
Case I


802.11n
802.11g
802.11b
802.11a
802.16d
802.16e
Single standard
=> RSSI
2
2.5
3
3.5
4
4.5
5
5.5
6

Case II

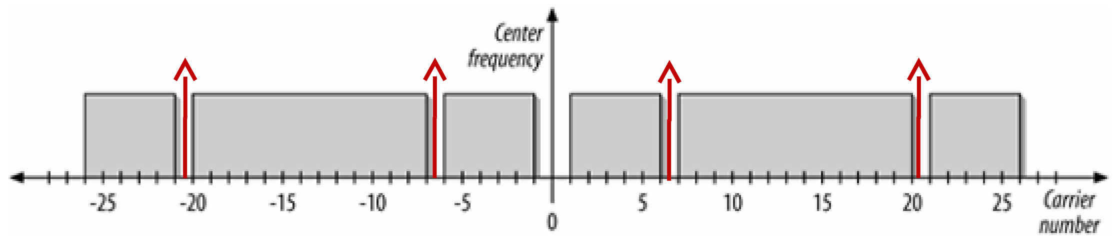

802.11n
802.11g
802.11b
802.11a
802.16d
802.16e
Two standards
Identify between OFDM and non-OFDM standards
=> OFDM characteristic

Case III

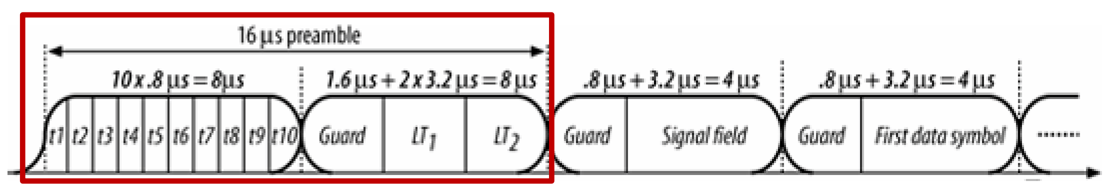

Three standards
Identification of multiple OFDM standards
=> Other feature
802.11n
802.11g
802.11b
802.11a
802.16d
802.16e

Common OFDM Signal Characteristic

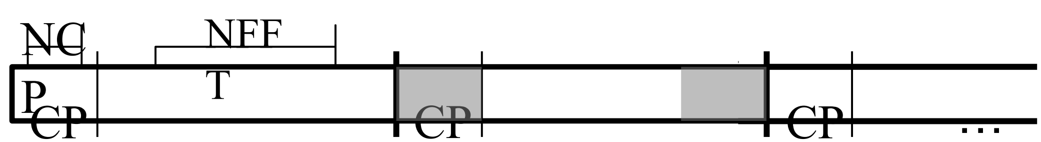
- Frequency domain
  - Pilot



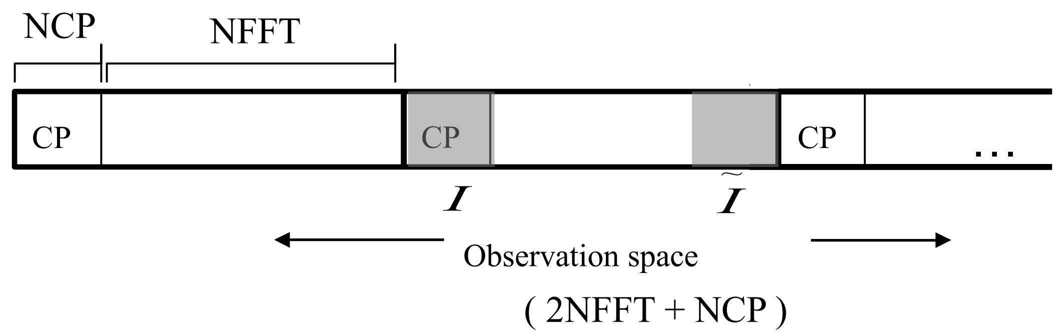
- Time domain
  - Preamble



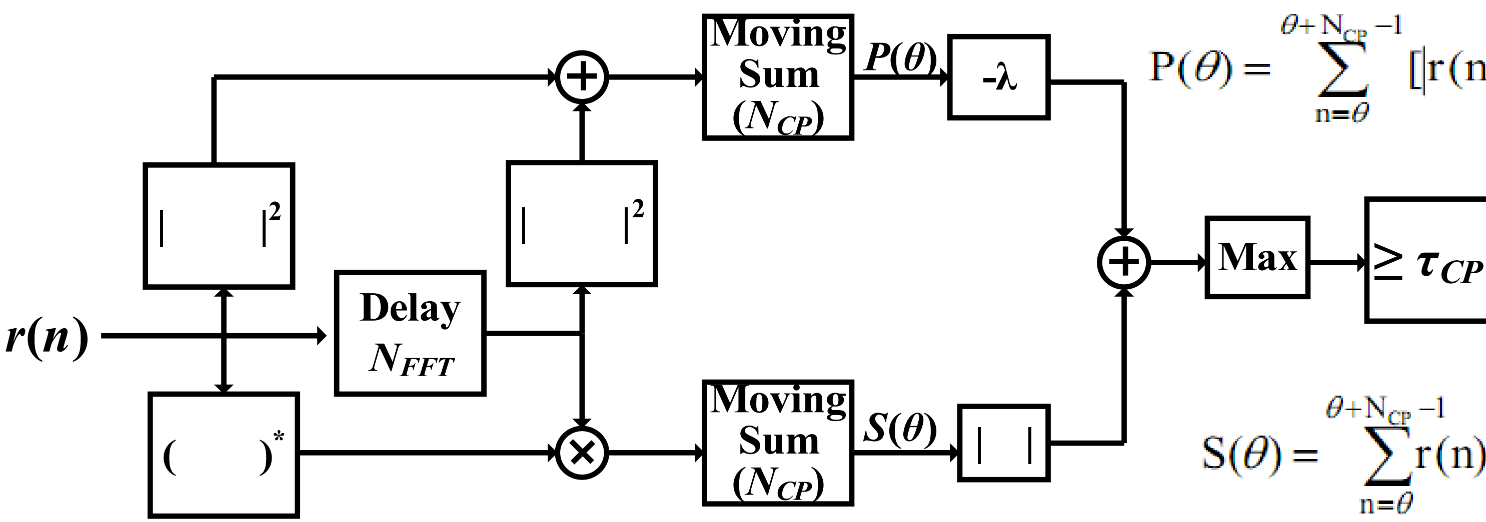
  - Cyclic prefix



Cyclic Prefix Detector



	FFT/data (samples)	CP (samples)	GI duration	Symbol duration
802.11a/g	64/48	1/4 (16)	0.8us	4us
802.11n	64/52	1/4 (16)	0.8us	4us
		1/8 (8)	0.4us	3.6us
	128/108	1/4 (32)	0.8us	4us
		1/8 (16)	0.4us	3.6us
Fixed WiMAX	256/192	1/8 (32)	8us	72us
Mobile WiMAX	512/360	1/8 (64)	11.4us	102.9us



$$P(\theta) = \sum_{n=\theta}^{\theta+N_{CP}-1} [|r(n)|^2 + |r(n+N_{FFT})|^2]$$

$$S(\theta) = \sum_{n=\theta}^{\theta+N_{CP}-1} r(n) r^*(n+N_{FFT})$$

Cyclostationary Property

- Cyclostationary

$$R_\alpha(t,\tau) = E\{x(t+\tau/2)x(t-\tau/2)\}$$

- Cyclic autocorrelation function (CAF)

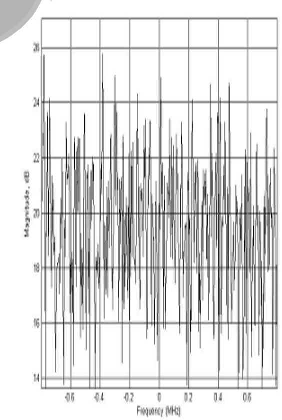
$$R_x^\alpha(\tau) = \lim_{\Delta t \to \infty} \frac{1}{\Delta t} \int_{-\Delta t/2}^{\Delta t/2} x(t+\tau/2)x(t-\tau/2)e^{-i2\alpha\pi t}dt$$

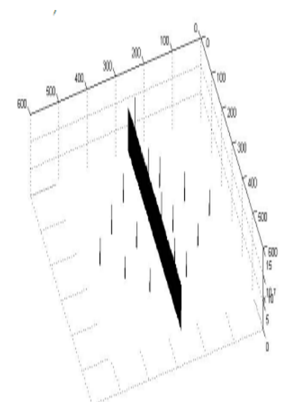
DFT

- Spectral correlation function (SCF)

$$S_x^\alpha(f) = \int_{-\infty}^{\infty} R_x^\alpha(\tau)e^{-j2\pi f t}d\tau$$

$$= \lim_{\Delta f \to \infty} \lim_{\Delta t \to \infty} \frac{1}{\Delta t} \int_{-\Delta t/2}^{\Delta t/2} \Delta f X_{1/\Delta f}(t, f+\alpha/2) X^*_{1/\Delta f}(t, f-\alpha/2)dt$$





[Annual Conference on Signals, Systems and Computers 2004]

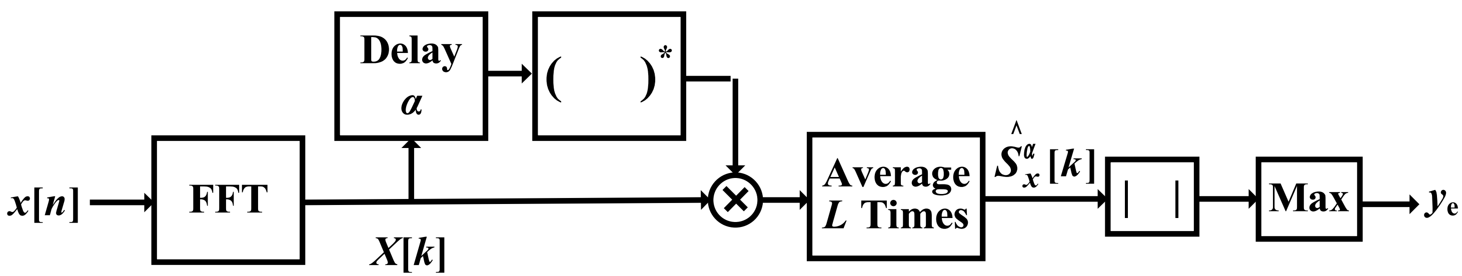
SCF Detector

[29]

- Design adopted uses a time-smoothed cyclic cross perio dogram

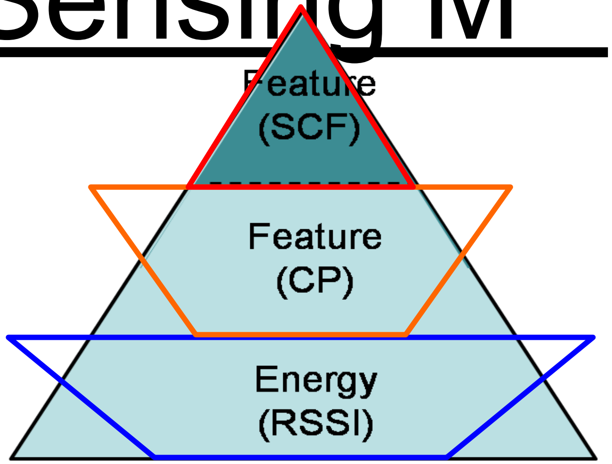
$$\hat{S}_x^{\alpha}[k] = \frac{1}{L}\sum_{t=0}^{L-1} X[k]X^*[k-\alpha]W[k] \qquad X[k] = \sum_{n=0}^{N-1} x[n]e^{-i2\pi nk/N}$$

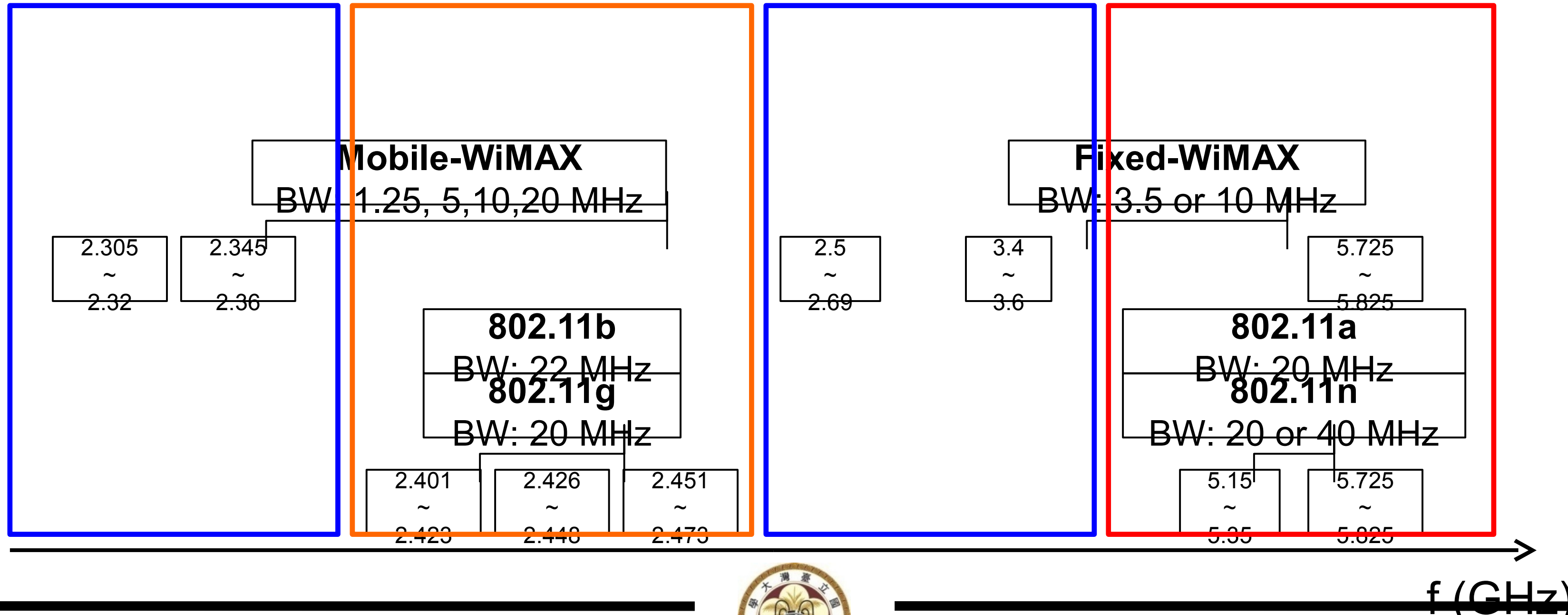
- Optimum feature detection is performed through correlati on of the cyclic periodogram with the spectral correlation function



Summary: Spectrum Sensing Method

- [Case I] single standard: RSSI
- [Case II] two standards: RSSI+CP
- [Case III] three standards: RSSI+SCF





Outline

- Background and Motivation
- Spectrum Sensing Methodology
- Implementation
- Simulation Results
- Conclusion

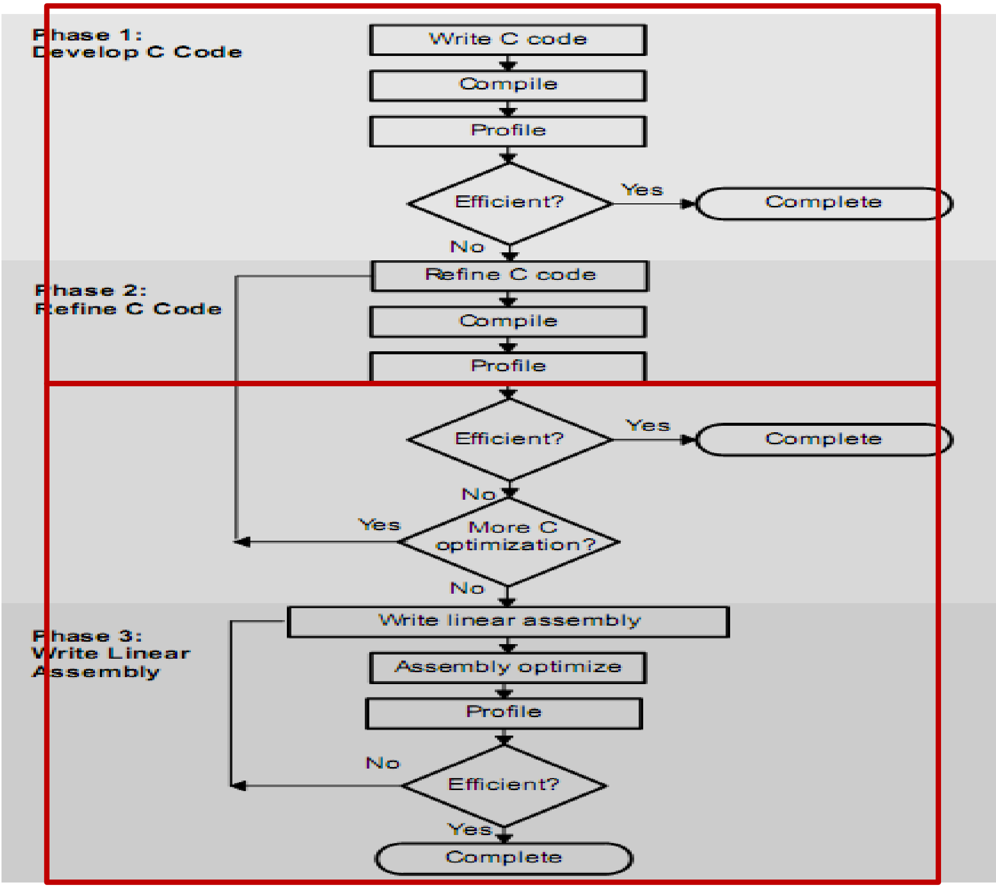
Software Implementation

- Advantage of software radio
  - Adaptable
  - Reduce the size and cost
- Disadvantage of software radio
  - Slow
- Selected software radio platform
  - TI C6416 DSP
- Optimization techniques
  - TI compiler optimization level-2 (software pipelining)
  - TI intrinsic

Design Flow

- Experimental platform
  - TI C6416 DSP
  - 600MHz clock frequency
  - Very-long-instruction-word (VLIW) architecture
  - 8 function units (2 multipliers and 6 ALUs)
  - **TI c6416 is more powerful than required**
- Survey for future accelerators
  - Operating freq. for co-processor with similar architecture
  - Processing power requirement

Code Implementation Flow



Naïve Coding

- Identify system requirement
- Fixed–point coding
- TI's compiler opt level-2

Hand Optimization

- Optimize common blocks
- Adopt TI's intrinsic

Outline

- Background and Motivation
- Spectrum Sensing Methodology
- Implementation
- Simulation Results
- Conclusion

Naïve Fixed Point C

<table>
<tr><th></th><th>RSSI(cycle)</th><th>CP(cycle)</th><th>SCF(cycle)</th></tr>
<tr><td>802.11a/g</td><td>2,849</td><td>477,856</td><td>2,253,203</td></tr>
<tr><td rowspan="4">802.11n</td><td rowspan="2">2,849</td><td>477,856</td><td rowspan="2">2,253,203</td></tr>
<tr><td>254,604</td></tr>
<tr><td rowspan="2">5,665</td><td>1,823,528</td><td rowspan="2">4,966,612</td></tr>
<tr><td>946,980</td></tr>
<tr><td>802.16d</td><td>11,297</td><td>3,646,584</td><td>10,376,996</td></tr>
<tr><td>802.16e</td><td>22,561</td><td>14,305,068</td><td>22,708,023</td></tr>
</table>

Number of Symbols to Meet Accuracy Requirements.

Symbols Required	RSSI	CP	SCF
	1	4	60
Effective Time	**RSSI(μs)**	**CP(μs)**	**SCF(μs)**
802.11a/g	4	16	240
802.11n	4	16	240
	3.6	14.4	216
	4	16	240
802.16d	72	288	4320
802.16e	102.9	411.6	6174

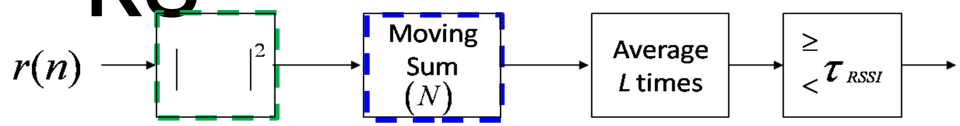
Naïve Fixed Point C

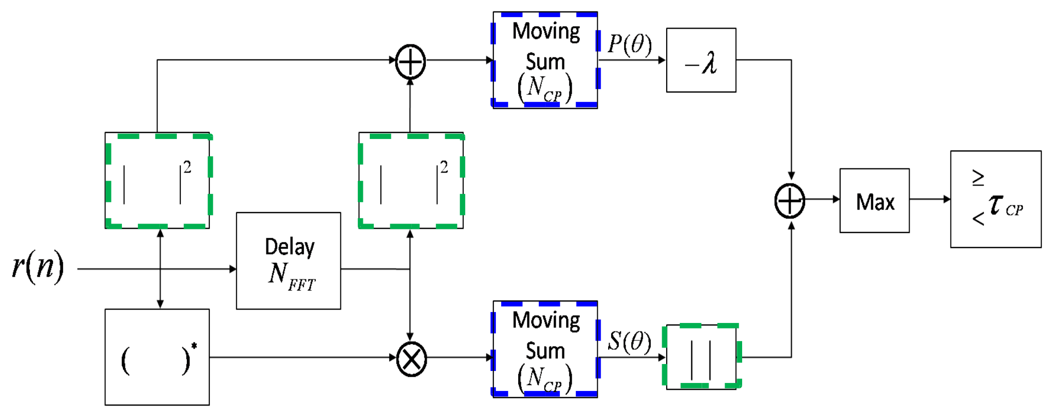
	RSSI (μs)	CP (μs)	SCF (μs)
802.11a/g	4.76	798.02	3,762.85
802.11n	4.76	798.02	3,762.85
		425.2	
	9.46	3,045.3	8,294.24
		1,581.46	
802.16d	18.866	6,089.8	17,329.6
802.16e	37.68	23,889.5	37,922.4

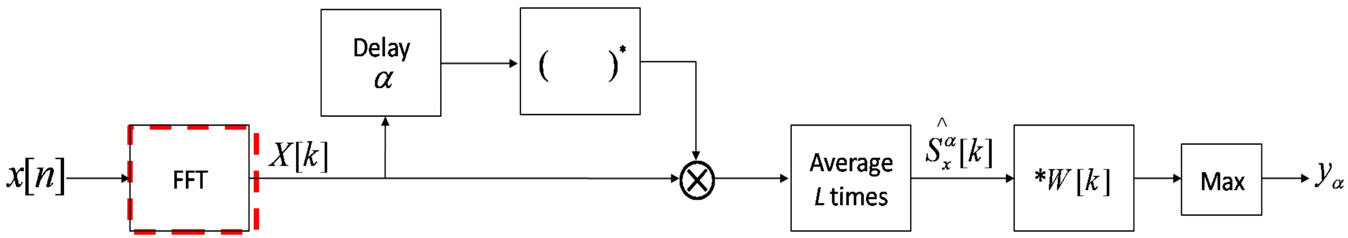
X:Does not meet the time constraint, optimization required !!

Optimization of Common Blocks

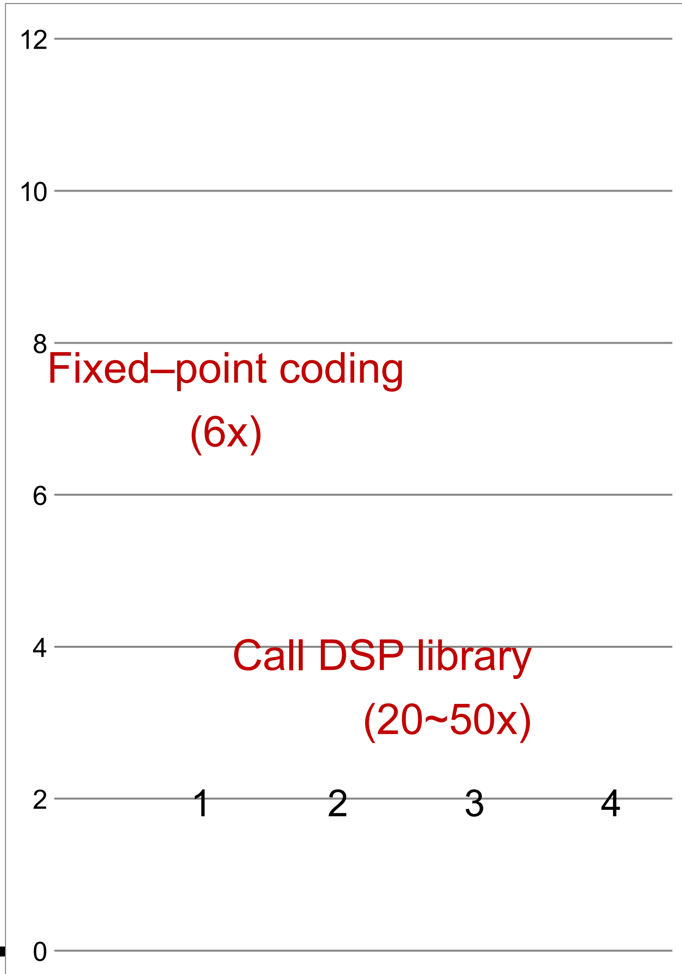
- Common blocks
  - sum of square
  - moving sum
  - FFT
- Optimization :
  - Call TI .asm library





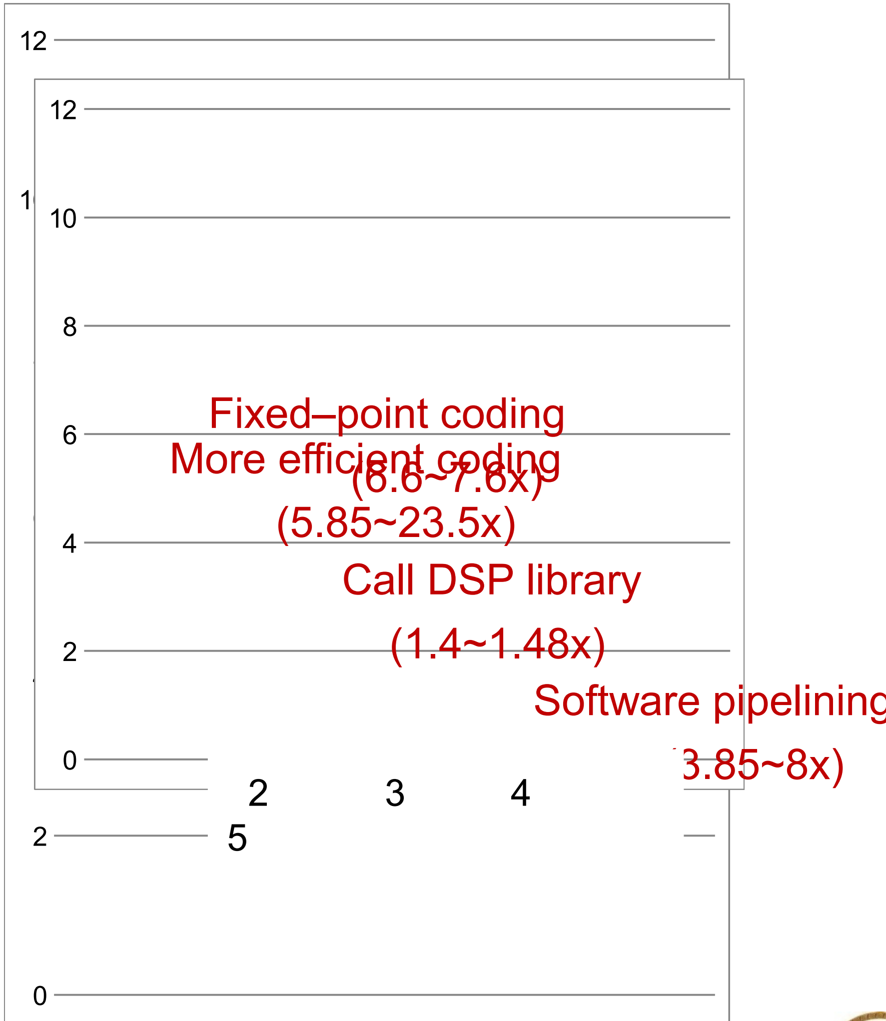


Overall Performance (RSSI)



	1. Ori. C (float)	2. Intrinsic (short)	3. DSPLib (short)	4. DSPLib (short) -o2
802.11a/g	13,184	2,209	103	103
802.11n	13,184	2,209	103	103
	26,773	4,353	135	135
Fixed WiMAX	54,095	8,641	199	199
Mobile WiMAX	107,163	17,217	327	327

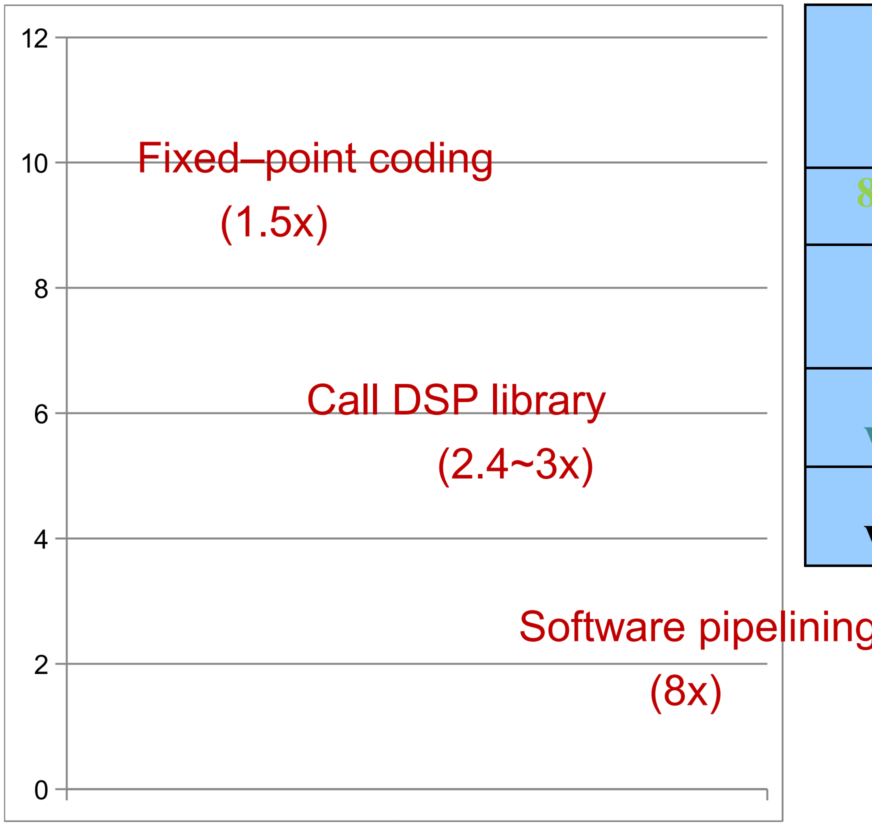
Overall Performance (CP)



	1. Ori. C (float)	2. Opt. C (float)
802.11a/g	3186926	544680
802.11n	3186926 1649214	544680 517524
	12637578 6432710	1105608 1054904
Fixed WiMAX	25032378	2103808
Mobile WiMAX	98754582	4205160

	2. Opt. C (float)	3. Intrinsic (short)	4. DSPLib (short)	5. Intrinsic (short) -o2
802.11a/g	544680	82504	59268	21396
802.11n	544680 517524	82504 79940	59268 58372	21396 20684
	1105608 1054904	151428 147904	104252 104124	28312 28020
Fixed WiMAX	2103808	281604	192956	41368
Mobile WiMAX	4205160	550604	371204	68584

Overall Performance (SCF)



	1. Ori. (float)	2. Fixed-point (int)	3. DSPLib (short)	4. DSPLib (short) -o2
802.11a/g	3,322,438	2,274,812	935,178	64,276
802.11n	3,322,438	2,274,812	935,178	64,276
	7,085,767	5,007,357	1854,105	128,056
Fixed WiMAX	14,604,211	10,456,013	3695,593	243,256
Mobile WiMAX	31,032,629	22,820,476	7,418,109	514,134

Results of Optimized Code

<table>
<tr><th></th><th>RSSI (µs)</th><th>CP (µs)</th><th>SCF (µs)</th></tr>
<tr><td>802.11a/g</td><td>0.172</td><td>35.73</td><td>107.34</td></tr>
<tr><td rowspan="4">802.11n</td><td rowspan="2">0.172</td><td>35.73</td><td rowspan="2">107.34</td></tr>
<tr><td>34.54</td></tr>
<tr><td rowspan="2">0.225</td><td>47.3</td><td rowspan="2">213.85</td></tr>
<tr><td>46.8</td></tr>
<tr><td>802.16d</td><td>0.332</td><td>69.1</td><td>406.24</td></tr>
<tr><td>802.16e</td><td>0.546</td><td>114.54</td><td>858.6</td></tr>
</table>

*All of the spectrum sensing techniques meet the time constraint

System Performance on TI C64

Case I: 40.978μs

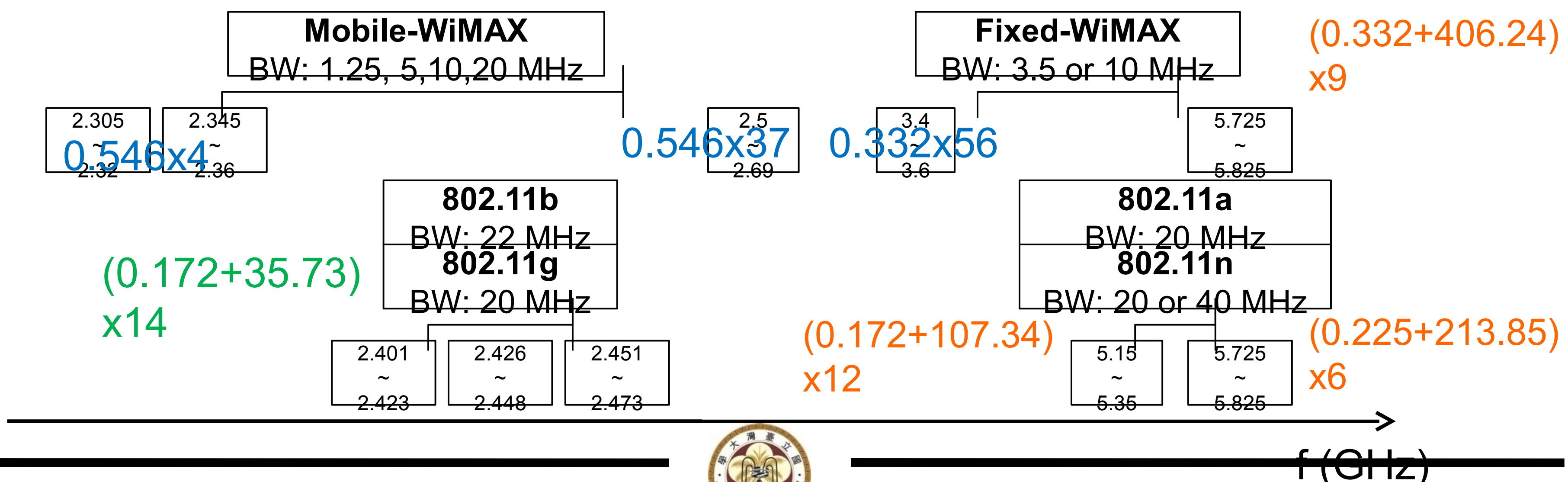
Case II: 502.628μs

Case III: 6233.742μs

Total: 6777.348μs ≈ 7ms

16

@600MHz	RSSI	CP	SCF
802.11a/g	0.172μs	35.73μs	107.34μs
802.11n	0.172μs	35.73μs	107.34μs
		34.54μs	
	0.225μs	47.3μs	213.85μs
		46.8μs	
Fixed WiMAX	0.332μs	69.1μs	406.24μs
Mobile WiMAX	0.546μs	114.54μs	858.6μs



Outline

- Background and Motivation
- Spectrum Sensing Methodology
- Implementation
- Simulation Results
- Conclusion

Conclusion

- Proposed a case base signal detection techniques for 802.11a/b/g/n and Fixed/Mobile WiMAX spectrum sensing.
- Identified the common blocks for spectrum sensing.
- Requires 7 ms to perform all the detections on TI-C6416,
- Scale DSP operating speed according to the required cognition frequency.

Review the issues of multi-standard spectrum sensing:

- Multiple PUs detection & identification.
- How many systems we can cover in our scenario?
- **Frequency to sense?** 7ms @600MHz (8 ALUs)

802.11a/b/g/n
Fixed/Mobile WiMAX

THANK YOU!!!