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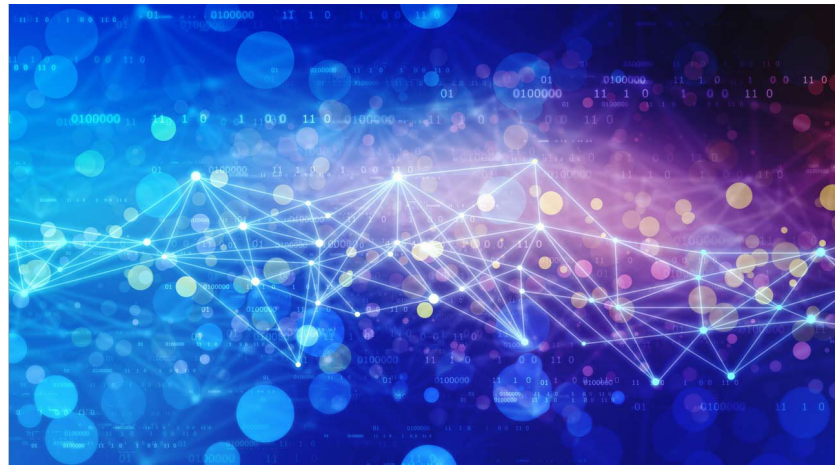

Overview of the MIDEAST Digital Engineering Testbed
24-26 May 2022

Principal Investigator: Bryan.Babcock@Sandia.gov

Program Manager: Jose.Castillo@Sandia.gov

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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Goals of the MIDEAST Digital Engineering Testbed (DET)

- Support Development and Assessment of Multidomain Information Warfare Solutions
  - Model theater-level information collection, processing, dissemination, denial, and corruption with enhanced and sufficient electromagnetic (EM) fidelity
  - Allows the user to inspect, alter, and track the flow of perceptions that influence battle management, command, and control (BMC2) “Agents”/behaviors
- Enable Rapid Exploration and Assessment of Coordinated and Coherent Electronic Warfare (EW) and Cyber Warfare (CW) Concepts (including cognitive warfare)
  - Improve scenario execution speed and intelligently balance speed with EM interaction fidelity
- Advance Component Plug-and-Playability and the OSD/OSAF Digital-Twin Objective
  - Incorporate models and interfaces based on the USAF Open System Architectures (OSAs):
    - Open Mission Systems (OMS)/Universal Command and Control Interface (UCI)
    - Sensor Open System Architecture (SOSA)
    - Weapon Open System Architecture (WOSA)
- Extend the Digital Engineering Paradigm to Complex, Heterogenous, Multidomain System of Systems (SoS)
  - Progress towards standardized import/export of constituent systems, networks, and levels of interoperability (systems of systems)

MIDEAST is rethinking mission modeling architectures to address current and future challenges

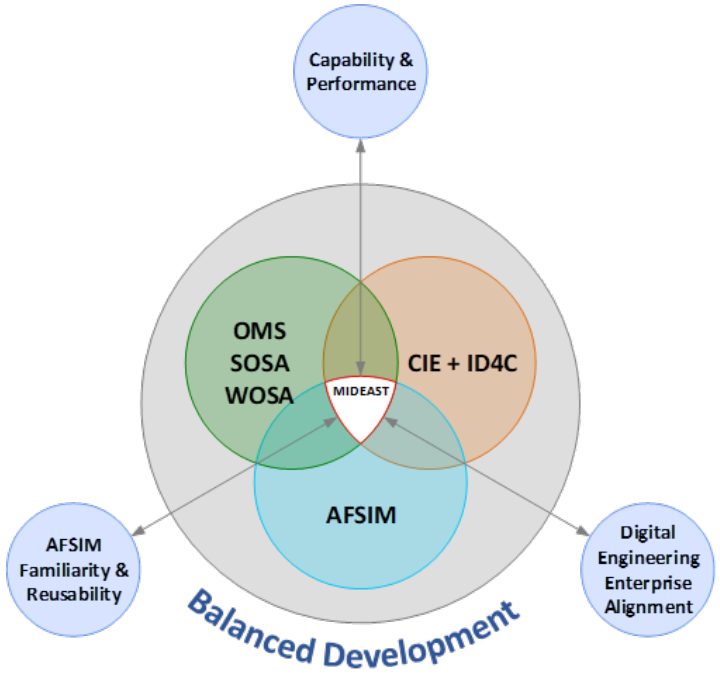
MIDEAST Concept Justification

Common Simulation Limitations:

- Too slow to do the desired variations or train artificial intelligence/machine learning (AI/ML) algorithms in an acceptable timeframe
- Congested / contested electromagnetic (EM) environments are underrepresented
- Unable to model sensing, datalinks, and/or EW/CW at a sufficient fidelity
- Simulation tool was developed before the prevalence of information warfare (simulation is platform centric, not information centric)

MIDEAST Advantages:

- Adaptable Distributed Computing Architecture
  - High execution speed with vast numbers of interacting platforms
  - Logical process manager adapts process allocation to target hardware
- Enhanced Electromagnetic Interaction Fidelity (sensors, datalinks, and EW)
  - Modeling EM environment using emitted & incident signal pulse-train parameters (SPPs)
  - Improved representation of highly congested/contested EM environment
  - Improved representation of coordinated, coherent, and multi-static EM spectrum superiority solutions
- Information-Centric Simulation Framework
  - Optimized to model information and cognitive warfare; separation of global truth & agent's unique perceptions
  - Visualization of information flow and electronic/cyber interactions (not just the physical world)
- Abstract Agent Interface
  - Common language for perceptions/tasking to enable BMC2 agent plug-and-play and machine learning
  - Support design and scrimmage of AI BMC2 agents at both the edge and hierarchal command authorities
  - Visualizations of agent perceptions and the decision making process
- Open System Architecture Inspired Models: OMS/UCI, SOSA, and later WOSA
  - Maximize commonality with real hardware/software and facilitates the use of common authoritative architectural models (e.g., Cameo)



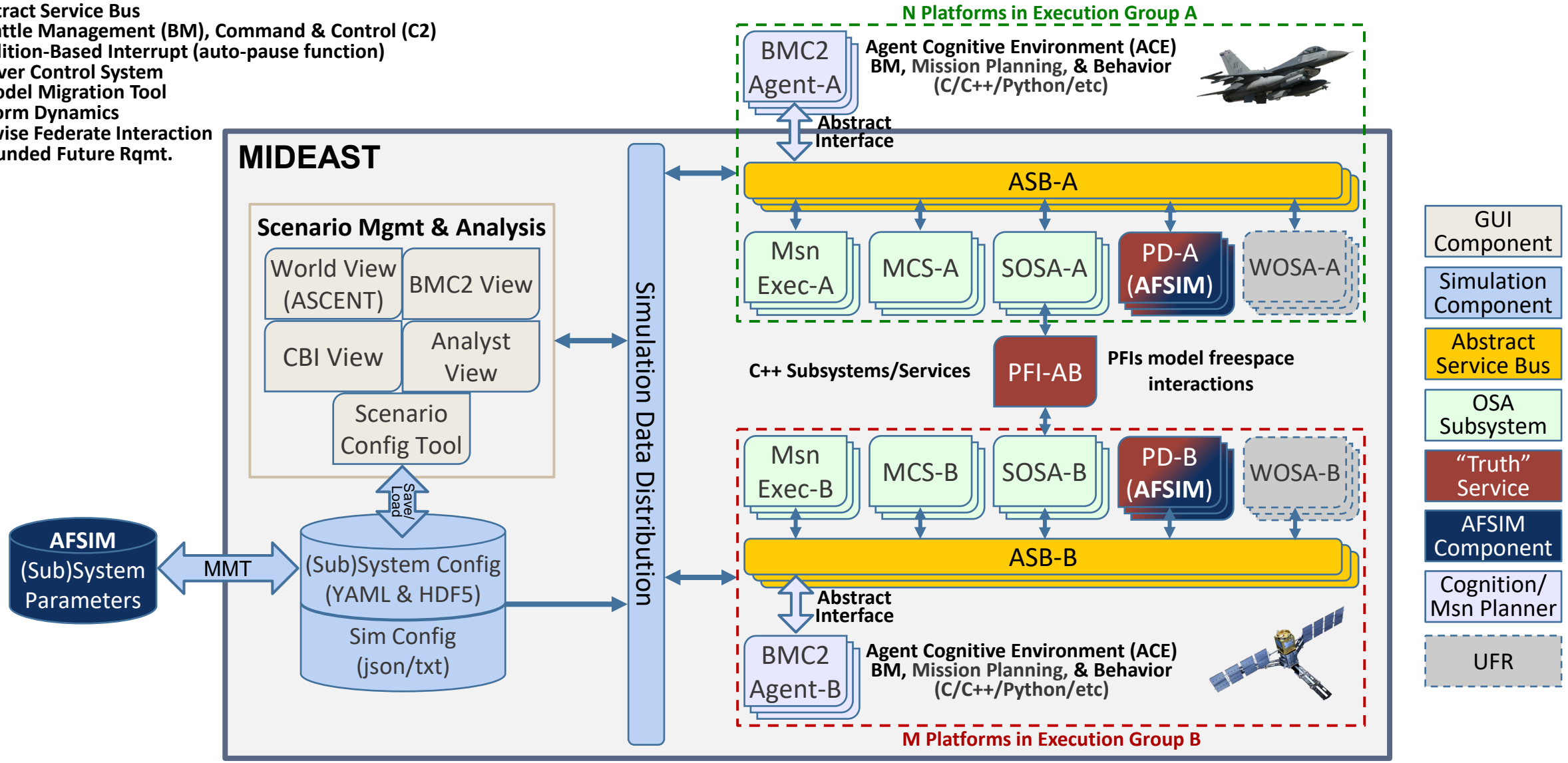
- **MIDEAST is an R&D effort: There will be missing capabilities and polishing will be needed**

MIDEAST Program & Stakeholders

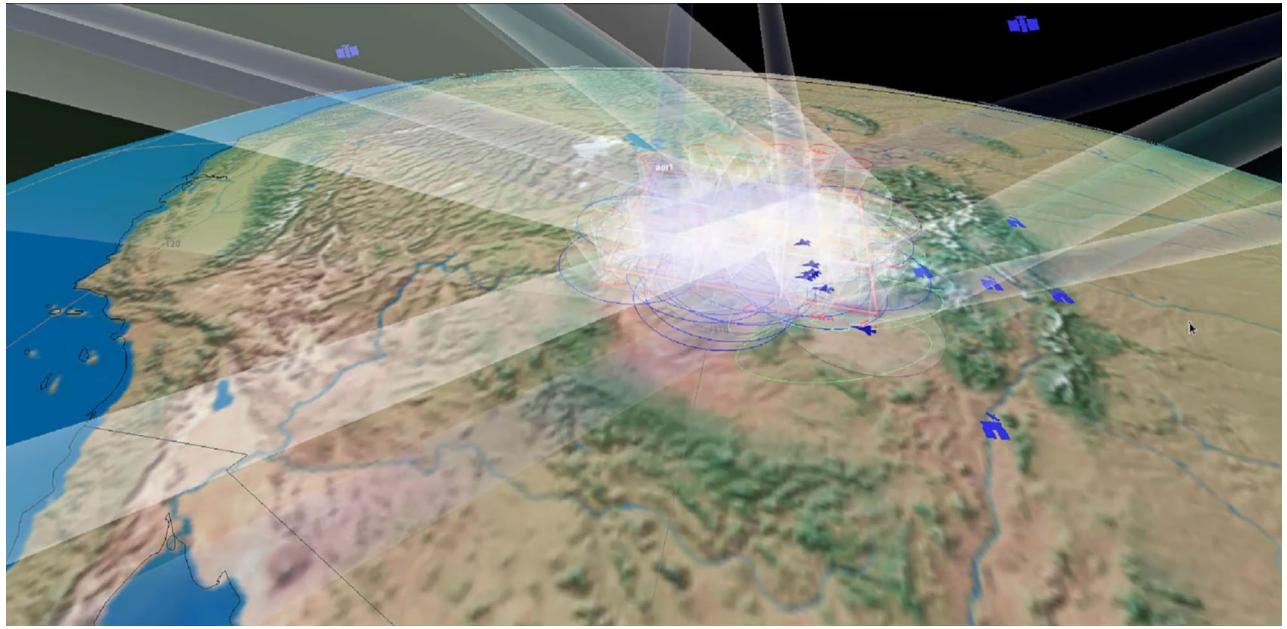
- Timeline
  - SiFi/SAFE-SiM: Leveraging previous DARPA investment in a high performance computing (HPC) version of Advanced Framework for Simulation, Integration and Modeling (AFSIM)
    - 10-100x faster than real-time
  - MIDEAST: FY20/Q4 – FY22/Q4
- Team:
  - Sandia National Laboratories
  - Stellar Science
  - Infinity Labs LLC
- USAF Stakeholders / POC:
  - Maj. Jason Sutherlin, HAF SAF/AQ, MIDEAST Founder
    - Program Director, AFPEO/CM
  - Mr. Jon (Tom) Graves, AFLCMC/WYN
    - MIDEAST Program Manager
  - Dr. Brian McBee, AFRL/RV
    - Portfolio Lead, Model-based Systems Engineering & Analysis
  - Mr. David Panson, AFRL/RSS & SDPE
    - AF Enterprise MS&A Lead
  - Mr. Bryan Larocca, AFLCMC/EZJA
    - Technical Advisor, Combat Effectiveness and Vulnerability Analysis Branch
    - Systems Analysis and Training Division
- Ownership
  - Government Off The Shelf (GOTS) Software
  - Software delivered to AFSIM Program Office for assessment, incorporation, further development, etc

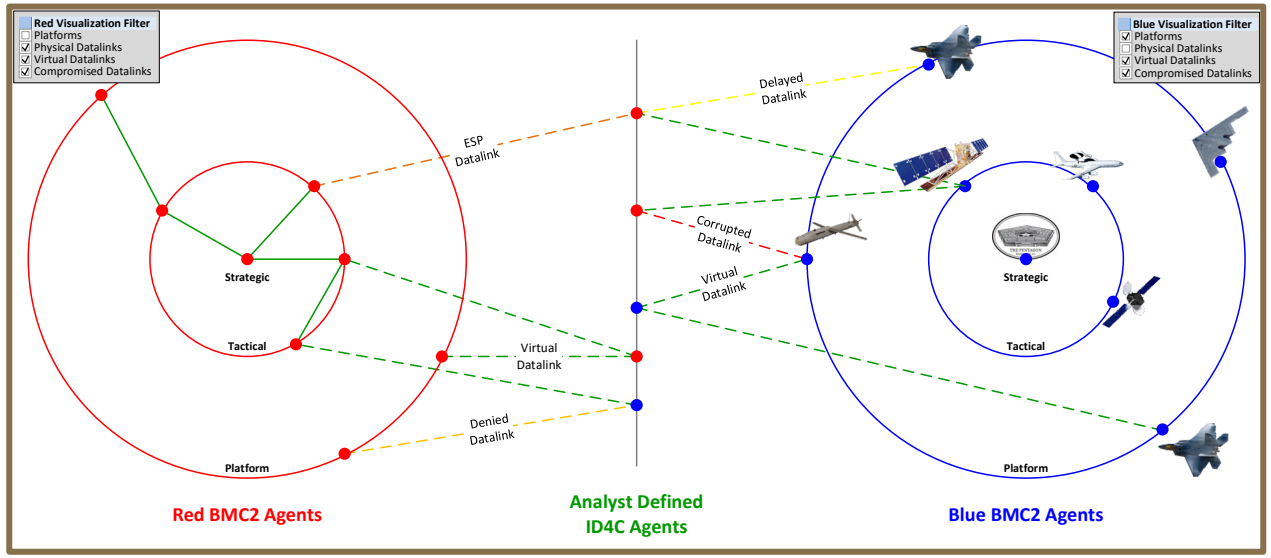
MIDEAST Digital Engineering Testbed Architecture Overview

ASB – Abstract Service Bus
BMC2 – Battle Management (BM), Command & Control (C2)
CBI – Condition-Based Interrupt (auto-pause function)
MCS – Mover Control System
MMT – Model Migration Tool
PD – Platform Dynamics
PFI – Pairwise Federate Interaction
UFR – Unfunded Future Rqmt.



Synchronized Visualizations of Global Truth & BMC2 Agent Activity





World View
(Physical Situational Awareness)

BMC2 View
(Information Situational Awareness)

- **Additional views include Analyst View and Condition-based Interrupt View**

Outline

- Overview
- Adaptable Distributed Computing Architecture
- Electromagnetic Interaction Modeling
- Summary

MIDEAST Distributed Architecture Design & Hardware

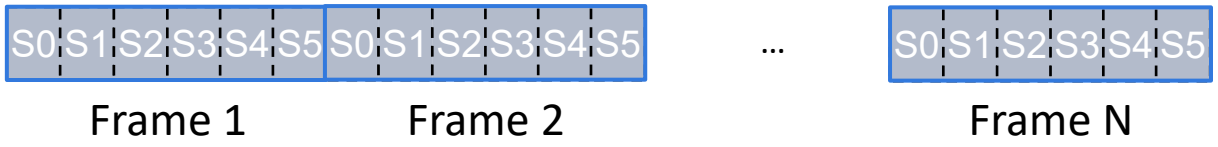
- Logical Process Manager (LPM) allocates parallel processes to computer cores
- Processes/cores are generally defined according to the subsystem represented:
  - Mission Executive (ME)
  - Mover Control System (MCS)
  - SOSA
    - Datalink (DL)
    - Sensor
    - Electronic Warfare (EW)
    - Directed Energy (DE)
  - Truth Services
    - Platform Dynamics (PD)
    - Pairwise Federate Interaction (PFI) Processing
- Inter-process Data Exchange/Synchronization:
  - MPI Shared Memory (SHM) for low latency data
  - ZeroMQ for less time critical data
- Frame Step File indicates the Step within each simulation Frame that each process is allowed to write to SHM
  - Current models operate with 6 Steps for each simulation Frame

Integration & Test Hardware

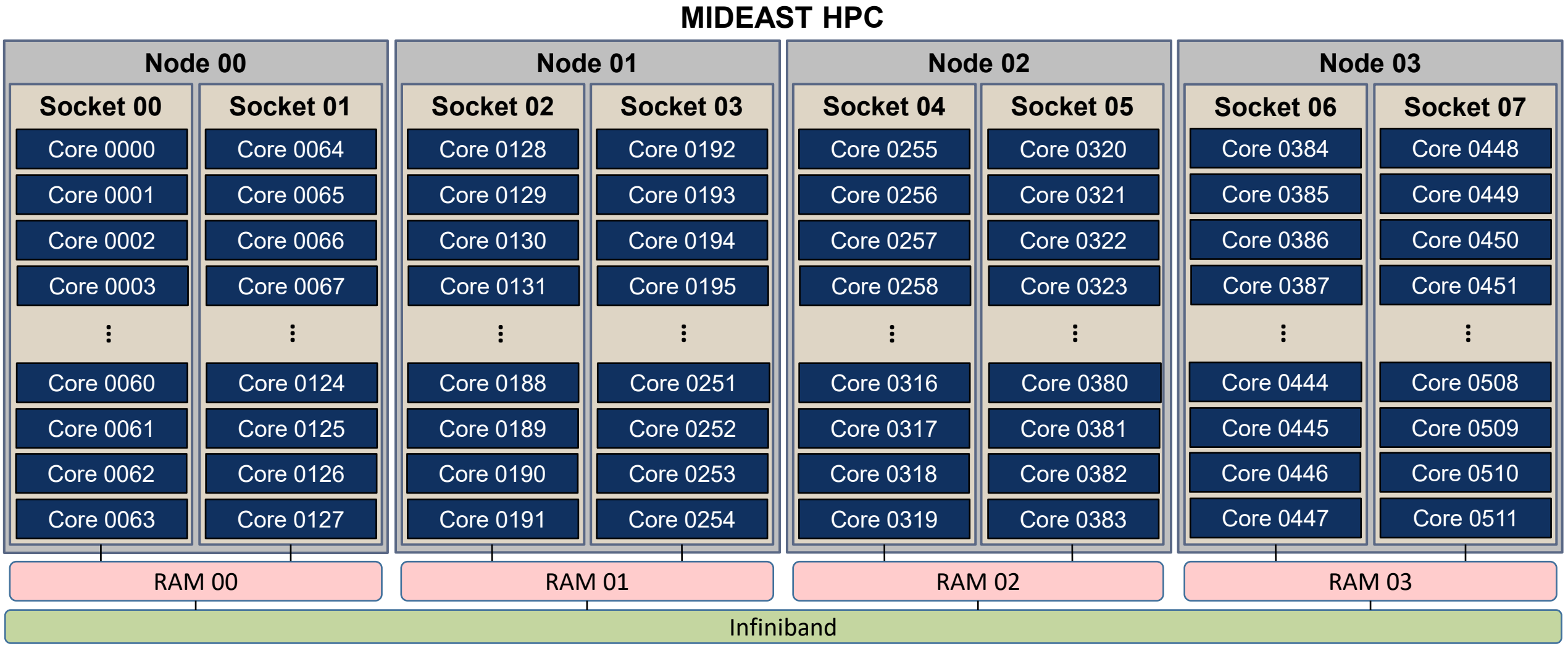
	Work Station/Server	HPC
OS	RHEL 7.7	RHEL 7.6
Nodes / Sockets / Cores	1 / 2 / 24	4 / 8 / 512
RAM per node	256 GB	1 TB
Middleware	ZeroMQ	ZeroMQ
Interconnect	N/A (Ethernet)	InfiniBand
Processor Frequency (normal / turbo) L3 Cache	Intel Xeon Gold 6136 3.00 GHz / 3.70 GHz 24.75 MB	AMD EPYC 7702 2.00 GHz / 3.35 GHz 256 MB
Runtime multiple using HPC/4 246 platforms, 64 signals/s	8.6x real-time	38.5x real-time

Approximate MIDEAST Minimum System Requirements:

- 11 Cores
- 64 GB of RAM

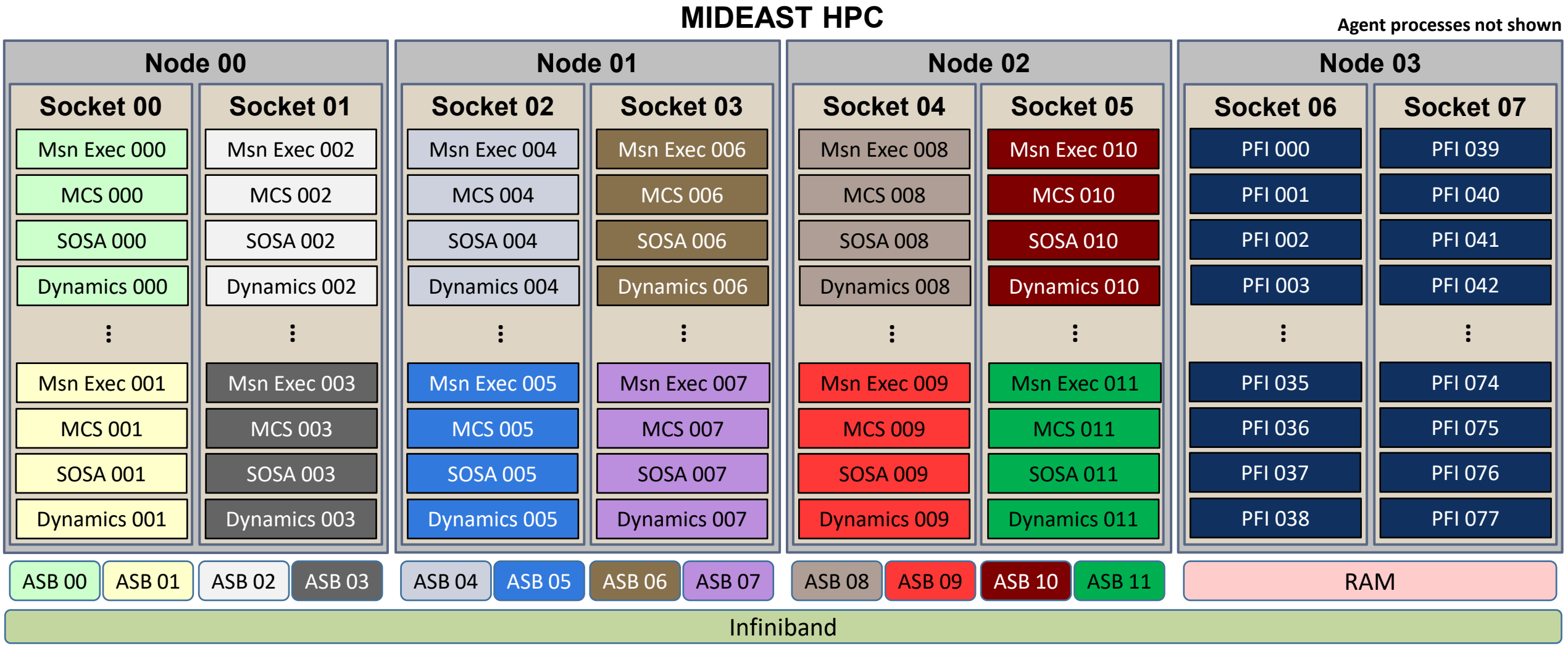


MIDEAST Distributed Framework – Hardware Perspective



- **Architecture supports a wide variety of computer hardware configurations**

MIDEAST Distributed Framework – Example Subsystem/Service Perspective



- Each ASB and set of associated processes make up an execution group containing a number of platforms

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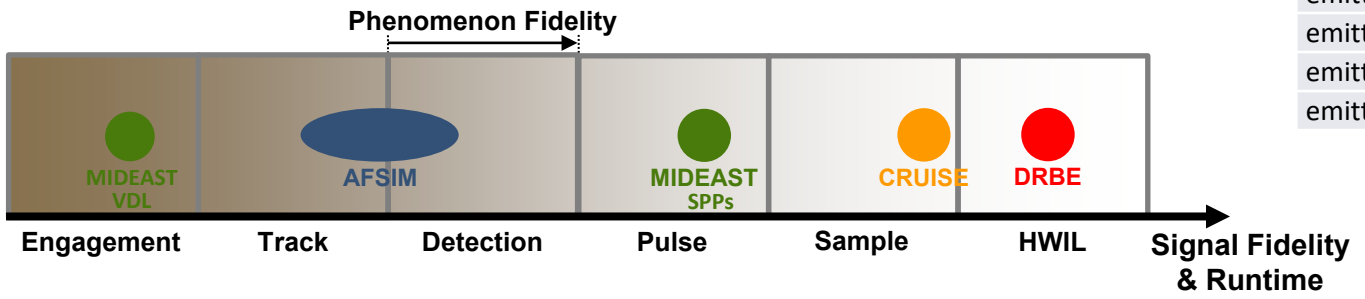
Parametric Pulse-level Modeling Utilizing Signal Pulse-train Parameters

- EM interactions in most simulations are:
  - Detection/track based – Fast, but low fidelity
  - Sample based – Very slow, but high fidelity
- A middle ground exist: pulse based
  - SPPs are an extensible method to define waveform/signal/pulse-train *truth* parameters, similar to how Pulse Descriptor Words (PDWs) define signal *perception/estimated* parameters
  - Moderate speed and fidelity compromise
  - All signals are represented equally
    - Red/Blue, intentional/unintentional interference, datalinks/sensing/EA, etc
  - Intrinsically supports bistatic radar
  - A given Receiver Output Model can be geared more towards higher fidelity or speed



Emitted/Reflected SPPs

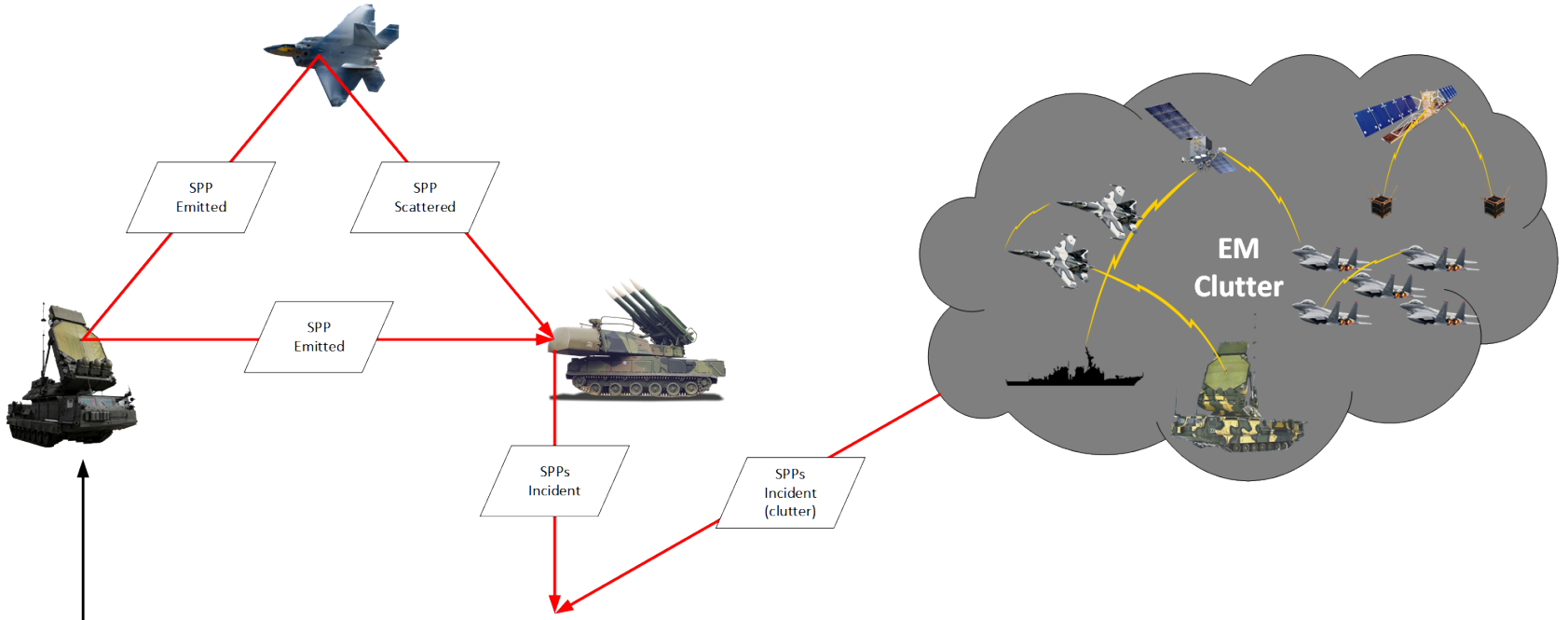
Fields
transmit platform ID (truth)
reflecting platform ID (truth)
signal ID (truth)
specific emitter ID (truth)
exciter gain pattern ID
ELNOT/CENOT (truth)
waveform/modulation type
code sequence ID
time of emission [seconds since scenario start]
emitted power [dBW]
center frequency mean [Hz]
frequency sequence ID
signal bandwidth [Hz]
pulse-compression/information bandwidth [Hz]
pulsewidth [s]
PRI mean [s]
PRI sequence ID [s]
waveform accuracy
dwell time [s]
emitted polarization (Jones Vector)
emitted phase [rad]
emitted azimuth angle [rad]
emitted elevation angle [rad]

Incident SPPs

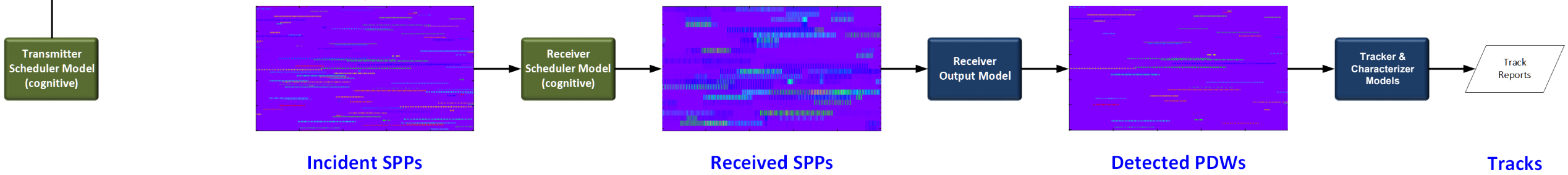
Fields
transmit platform ID (truth)
reflecting platform ID (truth)
receive platform ID (truth)
signal ID
specific emitter ID (truth)
ELNOT/CENOT (truth)
waveform/modulation type
code sequence ID
frequency hop sequence ID
signal bandwidth [Hz]
pulse-compression/information bandwidth [Hz]
pulsewidth [s]
PRI mean [s]
PRI sequence ID
waveform accuracy
dwell time [s]
time of arrival [seconds since scenario start]
incident power density [dB(W/m^2)]
observed center frequency mean [Hz]
observed polarization (Jones Vector)
incident phase [rad]
incident azimuth angle [rad]
incident elevation angle [rad]
multipath mean excess delay [s]
multipath RMS delay spread [s]
multipath mean Doppler spread [s]

DRBE – Digital RF Battlespace Emulator
HWIL – HardWare In the Loop
VDL – Virtual Datalink

Higher Fidelity Representation of Congested/Contested EM Environment



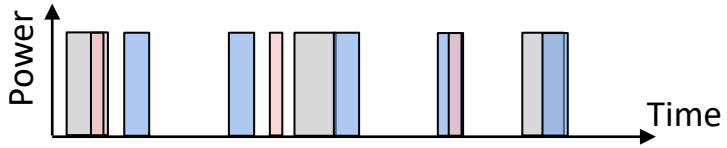
Notional Supported Capabilities
Multistatic coherent effects
Passive radars & TDOA trackers
Frequency agility & jammer seduction
Low-latency & wavefront manipulating DRFM
False targets on scatterers of opportunity
Matched filter gain vs clutter



- Exact transmitter/receiver fidelity is up to the modeler (fidelity vs runtime trade)
- Enables users to design cognitive Tx / Rx schedulers that "navigate" the EM spectrum to maximize mission effect

How Can We Reasonably Model Interference with SPPs?

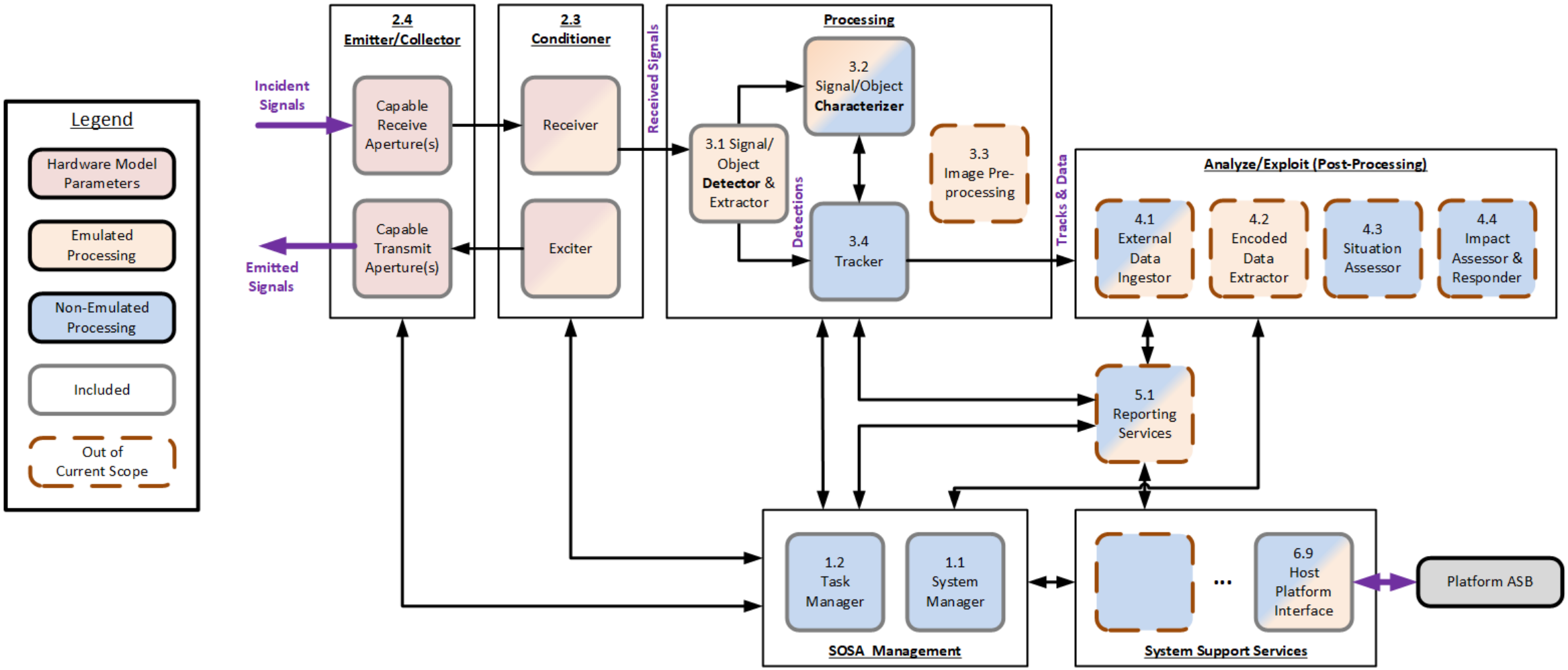
- Steps:
  - Do pulse collisions occur (spectrally and temporally)?
    - Probabilistic Representation – Faster but potentially lower fidelity
    - Discrete Representation – Slower but potentially higher fidelity



  - Are the waveforms coherent or incoherent?
    - Coherent waveforms add coherently (magnitude and phase)
    - Approximate incoherent signals as incoherently adding to each other's noise level
  - Calculate the Signal-to-Interference-plus-Noise Ratio (SINR)
  - Finally, perform detection processing against the resulting SINR
    - Check if: $SINR \geq detection\ threshold$

- Possible future capability to calculate cross-correlations between each waveform once in a preprocessing step for parametric use during simulation runtime

MIDEAST SOSA Model



- Generalized modular architecture supports representation of a vast array of capabilities and behaviors

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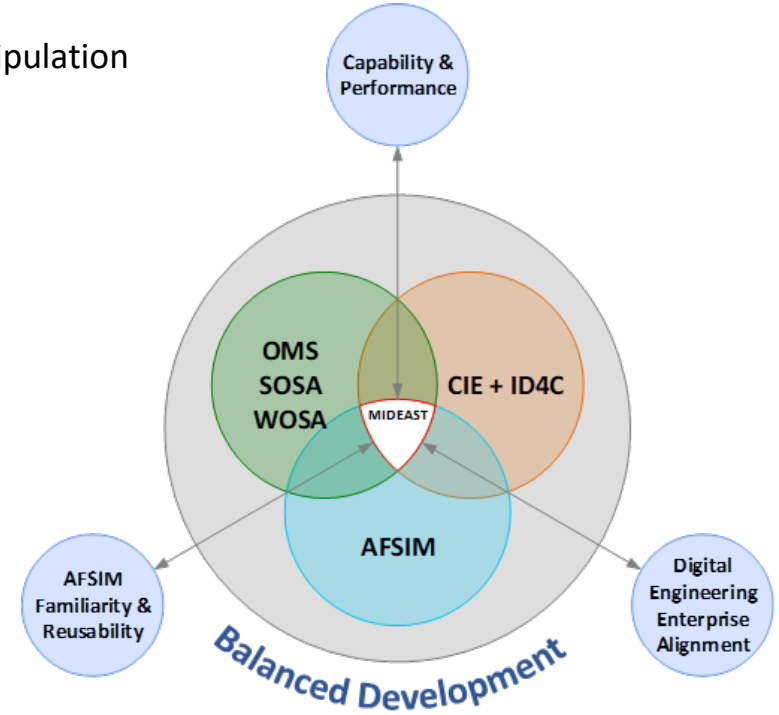
MIDEAST Deliverables and Summary

- Digital Engineering Testbed for Multidomain Information Warfare
  - High Performance Computer
  - Cameo SysML Model
  - AFSIM / USAF OSA-inspired Simulation Framework
    - Signal Pulse Parameter (SPP) EM Environment (physical interactions)
    - Information Discovery, Dissemination, Denial, & Corruption (ID4C) View for effects-based manipulation (virtual interactions)
  - BMC2 Agent Perception Management, Visualization, & Analyses
- Exemplar OSA Subsystem Models
  - Mission Executives
  - Mover Control Systems
  - SOSA
    - Electronic Surveillance Measure (ESM) Receiver
    - Agile Datalink
    - Radar
    - DRFM Jammer
- Representative “Cognitive” Services
  - Basic tactical & platform level BMC2 Agents



- All this, in order to:
  - Rapidly develop and assess all-domain force concepts within theater-level combat scenarios
  - Scrimmage red / blue cognitive BMC2 agents governing advanced IW capabilities
  - Capture architectural requirements for mission-effective all-domain interoperability

Questions?

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  505-284-1678

- MIDEAST uses a slightly modified version of AFSIM v2.8.0

- A pre-release version of MIDEAST can be provided at the sponsor's discretion:

  Major Jason Sutherlin

  jason.sutherlin@us.af.mil

Backup

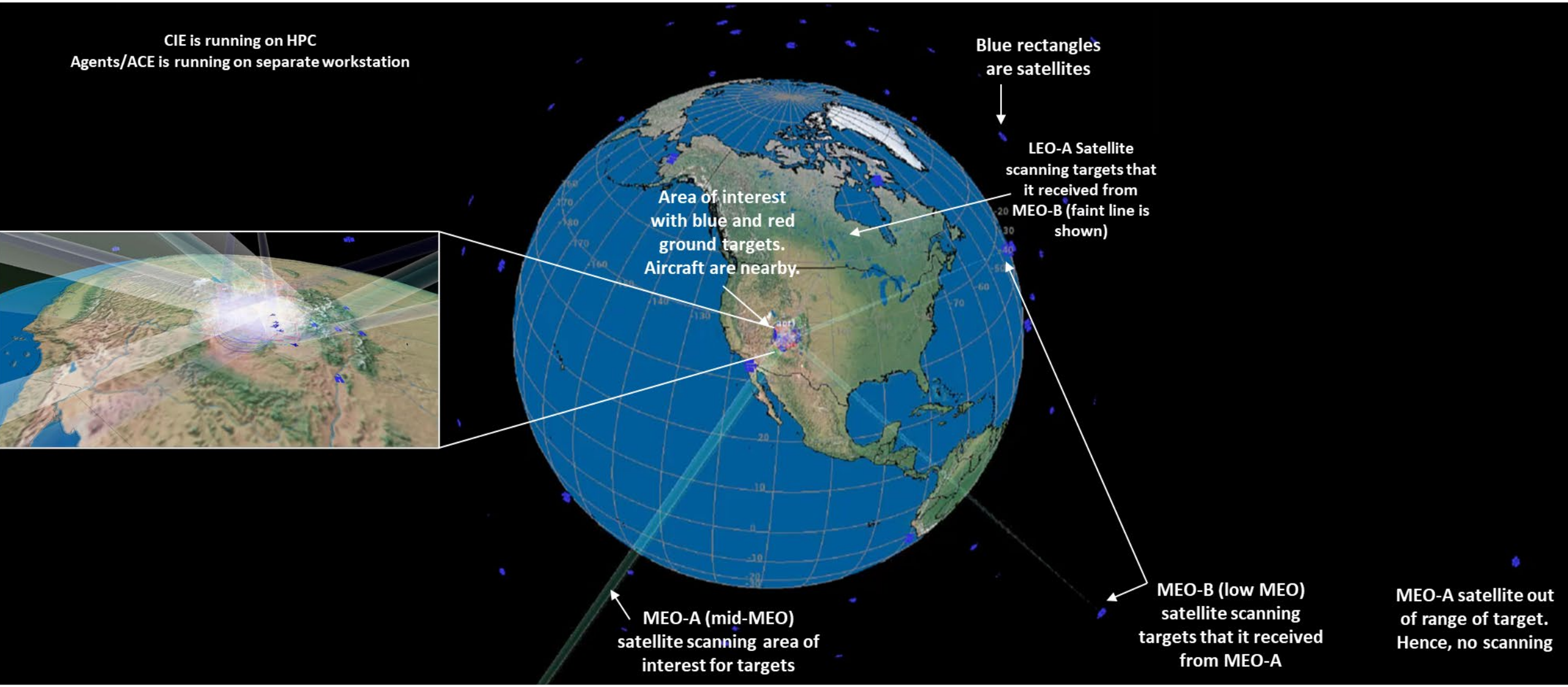
Acronyms

ACE	Agent Cognitive Environment	MBSE	Model-Base Systems Engineering
AFSIM	Advanced Framework for Simulation, Integration & Modeling	MCS	Mover Control System
AOI	Area of Interest	MIDEAST	Meaning is S//NF
AOR	Area of Responsibility	MMT	Model Migration Tool
API	Application Programming Interface	MoM	Message -oriented Middleware
ASB	Abstract Service Bus	MPI	Message Passing Interface
BDD	Block Definition Diagram (SysML)	MSIE	Modeling Simulation Integrated Environment
BIT	Built-In Test	MSTIC	Monitoring Systems & Technology Intern Center
BMC2	Battle Management Command, Control, and Communication	OMS	Open Mission Systems
CAL	Critical Abstraction Layer (in relation to OMS), Calibration	OSA	Open System Architecture
CDM	Common Data Model	RCS	Radar Cross-Section
CENOT	Communications Emitter NOTation	PD	Platform Dynamics
CICD	Continuous Integration, Continuous Deployment	PDW	Pulse Descriptor Word
CIE	Common Interaction Environment	PFI	Pairwise Federate Interaction
CONOPS	Concept of Operations	PRI	Pulse Repetition Interval
CW	Cyber Warfare, Continuous Wave	PNT	Precision Navigation & Timing
CWS	CADAC++ Weapon Simulation	RF	Radio Frequency
DET	Digital Engineering Testbed	SAFE-SiM	Secure Advanced Framework and Environment for Simulation and Modeling
DEVOPS	Development Operations	SCT	Scenario Configuration Tool
DOF	Degrees of Freedom	SEAD	Suppression of Enemy Air Defenses
DRFM	Digital Radio Frequency Memory	SEI	Specific Emitter Identification
EA	Electronic Attack	SHM	Shared Memory
ELINT	ELectronic Intellegence	SiFi	Simulation Framework for Interoperability
ELNOT	ELINT Notation	SIGINT	SIGnals INTelligence
EM	Electromagnetic	SMA	Scenario Management & Analysis
EO	Electro-Optical	SoS	System of Systems
EP	Electronic Protection	SOSA	Sensor Open System Architecture
ESM	Electronic Support Measure	SP	Special Perturbation
EW	Electronic Warfare	SPP	Signal Pulse Parameter
FCS	Flight Control Systems, Fire Control System	TACSIT	Tactical Situation
FED	Federate	TDOA	Time Difference of Arrival
GFI	Government Furnished Information	TEL	Transporter Erector Launcher
GT	Ground Threat	TLE	Two-line Element
HPC	High Performance Computing	UCI	Universal Command & Control Interface
IBD	Internal Block Diagram (SysML)	UID	Unique Identifier
ID4C	Information Discovery, Dissemination, Delay, Denial, & Corruption	VDL	Virtual Data Link
IPT	Integrated Project Team	WOSA	Weapon Open Systems Architecture
LPM	Logical Process Manager	YAML	Yet Another Mark-up Language, YAML Ain't Mark-up Language
M2CS	Multi-Vehicle Mission Control System	ZMQ	Zero MQ

MIDEAST Cameo Model Glossary

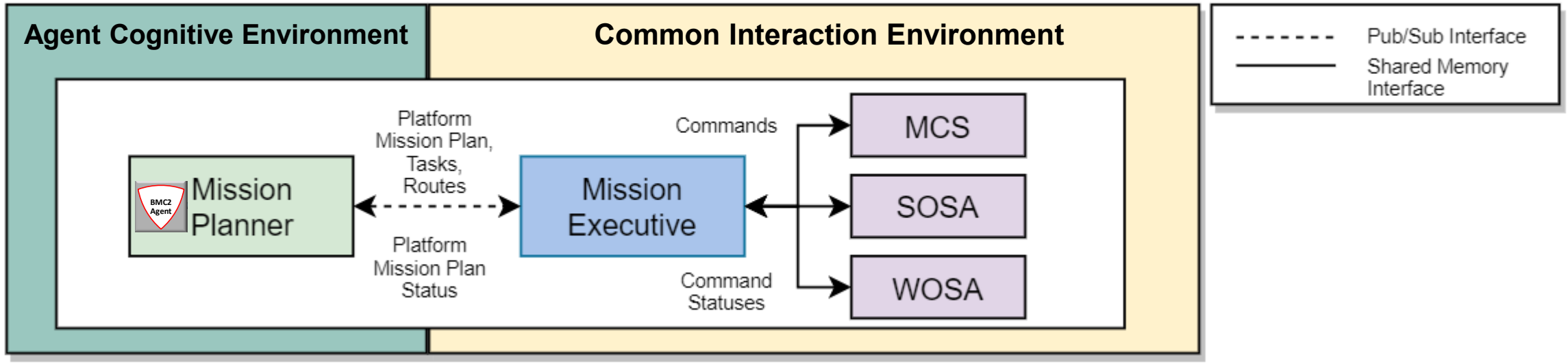
#	△ Term	Description
1	ACE	Agent Cognitive Environment Hosts virtual (effects-based) interactions based on battle manager perceptions & behaviors. Uses the reconfigurable pub/sub [perception data pathway?] network.
2	Antenna	The Antenna (AKA Aperture, AKA Emitter/Collector) module contains antenna definition and capability parameters, and antenna patterns (antenna gain versus azimuth/elevation angles). Antennas convert between freespace Electromagnetic (EM) energy and transmission line EM energy, performing receive functions, transmit functions, or both. This module may include mechanical and electronic steering, beam forming, and focus control.
3	BMC2 Agent	The Agent (process) in the ACE that responds to perceptions and can send/receive task orders to perform functions.
4	CIE	The Common Interactive Environment (CIE) module contains the following processes: Mission Executive, SOSA Payload, PFI, MCS, and Platform Dynamics. The CIE is responsible for data synchronization between all processes operating in the CIE. Data synchronization is implemented through shared memory.
5	Detector	The signal/target Detector module contains signal processing and detector definition and capability parameters, and behavior. It is responsible for simulating detection of EM signals or physical objects among the noise and other signals and objects in the environment (e.g., clutter or interference). This module extracts a detected signal, detected object, or image chip for downstream processing. Techniques to perform this may include clutter suppression and extraction of scintillation/de-correlation information, interference suppression, the use of constant false alarm rate techniques, coherent and non-coherent integration, Space-Time Adaptive Processing (STAP), image enhancement (including edge detection and sharpening), and employment of gating logic to manage and balance search volume returns with existing object tracks.
6	Digital Engineering Testbed	Full simulation testbed consisting of the Scenario Management and Analysis (SMA) component, the Agent Cognitive Environment (ACE) component and Common Interaction Environment (CIE) component.
7	Federate	A Federate is a grouping of platforms (AKA systems) participating in a collective parallelized simulation. Each federate grouping is assigned parallel computing resources relative to each other, and interactions between federates are handled by a Pairwise Federate Interaction (PFI) simulation service that is instantiated for each pair of federates, plus an instantiation to handle platform interactions within each individual Federate.
8	LPM	The Logical Process Manager is used to launch the processes in the CIE; in addition, the LPM configures processes on the High Performance Computer (HPC).
9	Mission Executive	Mission Executive gets instructions from Mission Planner. Mission Executive begins to execute the plan to complete the mission. Tasking is dynamic, depending on events. Sends info. back to BMC3 agent (OMS Mission Planner).
10	Mission Plan Sequencer	The Mission Plan Sequencer is responsible for ingesting multiple mission plans for the satellites and/or aircraft and producing a single current Mission Plan for the Mission Executive.
11	Model Migration Tool	The Model Migration Tool (MMT) is responsible for migrating/converting AFSIM Sensor/Datalink/EW models to/from the MIDEAST SOSA Library format. For Sprint 1, it must only migrate an Electronic Support Measure (ESM) receive-only sensor models from native AFSIM to the MIDEAST SOSA library for use in a scenario.
12	Mover Control System	Mover Control System (MCS) The MCS is a perception-based self-directing platform mover control subsystem. It provides flight/spacecraft/vehicle motion control by utilizing the current platform state estimate and desired position/velocity/orientation motion or waypoints/end-points to determine how the platform will move in each simulation frame step.
13	PFI	Pairwise Federate Interaction The PFI is a truth-based simulation service that handles signal propagation and weapon detonation truth. The PFI takes emitter Signal Pulse Parameters and Platform State, and determines the incident Signal Pulse Parameters at each relevant Platform. For weapon interactions, the PFI will exchange weapon detonation truth between the weapon system and potentially affected Platforms models/subsystems. There is one PFI between each pair of Federates, as well as an" internal" PFI dedicated to each Federate to handle interactions among Platforms within each Federate.
14	Platform Dynamics	Platform Dynamics is responsible for modeling the physics of how the platforms within a given Federate move through space and propels itself (position, velocity, acceleration (thrust, gravity, etc.), orientation, aerodynamics, etc. It is not a physical subsystem but models platform state truth.
15	Receiver	The Receiver module contains receiver definition and capability parameters, and behavior. It is responsible for simulating receive task execution. Receive tasking may include receive calibration, channelization, image formation, tagging with metadata, data framing, and data cube formation. The signal may be amplified, filtered, frequency translated, distributed, and signal domain converted – Analog to Digital Conversion (ADC) and Digital to Analog Conversion (DAC).
16	SCT	Scenario Configuration Tool configures federates & platforms sensors, weapons, etc. for the simulation run
17	SMA	Scenario Management & Analytics the umbrella application that hosts a suite of tools to manage and view scenarios (currently, for Sprint 1, the tools include the SCT – Scenario Configuration Tool, WorldView, BMC2 View, Analysis View, and the Common Data Model)
18	SOSA Payload	Sensor Open System Architecture A SOSA Payload is the sensor, datalink, illuminator, and/or electronic warfare subsystem (potentially multi-function). In Sprint-1 it can possess radio frequency (RF) antennas, transmitters, receivers, and detector modules (components), which are combined to make up the complete payload/subsystem.
19	Transmitter	The Transmitter (AKA Exciter) module contains transmitter definition and capability parameters, and behavior. It is responsible for simulating transmit task execution. Transmit tasking may include waveform generation, transmit calibration, and adaptation to spectrum use. The signal may be amplified, filtered, frequency translated, distributed, and signal domain converted – Analog to Digital Conversion (ADC) and Digital to Analog Conversion (DAC).
20	WorldView	The view within the SMA that displays states and events on a globe that occur within the CIE.

Sprint-2 Demonstration Scenario Results

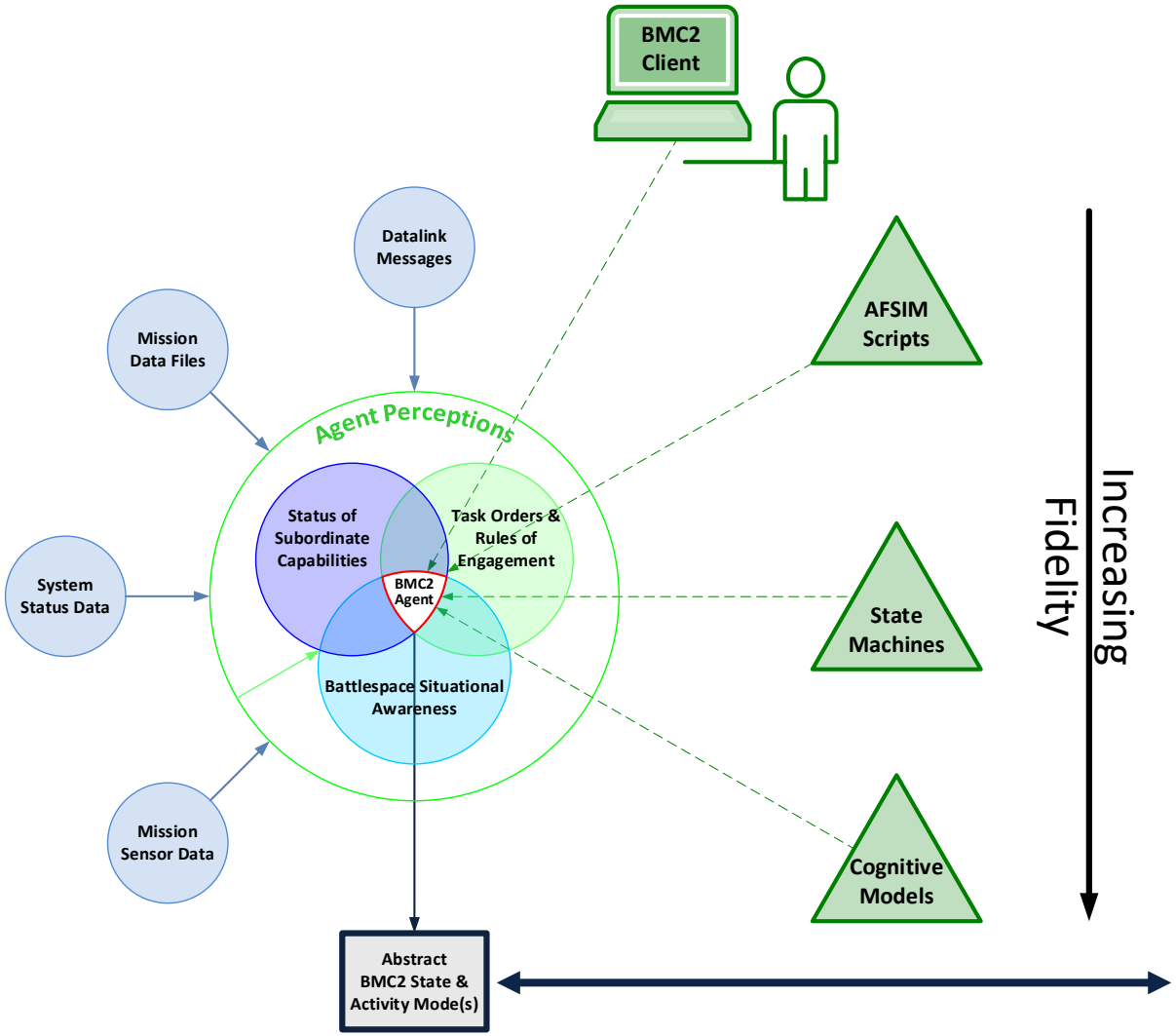


Mission Management via Mission Planner & Mission Executive

- Within MIDEAST, Mission Management was split up between two components:
  - Agent / Mission Planner:
    - Longer term cognition and planning based on overall goals/objectives
    - Done at the strategic, tactical, or operational/platform level
  - Mission Executive:
    - Shorter term planning, management, and execution
    - Responsible for refining, orchestrating, and delegating Tasks and Routes received from the Agent / Mission Planner to subordinates and platform subsystems



Standardization of BMC2 Agent Perceptions, States, and Commands



Agent State	Activity Mode	Example Activities
Idle	communicating	transmit status & receive task orders
	mission planning	route optimization
mission execution	communicating	service datalinks, report tracks & battle damage
	mission planning	sensor collect planning, weapon selection
	moving	move from standoff location to killbox
	surveilling	track while scan killbox
	targeting	geolocate & track targets and select weapons
	engaging	launch weapon & provide IFTU
	assessing	target battle damage assessment post engagement
mission suspend / abort	communicating	report pop-up threat detection(s)
	mission planning	survivability autorouting
	moving	move from killbox to standoff location
	suspending	terminate active sensing due to threat detection
	evading	maneuver to get out of surface to air missile (SAM) engagement zone
system / capability recovery	communicating	report capability status
	mission planning	optimize attitude to collect solar energy & radiate waste heat
	moving	change attitude with respect to sun or rendezvous with tanker
	refueling	collect solar energy or fuel from tanker
	rearming	charge DE battery magazine, rearm aircraft weapons
	manage thermal	radiate waste heat into space

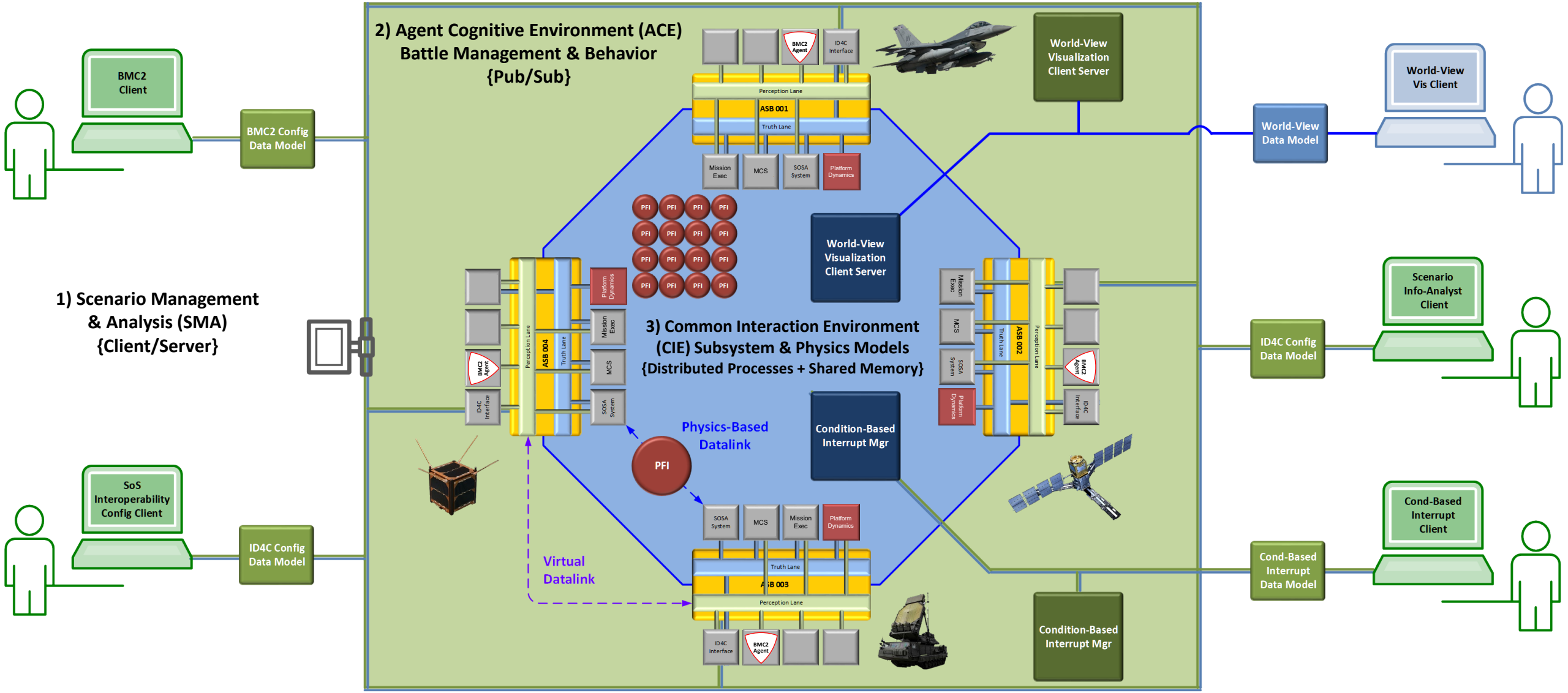
capability status
fully operational
temporarily degraded
permanently damaged
exhausted
expired / killed

Simplify control, visualization & assessment of battlespace using a finite number of abstract BMC2 agent states, modes & status

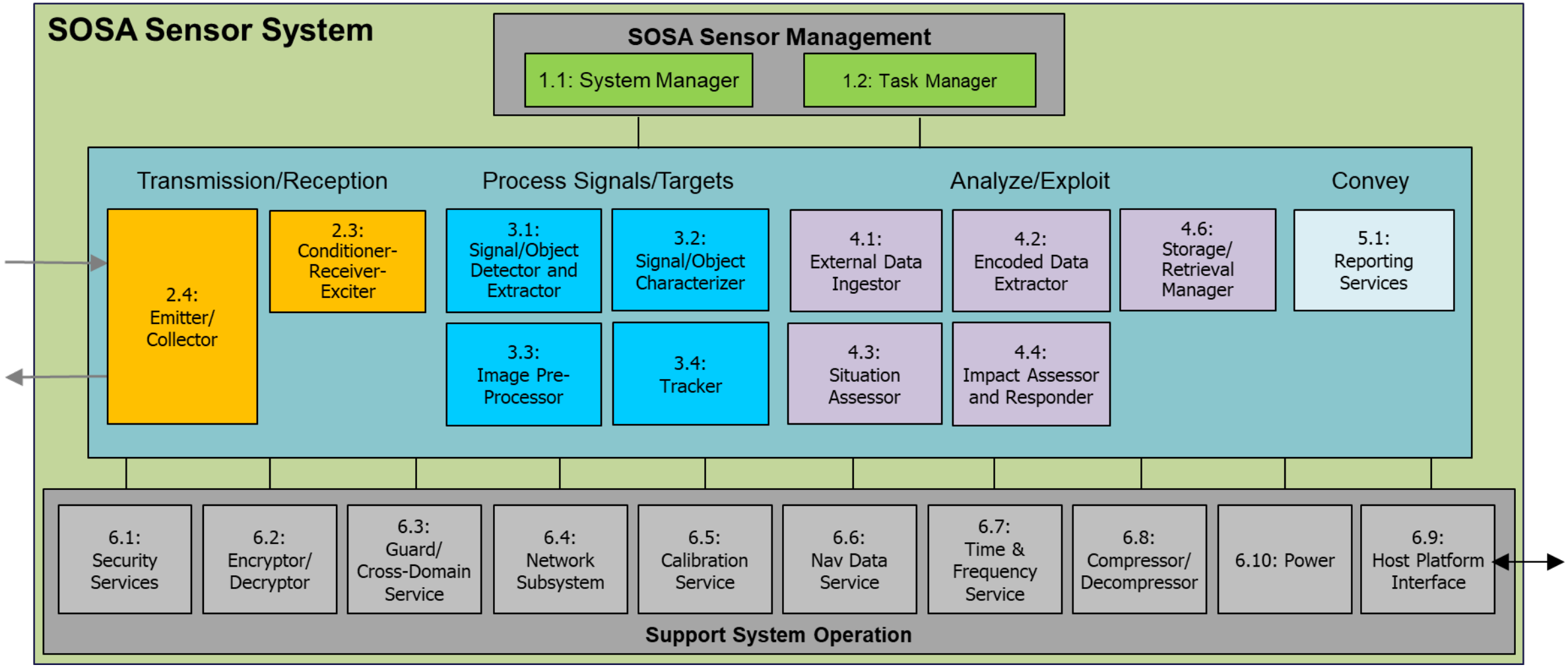
Abstract Agent Interface

- Provide Agent processes running internal or external to MIDEAST a generalized ability to:
  - Get simulation data
  - Perform custom processing (decision making, etc.)
  - Inject data / commands into the rest of the simulation
- Developing support of 3rd party processes through interface and API
  - The GOAL: Low cost to entry for interfacing existing codes with the MIDEAST simulation environment
- Previously Demonstrated Capability
  - Satellite taskers and Aircraft routers determine tasking for their platforms based on perceived tracks and platform states
- Current Development
  - Find and demonstrate interface with a 3rd party model developed outside of the MIDEAST project

MIDEAST Digital Engineering Testbed Architecture Overview



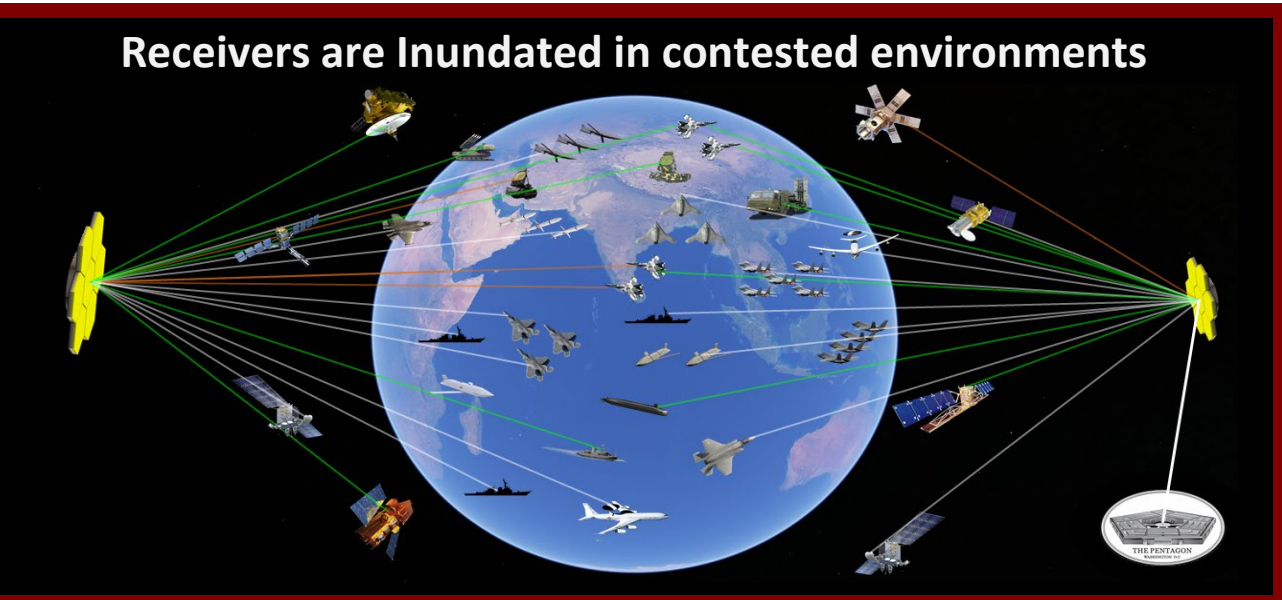
Sensor Open Systems Architecture Modules



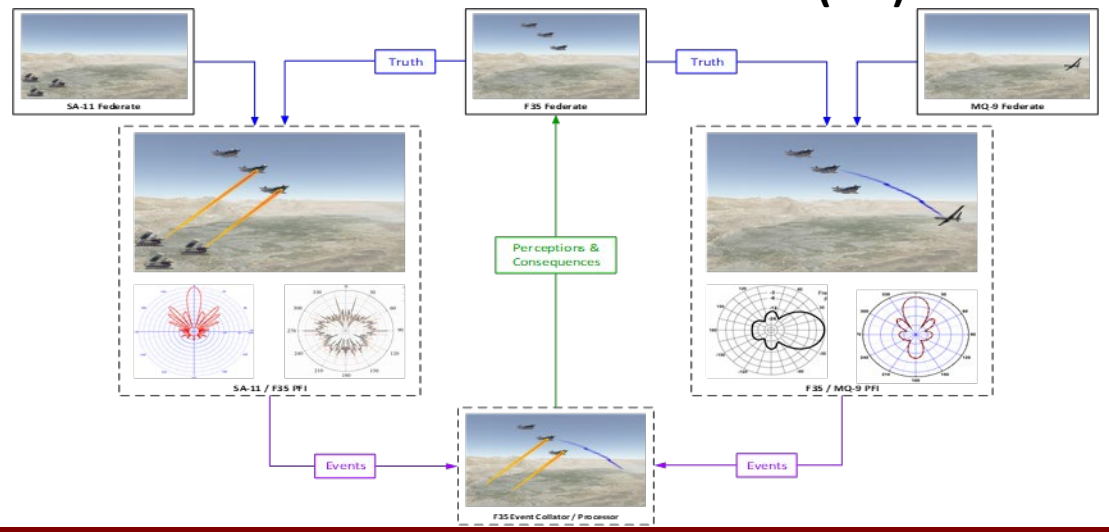
MIDEAST is developing exemplars for the minimum set of SOSA Models & Services required for DET operation

AFSIM-HPC Framework Distributes Processing of Interactions

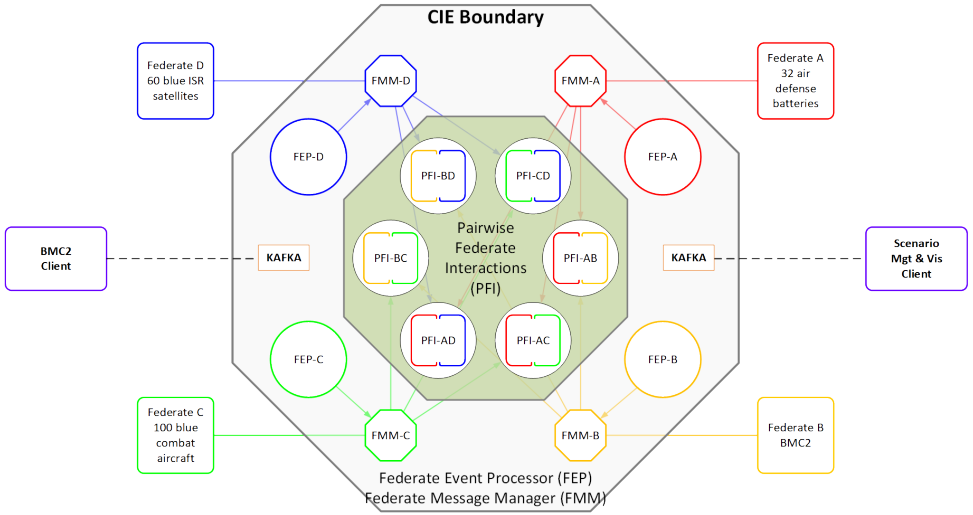
Receivers are Inundated in contested environments



Pairwise Federate Interaction (PFI)



Common Interaction Environment (CIE)



Simulation Architecture Optimized for Speed & Scalability