Applying Cognitive Radio Concepts to Next Generation Electronic Warfare

SDR`10
Wireless Innovation Conference and Product Exposition

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Agenda

- Yin Yang of tactical communications & EW
- SDR-based EW and CR-based next gen EW
- Planning & scheduling algorithms
- Simulation framework design
- Some performance observations
- Conclusion

Yin Yang of Communications & EW

The Yin Yang of Tactical Communications

- Effective command & control depends on reliable tactical communications (comms)
- EW goals
  - Protect friendly C2
  - Deny adversary's C2
- "Electromagnetic Spectrum (EMS) Control" (EMC)
  - "Achieve effective management and coordination of friendly systems while countering adversary systems"

- Next gen comms (CR) vision
  - Autonomously & cooperatively establish a comm link

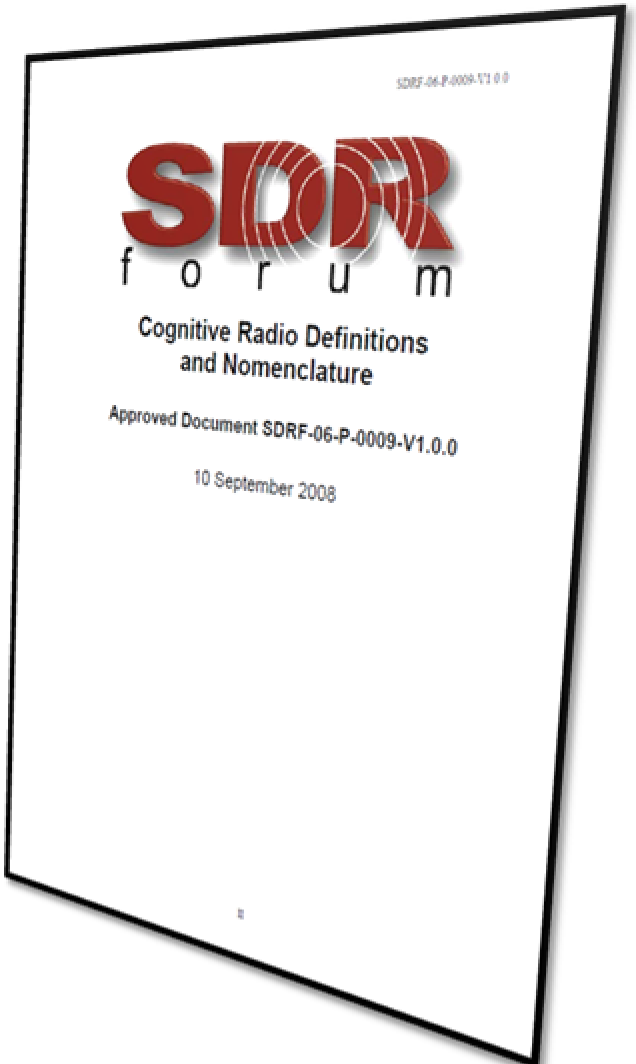
- Next gen EW vision
  - Autonomously observe comm links in order to autonomously & uncooperatively degrade specific comm links of interest

The Three Pillars of EW

- Electronic Support (ES)
  - Search for, intercept, identify and locate emitters for the purpose of immediate threat recognition, targeting, planning and conducting of future operations
- Electronic Attack (EA)
  - Prevent or reduce an enemy's use of the EMS, both non-kinetic (e.g., jamming & EM deception) and kinetic (e.g., anti-radiation missiles); includes both offensive and defensive activities
- Electronic Protection (EP)
  - Protect personnel, facilities & equipment from effects of friendly or enemy use of the EMS that degrade, neutralize or destroy friendly combat capability; includes EMS management, EM hardening, emission control, etc.

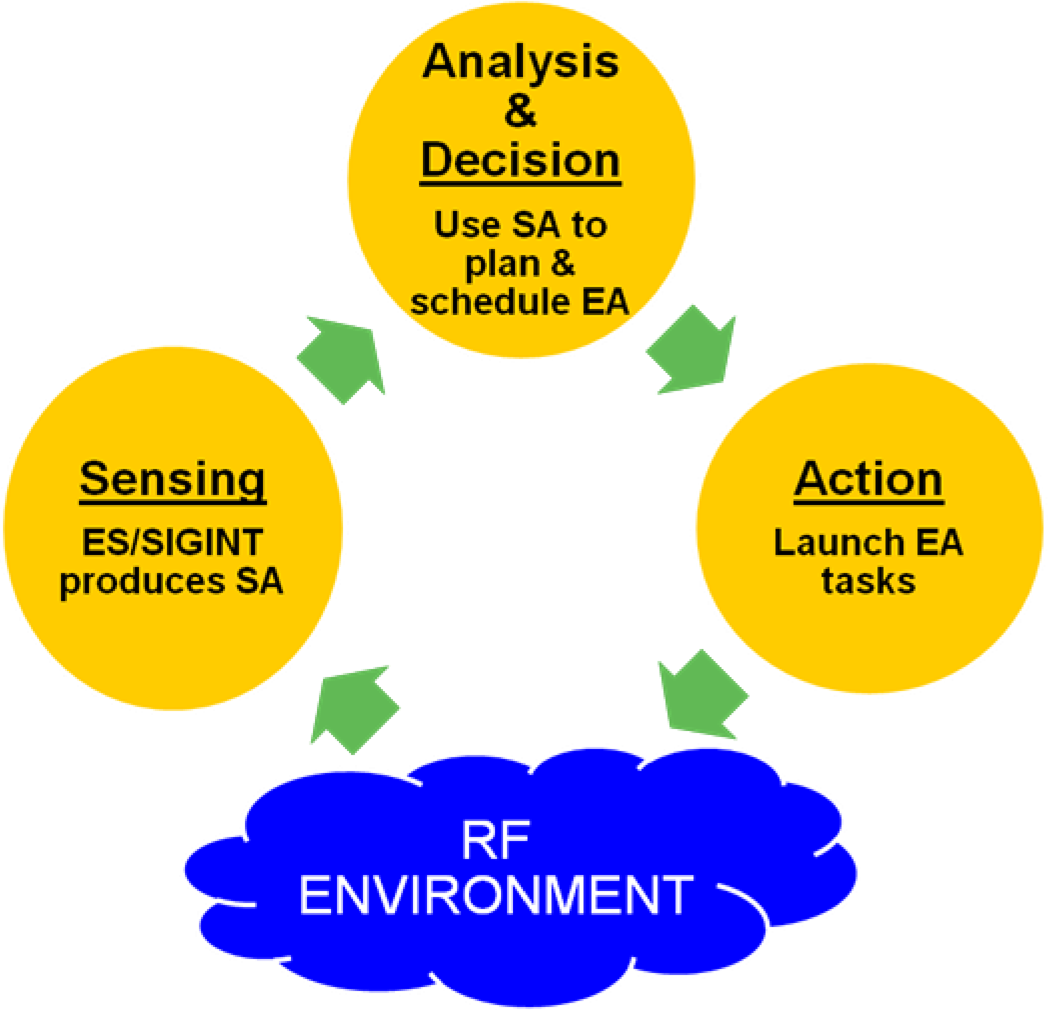
Rehashing the Basics of CR for EW

The CRWG of the SDRF has defined a CR as a "radio in which communication systems are aware of their environment and internal state and can make decisions about their radio operating behavior based on that information and predefined objectives"



- Spectrum awareness ~ SIGINT
- Radio operating behavior ~ EA
- Making decisions based on internal state, spectrum awareness & predefined objectives ~ COGNITION

Basic Notions of CR vis à vis EW



Spectrum Etiquette

CR	EW
Where is there a hole in the spectrum?	Where is there NOT a hole in the spectrum? Is it a signal of interest (SOI)?
Do NOT transmit if a Primary User wants that hole	DO transmit if the Primary User is a SOI on a target list
Use the best waveform to MINIMIZE interference	Use the best waveform to MAXIMIZE interference

Recent DOD SDR & CR R&D Efforts

- DARPA's existing SDR & CR communications programs
  - XG = neXt Generation (2003-2009)
    - Develop radios that could adapt and select the environments in which it works best and bring other similar radios into its network using DSA
  - WNAN = Wireless Network After Next (2006-present)
    - Goes further than XG in creating a flexible architecture for military comms
    - Key aspect of WNAN is to develop and test an inexpensive handheld SDR that is capable of selecting its own frequencies and forming small networks within a larger battlefield network
    - Competitive with JTRS
  - PREW = PRecision EW (2010)
    - Array of >40 robust, low cost, small (<5#) SWAP distributed platform with sync'd clocks to perform **SURGICAL** jamming
- Other efforts to add CR capabilities to existing tactical military radios
  - AN/PRC-117F Multiband Manpack Radio (MBMMR) (2008)
    - Army/Navy SDR built by Harris
    - JHAPL R&D effort added a CR DSA appliquè to the radio
  - JTRS Falcon III handheld tactical radio running the VULOS waveform (2010)
    - Harris R&D effort inserted DSA technology into the SCA architecture

Recent DOD Cognitive EW R&D Efforts

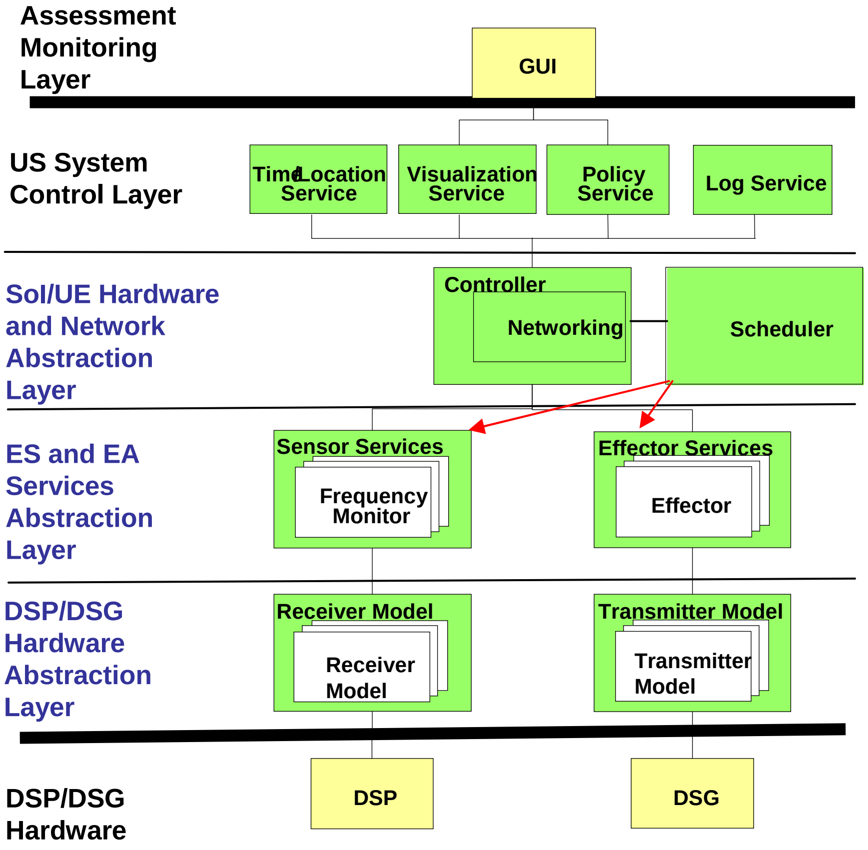
- USA: I2WD's Urban Saber program (2009)
  - Will present in following slides
- USAF: AFRL's Cognitive Jammer program (2010)
  - CONOP: Develop a multi-functional and flexible first-generation Cognitive Jammer architecture that can target SDR/CRs utilizing DSA
  - Cognitive aspect: Architecture is to provide EA capabilities that can sense, learn and adapt so as to be able to deliver proactive countermeasures with a reaction time in "seconds to minutes" instead of "days to months"
- USN: NRL's Cognitive Communications EW program (2010)
  - CONOP: Create a cognitive communications jammer since smart phones and CRs can defeat current EA techniques
  - Cognitive aspect: Leverage previous applied machine learning algorithms to EA technique development in order to learn and predict threat behavior
- DARPA's BLADE program (2010)
  - CONOP: Develop novel algorithms and techniques that will enable our EW systems to automatically learn to jam new RF threats in the field
  - Cognitive aspect:
    1. Automatically detect & characterize a new threat
    2. Learn to effectively & efficiently jam the new threat
    3. Accurately assess jam effectiveness in the field

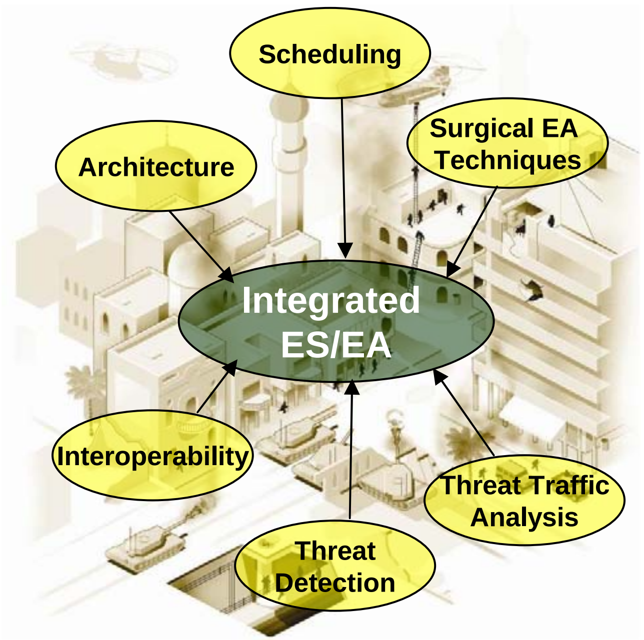
SDR-Based EW

And

CR-Based Next Gen EW

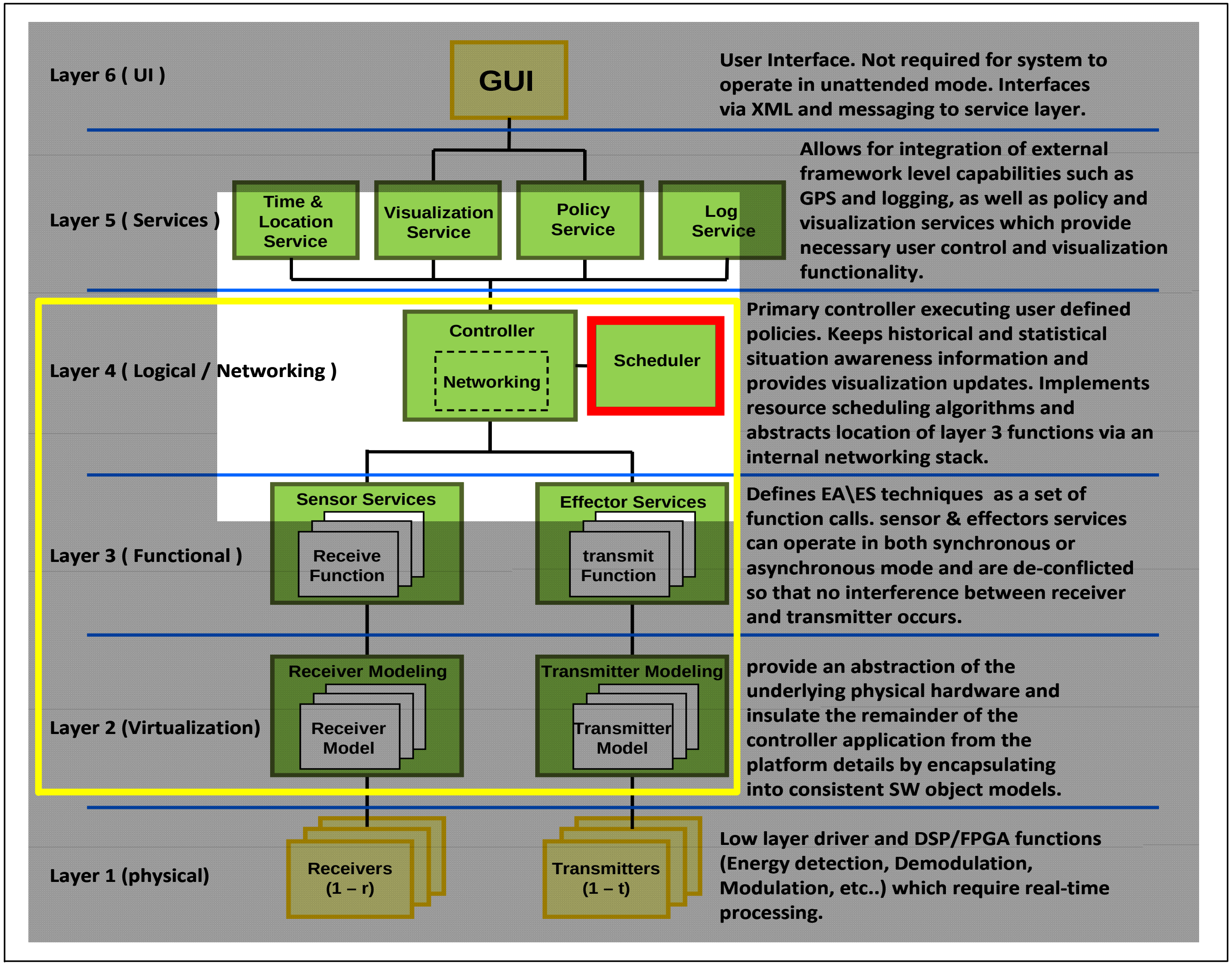
Urban Sabre System Architecture





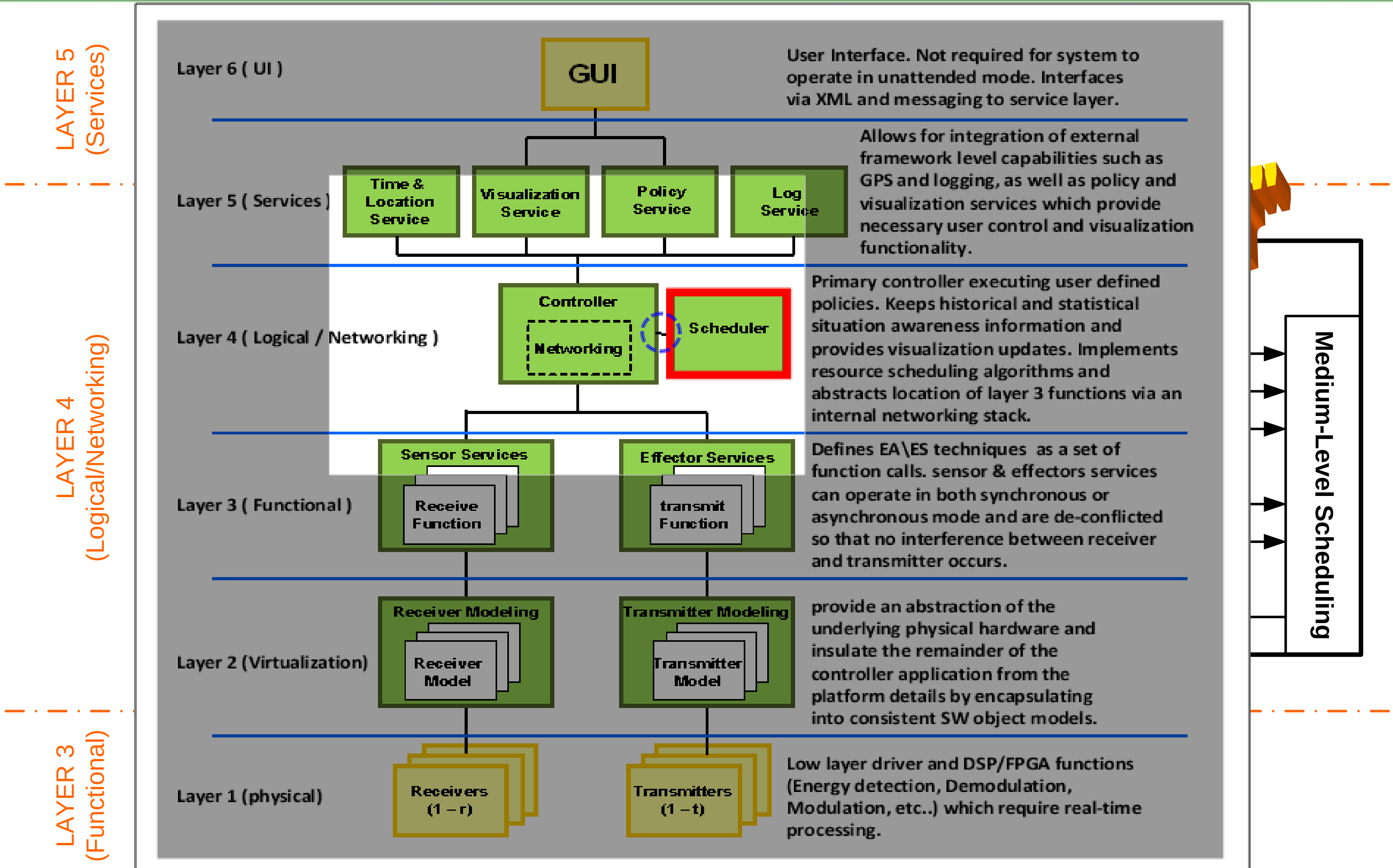
Perform detect/ID/classification/geolocation/attack of a broad set of high priority wireless devices to regain & maintain control of the RF spectrum

The Initial Focus



- I2WD's notional software architecture
  - Prototype used round robin scheduling
- Scheduler remained our primary focus
  - Single I/O path
- Layers 2-4 comprised the target environment for simulation

The Scheduler's View of the World



Planning & Scheduling Algorithms

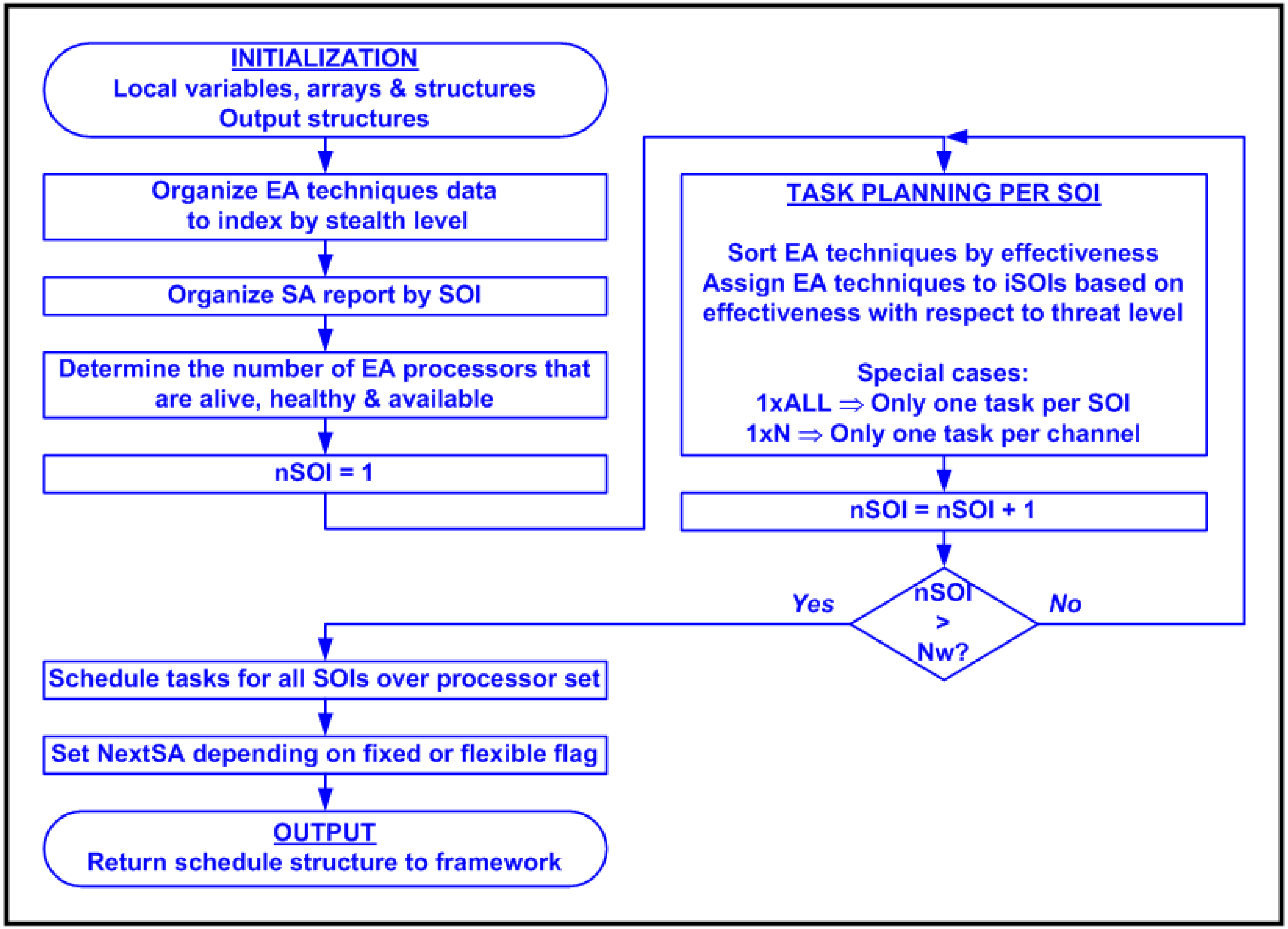
Theoretic-based Scheduling Algorithms

- Theoretic ("hope it works")—based on mapping approaches from the relevant domains to this problem
  - "AIOR" (AI + OR) or "AO"
  - AI = Artificial Intelligence—for autonomous planning
  - OR = Operations Research—for optimized scheduling
- AI-based planning for creating EA tasks
  - Pragmatic AI approach
  - Use Partial Order Planning (POP) based on the Hierarchical Task Network (HTN) notion
  - Re EA task creation, this reduces to probabilistic-based ranking of techniques
- OR-based scheduling for ordering the EA tasks w.r.t. time and processor
  - Classical OR approach to optimize the use of resources, typically w.r.t. time
  - Applied flexible scheduling approaches
  - Leveraging the TORSCHE MATLAB scheduling toolbox from the Czech Technical University in Prague

Pragmatic Algorithms: Overview

- Pragmatic ("expect it to work")—based on published NASA oversubscribed satellite network resource management
  - Best Effort (BE)
    - Discovered and adapted during study phase
  - Best Effort Optimized (BEO)
    - Improved BE developed during M&S
- Best Effort (BE)
  - Greedy scheduling algorithm
  - Pre-Simulation creates a look up table for techniques available to each SOI type and channel pair and orders them by their effectiveness level
  - Ranks each individual SOI type and channel pair according to priority allocated for each new SA report received
  - Guarantees the highest value targets will get scheduled first
  - Guarantees highest value targets will utilize most effective techniques for given SOI
- Best Effort Optimized (BEO)
  - Similar to BE
  - Starts to look at the group as a whole
  - Pre-Simulation creates a look up table for techniques available to each SOI type and channel pair and orders them by their effectiveness level
  - Ranks each individual SOI type and channel pair according to priority allocated for each new SA report received
  - Re-orders look up table created pre-simulation due to the number of SOI type and channel pairs contained in the SA report
  - Rest of algorithm matches BE

Conceptual Flowchart of Algorithms



Measuring Performance: MOE & BDA

- MOE: Scheduler metric
  - Measures the number of SOIs successfully scheduled versus the number of SOIs reported in the SA reports.

$$MOE = \sum \frac{SOIs\_scheduled}{SOIs\_reported}\left(\left\| priority\_vec \right\|\right)$$

- BDA: System metric
  - Measures the number of SOIs successfully attacked and destroyed versus the number of SOIs reported in the SA report

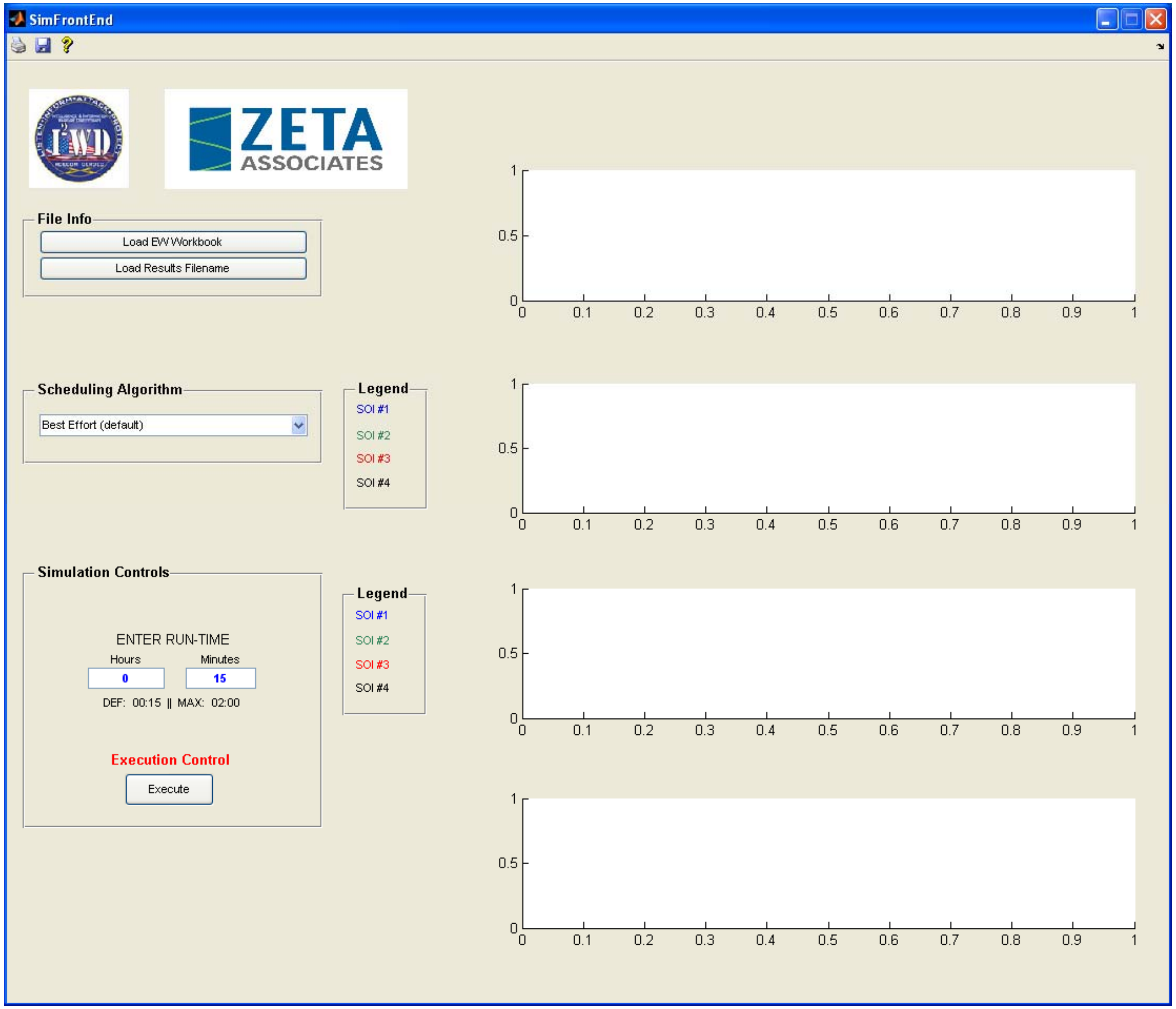
$$BDA = \sum \frac{SOIs\_destroyed}{SOIs\_reported}\left(\left\| priority\_vec \right\|\right)$$

Simulation Framework Design

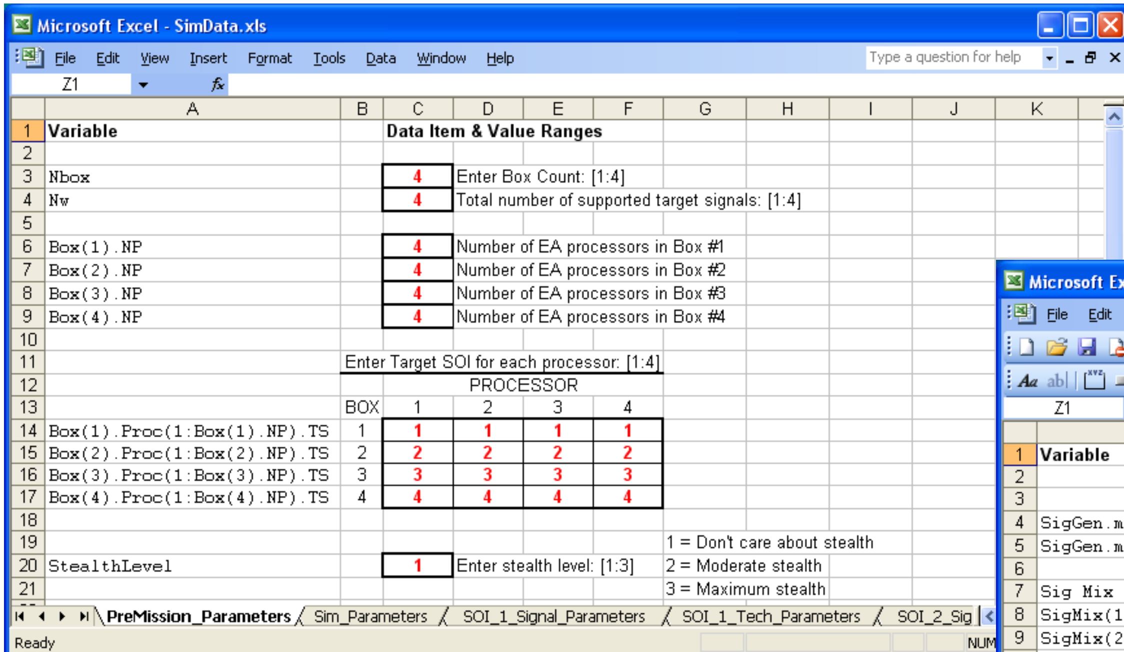
Simplified Component View

- Test harness
  - Environment sampled by ES resources
  - Generates SA reports
- Composer
  - Consumes SA reports and generates an optimal schedule based on user EW Policy and resources
  - Best Effort & AIOR
- Conductor
  - Executing schedule against signal targets
  - Simulated in the framework

Control Panel Pre-Run



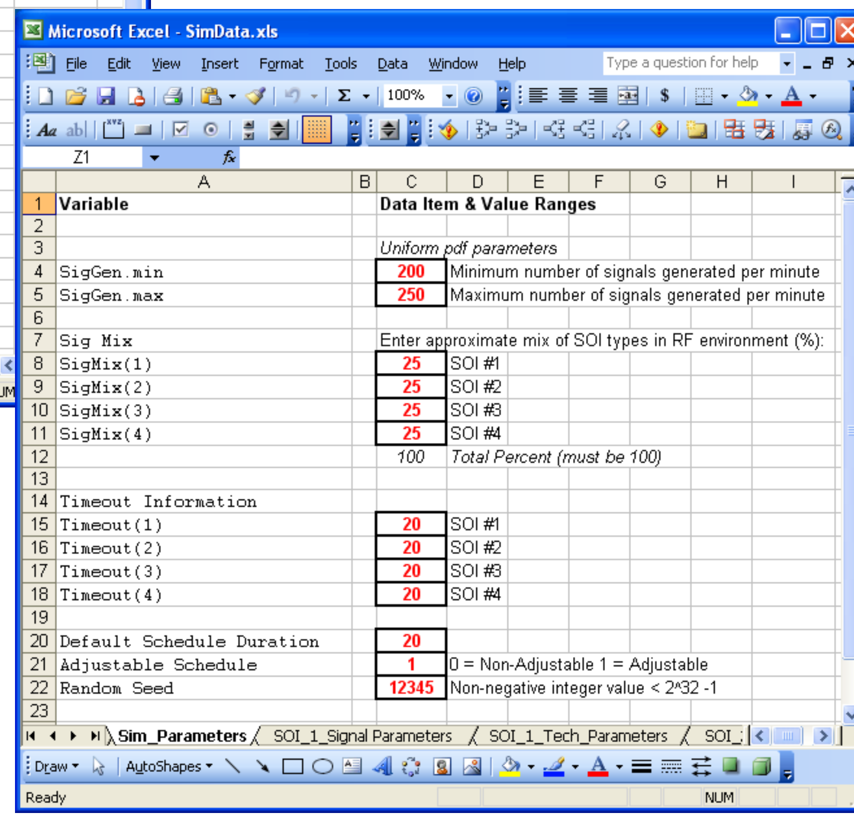
Parameter Data Entry



Microsoft Excel - SimData.xls

	A	B	C	D	E	F	G
1	Variable		Data Item & Value Ranges				
2							
3	Nbox		4	Enter Box Count: [1:4]			
4	Nw		4	Total number of supported target signals: [1:4]			
5							
6	Box(1).NP		4	Number of EA processors in Box #1			
7	Box(2).NP		4	Number of EA processors in Box #2			
8	Box(3).NP		4	Number of EA processors in Box #3			
9	Box(4).NP		4	Number of EA processors in Box #4			
10							
11		Enter Target SOI for each processor: [1:4]					
12			PROCESSOR				
13		BOX	1	2	3	4	
14	Box(1).Proc(1:Box(1).NP).TS	1	1	1	1	1	
15	Box(2).Proc(1:Box(2).NP).TS	2	2	2	2	2	
16	Box(3).Proc(1:Box(3).NP).TS	3	3	3	3	3	
17	Box(4).Proc(1:Box(4).NP).TS	4	4	4	4	4	
18							
19							1 = Don't care about stealth
20	StealthLevel		1	Enter stealth level: [1:3]			2 = Moderate stealth
21							3 = Maximum stealth

PreMission_Parameters / Sim_Parameters / SOI_1_Signal_Parameters / SOI_1_Tech_Parameters / SOI_2_Sig



Microsoft Excel - SimData.xls

	A	B	C	D
1	Variable		Data Item & Value Ranges	
2				
3			*Uniform pdf parameters*	
4	SigGen.min		200	Minimum number of signals generated per minute
5	SigGen.max		250	Maximum number of signals generated per minute
6				
7	Sig Mix		Enter approximate mix of SOI types in RF environment (%):	
8	SigMix(1)		25	SOI #1
9	SigMix(2)		25	SOI #2
10	SigMix(3)		25	SOI #3
11	SigMix(4)		25	SOI #4
12			*100*	*Total Percent (must be 100)*
13				
14	Timeout Information			
15	Timeout(1)		20	SOI #1
16	Timeout(2)		20	SOI #2
17	Timeout(3)		20	SOI #3
18	Timeout(4)		20	SOI #4
19				
20	Default Schedule Duration		20	
21	Adjustable Schedule		1	0 = Non-Adjustable 1 = Adjustable
22	Random Seed		12345	Non-negative integer value < 2^32 -1
23				

Sim_Parameters / SOI_1_Signal Parameters / SOI_1_Tech_Parameters / SOI_

Signal & Technique Parameters Data Entry

Microsoft Excel - SimData.xls

	A	B	C	D	
1	Variable		Descriptions	Input Values	
2					
3	TS(1).Nchans			14	Number (
4	TS(1).Nusers			2	Number (
5	NumHVChan			3	Number (
6	HVChan Number			7	High Valu
7	HVChan Value			2	High Valu
8	HVChan Number			5	High Valu
9	HVChan Value			2	High Valu
10	HVChan Number			4	High Valu
11	HVChan Value			5	High Valu
12					

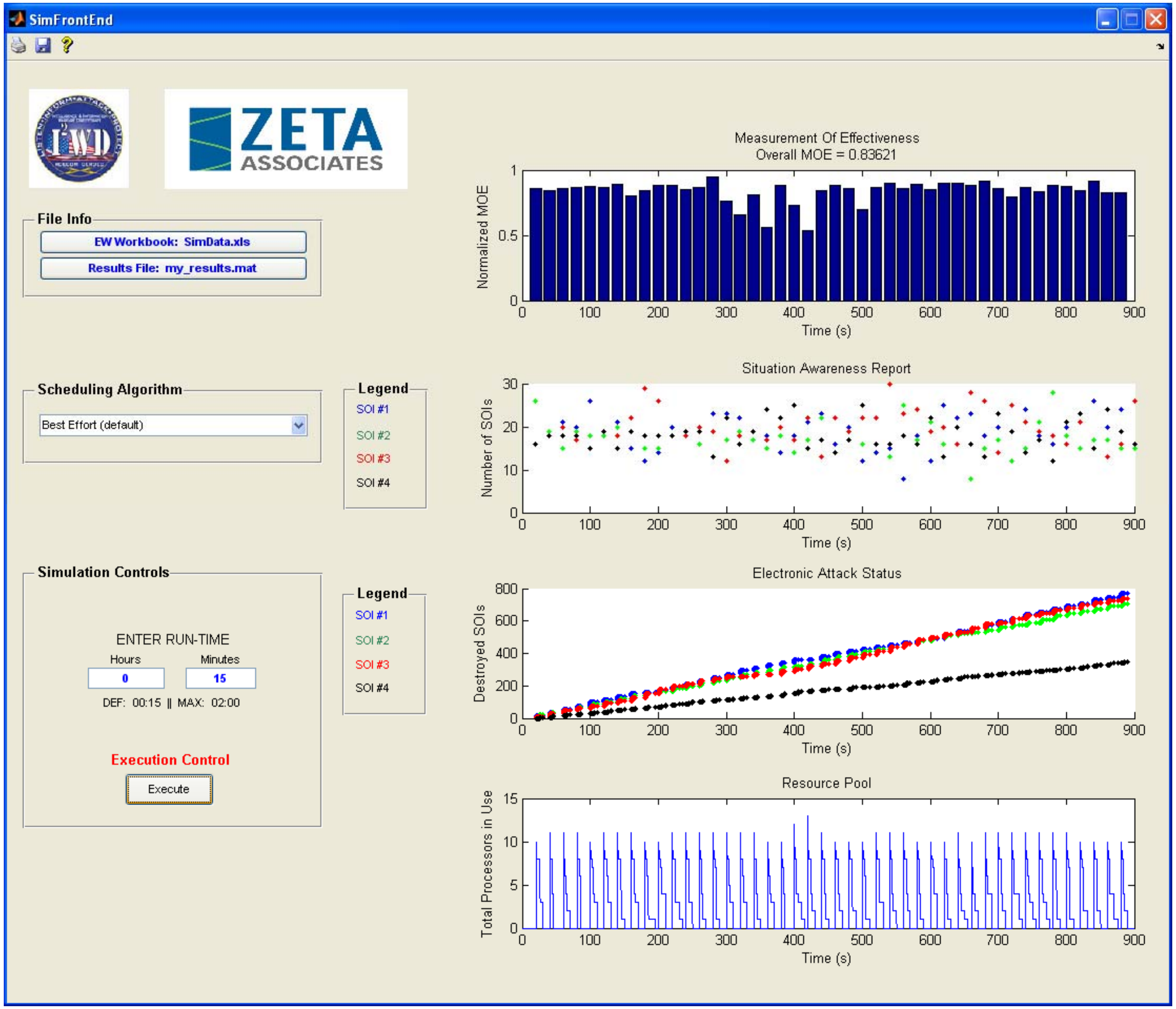
Sim_Parameters / SOI_1_Signal Parameters / SOI_1_Tech_Parameters

Microsoft Excel - SimData.xls

	A	B	C	D	E	F	G
1	Variable		Descriptions	Input Values	Notes		
2							
3	Nz(1)			4			
4							
5	TT(1,1).Sp			34.0E-6			
6	TT(1,1).PercentSuccess			0.90			
7	TT(1,1).StealthMin			2			
8	TT(1,1).MultiTarget			-3	1XN = -3, 1X1 = -2, 1XAll = -1		
9							
10	TT(1,2).Sp			3.0E+0			
11	TT(1,2).PercentSuccess			0.75			
12	TT(1,2).StealthMin			2			
13	TT(1,2).MultiTarget			-3	1XN = -3, 1X1 = -2, 1XAll = -1		
14							
15	TT(1,3).Sp			34.0E-6			
16	TT(1,3).PercentSuccess			0.70			
17	TT(1,3).StealthMin			2			
18	TT(1,3).MultiTarget			-3	1XN = -3, 1X1 = -2, 1XAll = -1		
19							
20	TT(1,4).Sp			34.0E-6			
21	TT(1,4).PercentSuccess			0.60			
22	TT(1,4).StealthMin			2			
23	TT(1,4).MultiTarget			-3	1XN = -3, 1X1 = -2, 1XAll = -1		
24							
25	TT(1,5).Sp						
26	TT(1,5).PercentSuccess						
27	TT(1,5).StealthMin						
28	TT(1,5).MultiTarget				1XN = -3, 1X1 = -2, 1XAll = -1		
29							

PreMission_Parameters / Sim_Parameters / SOI_1_Signal_Parameters / SOI_1_Tech_Parameters / SOI_2_Sig

Control Panel Post-Run



Some Performance Observations

Some MOE Performance Data

<table>
<tr><th>Data Set</th><th colspan="9">Scheduling Algorithms</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">BE</th><th rowspan="2">BEO</th><th colspan="3">$Pm| |C_{max}$</th><th colspan="2">$Pm| |\Sigma C_j$</th><th colspan="2">$Pm| |\Sigma w_j C_j$</th></tr>
<tr><th>SPT</th><th>WSPT</th><th>LPT</th><th>ECT</th><th>EST</th><th>ECT</th><th>EST</th></tr>
<tr><td>Fast Timeout</td><td>97.8</td><td>99.9</td><td colspan="7">98.9</td></tr>
<tr><td>Low Success</td><td>95.6</td><td>92.5</td><td colspan="7">64.4</td></tr>
<tr><td>Norm Conditions</td><td>40.4</td><td>55.9</td><td colspan="7">55.9</td></tr>
<tr><td>Over-loaded</td><td>81.7</td><td>98.2</td><td colspan="7">98.6</td></tr>
<tr><td>Priorities</td><td>99.1</td><td>98.0</td><td colspan="4">95.3</td><td>97.2</td><td>95.3</td><td>97.2</td></tr>
<tr><td>SimData</td><td>83.6</td><td>83.6</td><td colspan="7">83.4</td></tr>
<tr><td>Under-allocated</td><td>43.3</td><td>73.0</td><td colspan="7">71.3</td></tr>
</table>

Observations & Possible Solutions

- Some obvious observations present themselves
  - The system can suffer from dead space since the SOI with the longest suppression times will bound the schedule
    - Can EA processors handle more than one SOI to improve techniques coverage?
  - The AIOR is bound by the inability to interleave techniques' bursts
    - What agility can be expected from the Controller?
  - The AIOR variants all behave the same because AI planning always picks the highest rank technique in a memoryless system
    - Employ memory to enable CR notion of learning
    - Hooks are in the code, but haven't validated them
- More can be found using the sim framework
  - Very multi-dimensional

Performance Bound for Single SOI/Proc

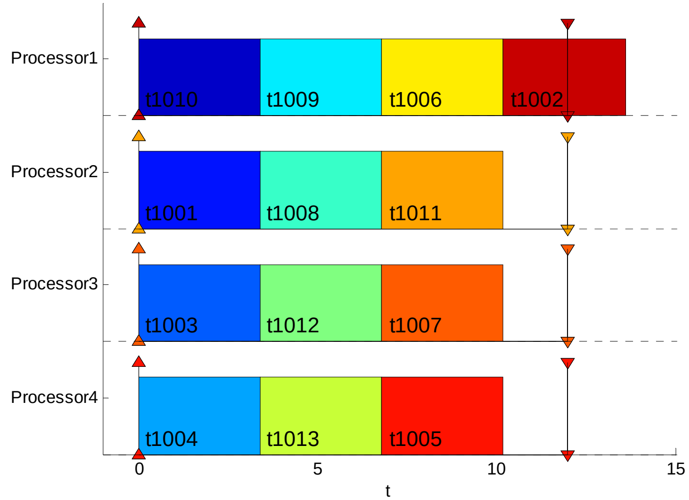
Sim Parameters

- SimData
- SchedDur = 12
- SigGen = [50:100]
- SigMix = 25%/SOI
- Box = 4 x 4
- Stealth Level = 1
- Early AIOR

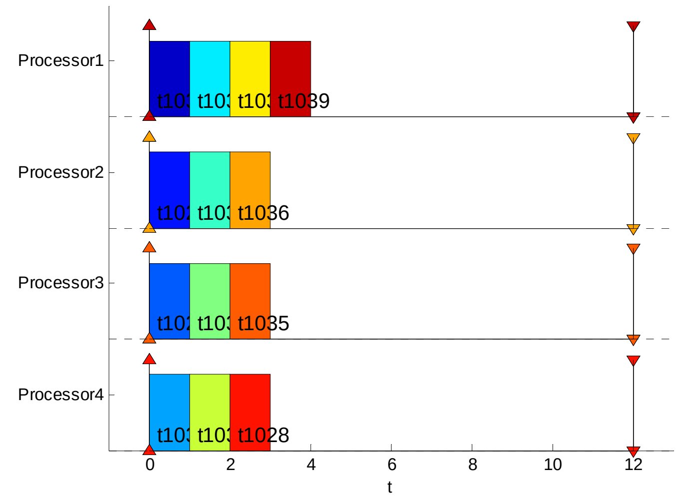
Observations

- Lost EA jobs
  - SOI#1; Proc1
  - SOI#4: Procs 1-3
- Idle Procs
  - SOI#2: Procs 1-4
  - SOI#3: Procs 2-4

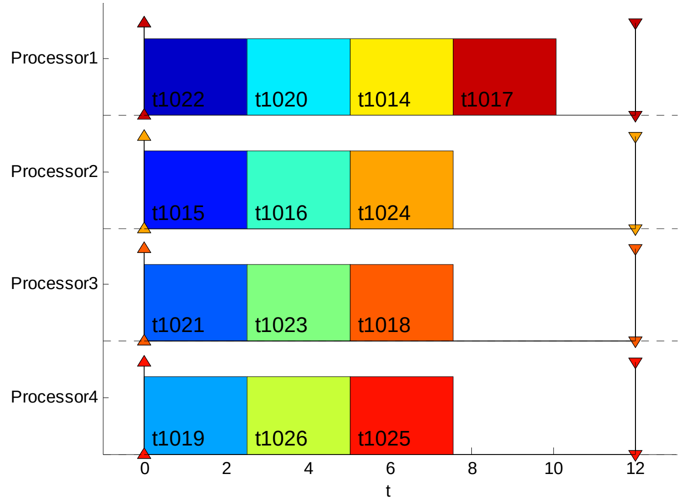
SOI#1



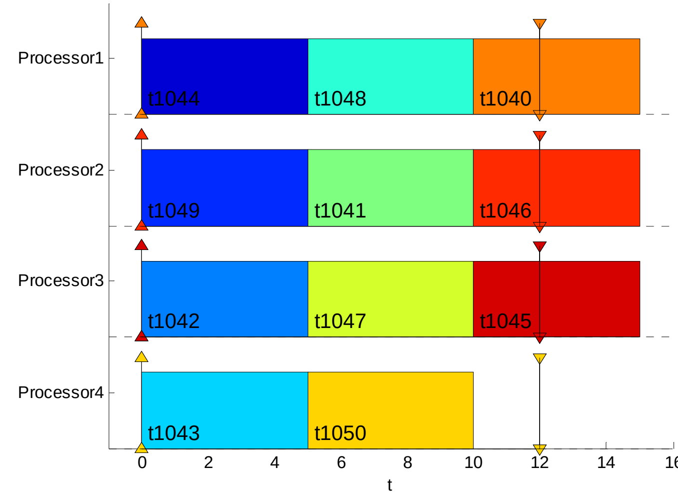
SOI#2



SOI#3



SOI#4



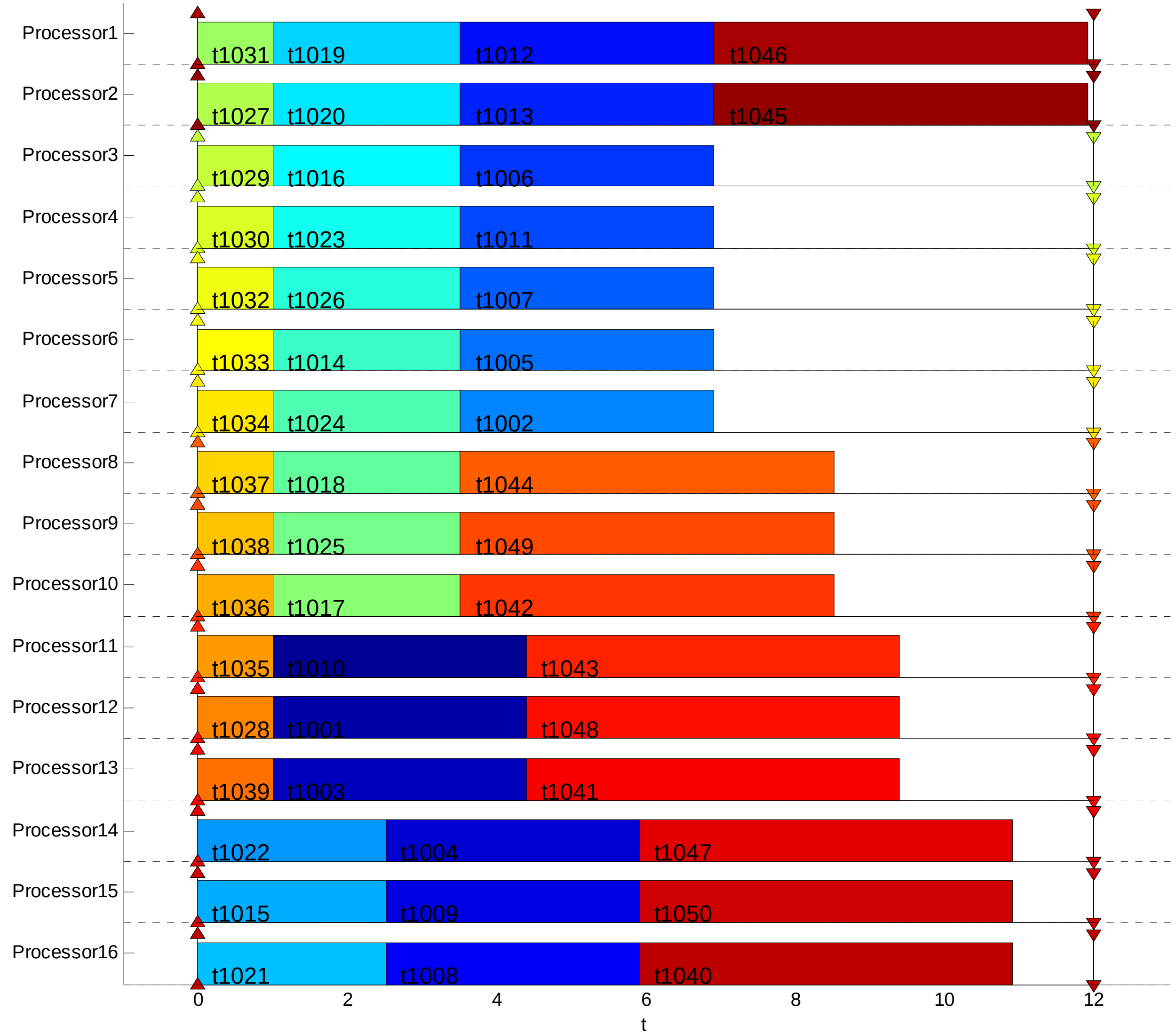
Performance Improvement for Flexible Processor

Sim Parameters

- SimData
- SchedDur = 12
- SigGen = [50:100]
- SigMix = 25%/SOI
- Box = 4 x 4
- Stealth Level = 1
- Early AIOR—BUT all processors are able to prosecute all four SOIs

Observations

- NO Lost EA jobs
- Still have some idle processors
  - Procs 3-13



Conclusion

Summary

- EW summary
  - Dense & dynamic RF is a demanding comms EW environment
    - May require autonomous ES & EA capabilities
    - Pre-mission policy must be well defined
  - Optimal concurrent ES & EA scheduling & control is a potential answer
    - Pragmatism and robustness are important attributes for the planning & scheduling algorithms
    - System requirements for increasing EA density
      - SDRs must be flexible to support multiple EA techniques
      - Architecture needs to support fine-grained control
- CR summary
  - Next gen EW will require CR notions, techniques and architecture