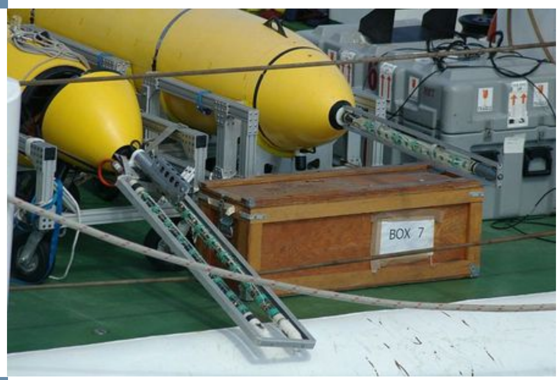
Physics-based Simulation Environment for Adaptive and Collaborative Marine Sensing with MOOS-IvP

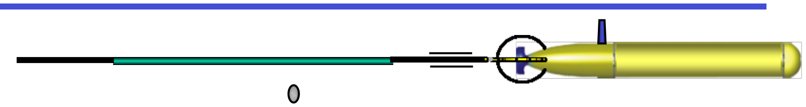


Prof. Henrik Schmidt

Laboratory for Autonomous Marine Sensing Systems
Massachusetts Institute of technology
617-253-5727
henrik@mit.edu

http://lamss.mit.edu

MOOS-DAWG'11
July 19-20, 2011

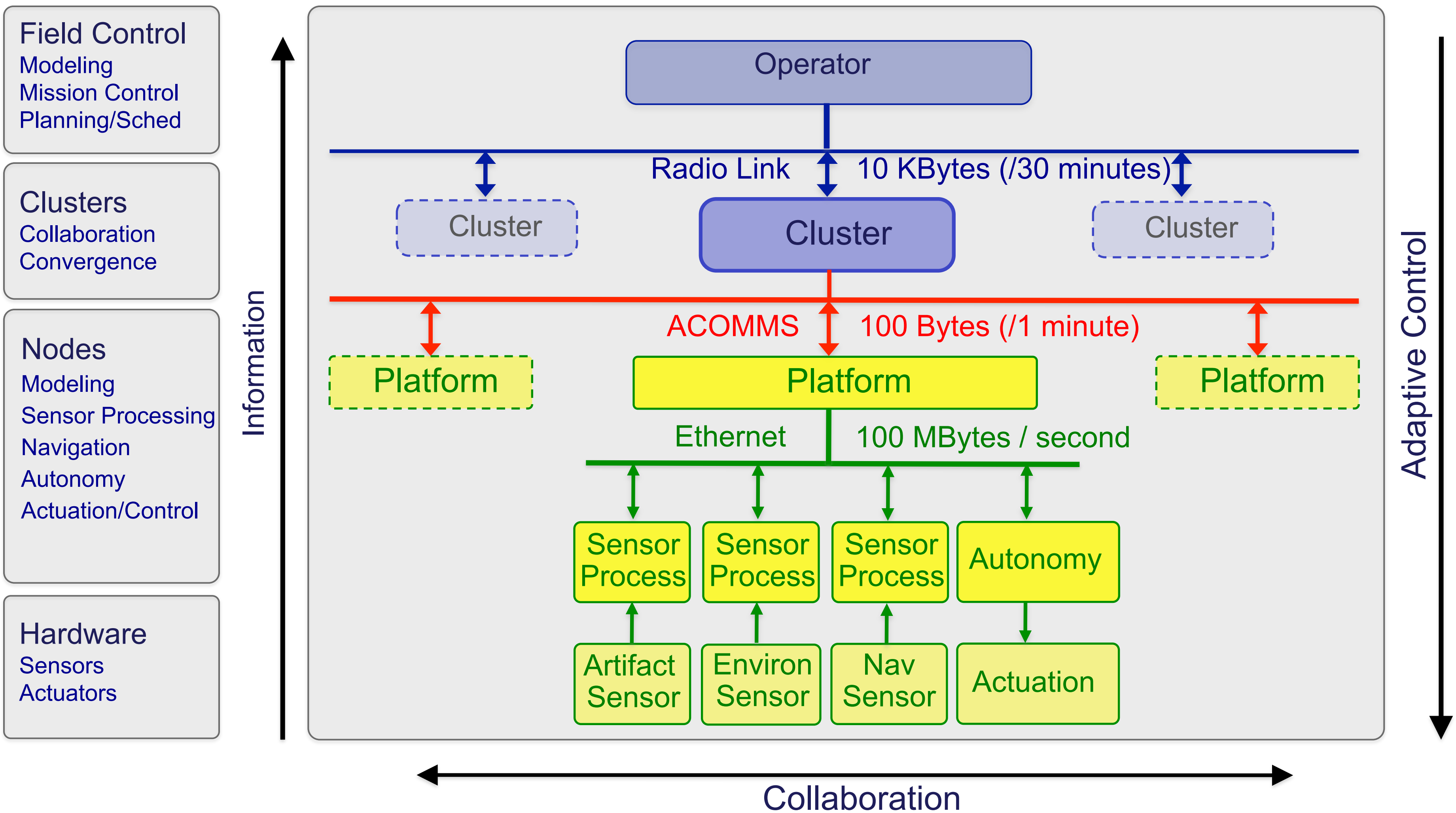


Outline

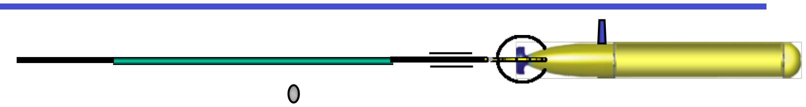
- The Nested Autonomy Paradigm
- Simulation environment – motivation and approach
- Distributed, adaptive and collaborative acoustic sensing
    - MOOS-IvP Payload Autonomy
    - Virtual communication network
    - Virtual acoustic sensing environment
    - HWITL MOOS-IvP acoustic sensing node simulator
    - LAMSS hybrid at-sea/virtual undersea network environment
    - Application examples

Massachusetts Institute of Technology

Undersea Distributed Sensing Networks Communication Infrastructure

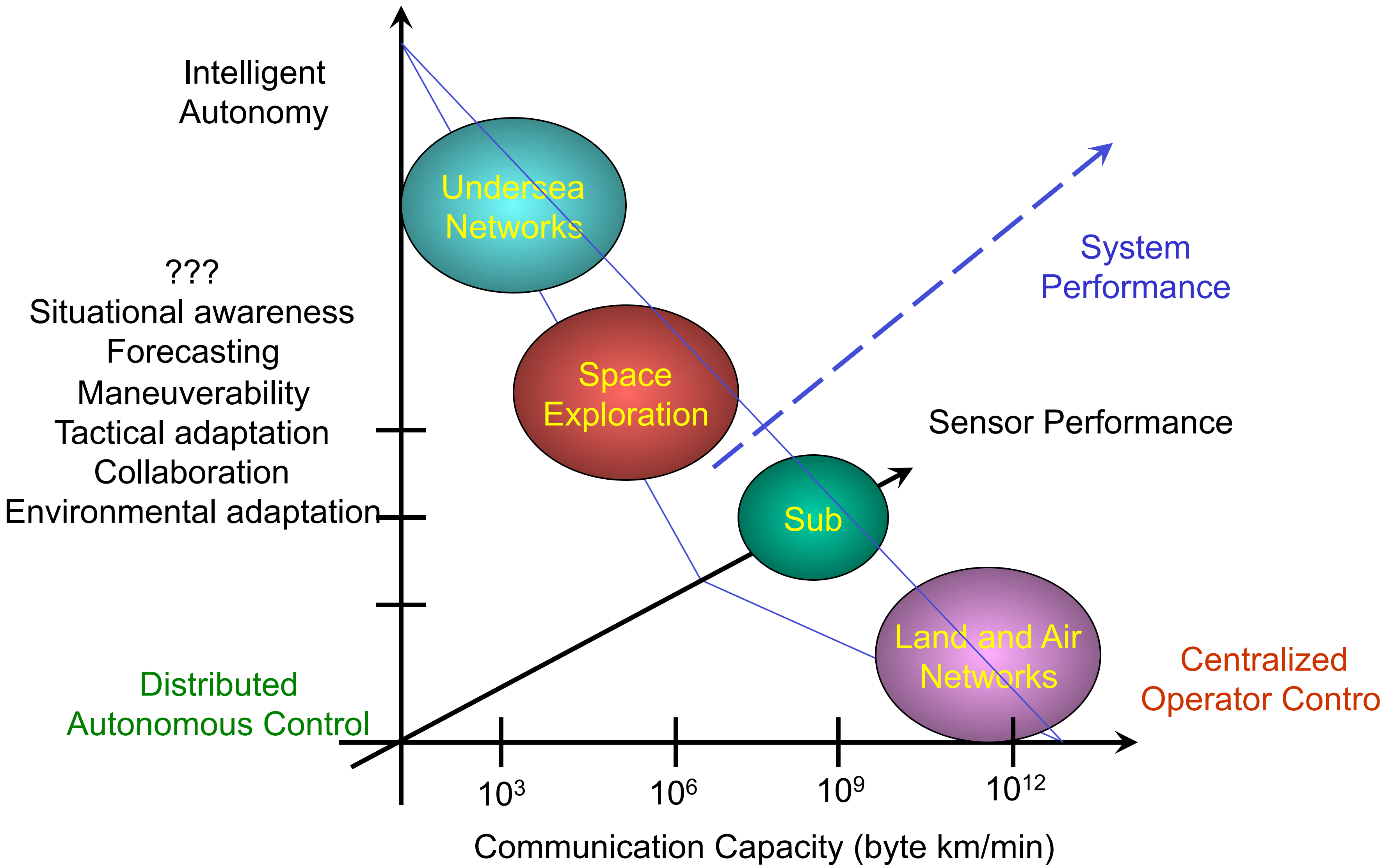


MIT Laboratory for
Autonomous Marine Sensing

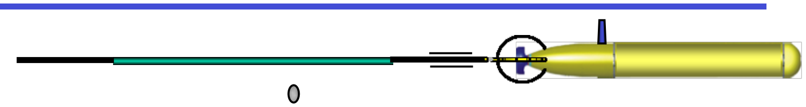


Massachusetts Institute of Technology

Networked Sensing Trade Space



MIT Laboratory for
Autonomous Marine Sensing



Massachusetts Institute of Technology

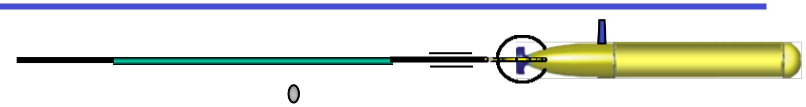
What is Intelligent Autonomy?

Integrated Sensing, Modeling and Control

Automated processing of sensor data for detection, classification and localization of tactical or environmental event

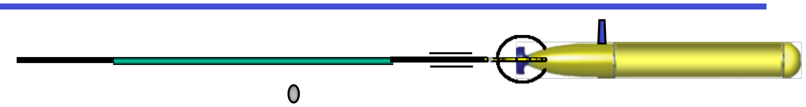
Data-driven modeling for forecasting of tactical and environmental situation

Intelligent decision-making based on situational awareness, adaptive and collaborative strategies (behaviors), and learning, to adapt to forecast for enhanced performance



Nested Autonomy
Command and Control Architecture

- Network Command and Control
  - Managed through communication gateways via RF above sea level and acoustic communication (ACOMMS) underwater
  - The underwater ACOMMS connectivity organized through a slotted MAC scheme with self discovery and organization
- Clusters
  - Autonomous platforms and acoustic gateways with current ACOMMs connectivity will self-organize through distributed control into clusters exploiting collaborative behaviors for improved sensing performance
  - Dynamic clustering topology depending on current ACOMMS connectivity
- Platforms
  - Each platform must be capable of completing mission objectives in absence of communication connectivity
  - Each platform will broadcast status reports at regular intervals in the communication slot assigned by its current cluster



Massachusetts Institute of Technology

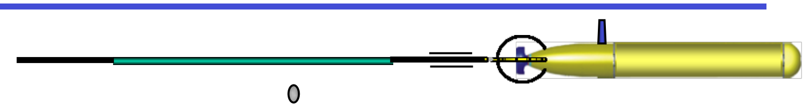
MOOS-IvP
Nested Autonomy Network Simulator

Motivation

- Testbed for autonomy system development
  - Mission management processes
  - Sensor processing
  - IvP behaviors
  - Adaptive and collaborative autonomy
- Complex autonomy architecture requires extensive pre-deployment testing
- At-sea testing expensive
- Opportunity too sparse - ~1% of testing required

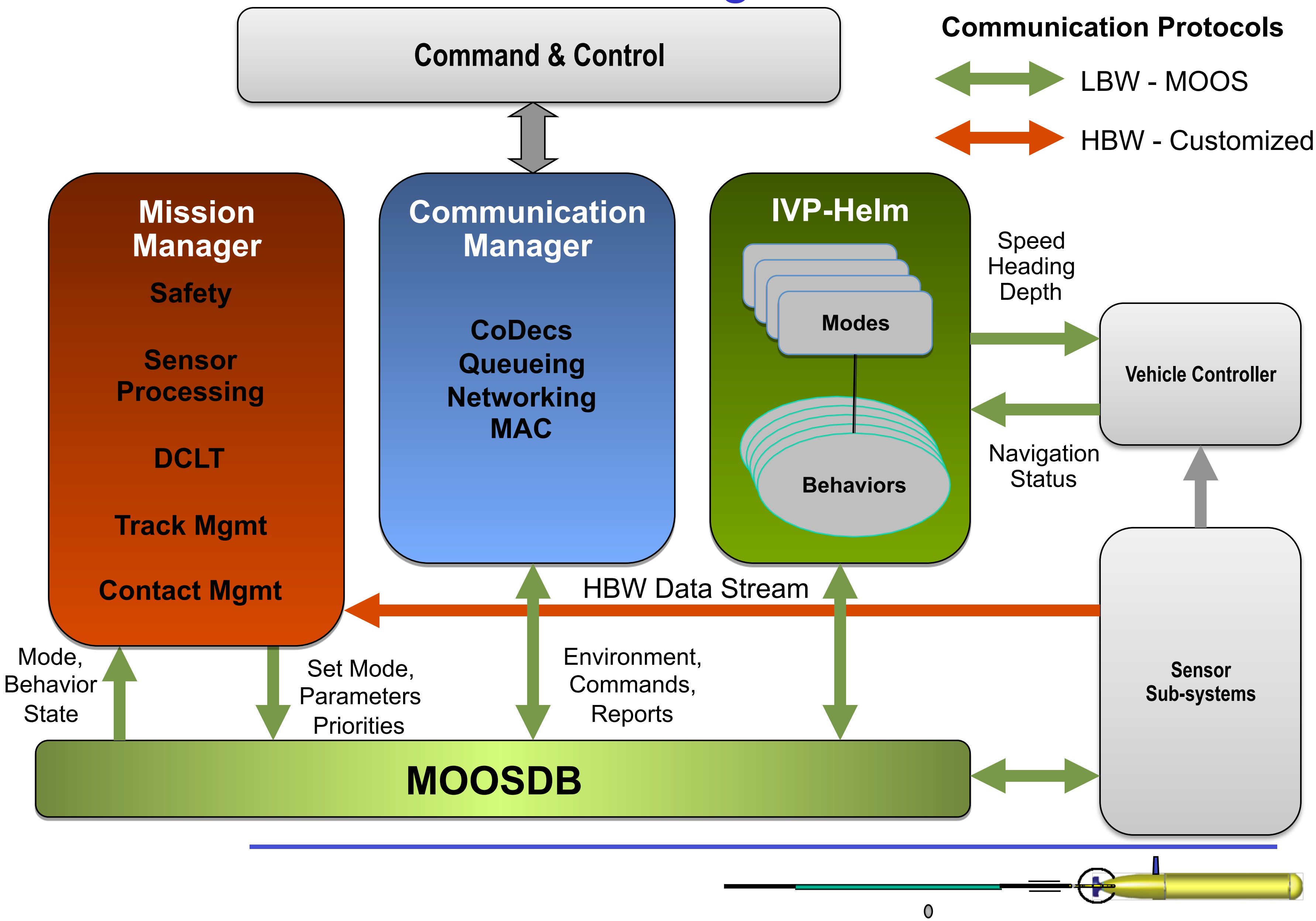
Approach

- MOOS-IvP Payload Autonomy system identically configured for real and virtual vehicles
- 'Transparency' to MOOS-IvP autonomy whether operating on real or virtual platform
- High-fidelity, physics-based simulation of 'connections to rest of the world'
  - 'Frontseat driver' control and navigation
  - Communication networking
  - Mission sensors
- Simulators ideally operated in separate communities with interfaces identical to at-sea systems. At minimum MOOSDB interface identical.

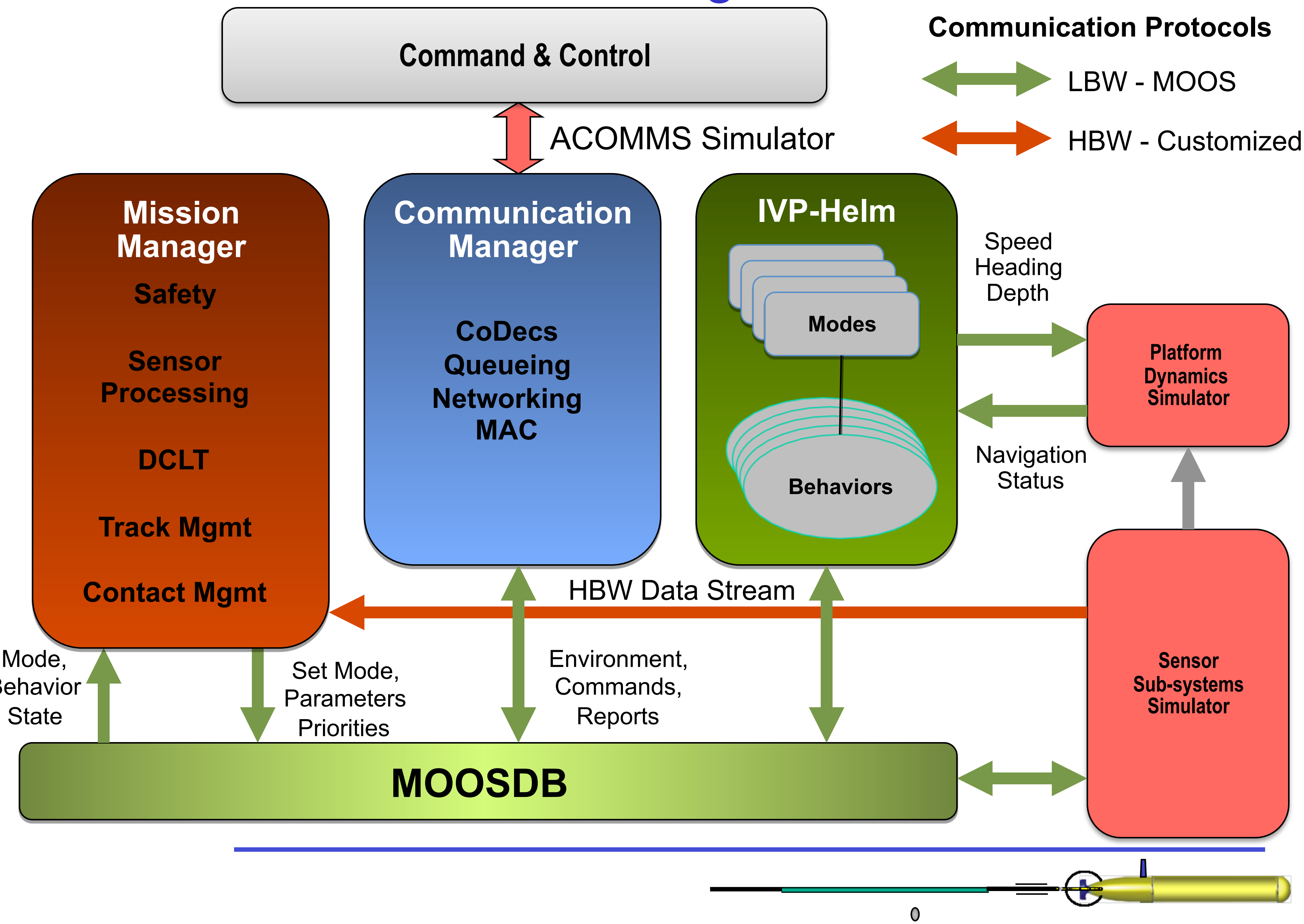


Massachusetts Institute of Technology

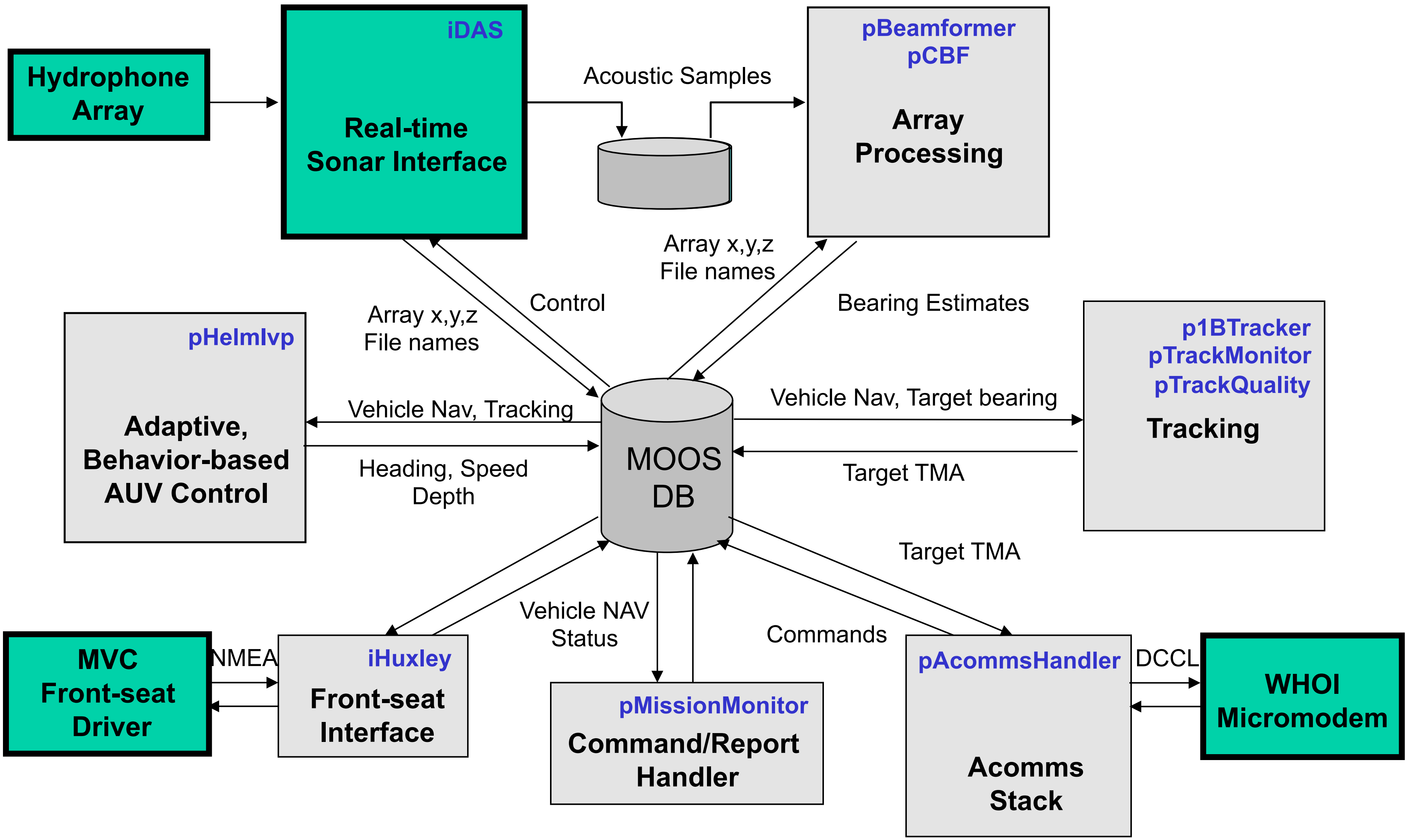
MOOS-IvP Payload Autonomy
At-sea Sensing Platform

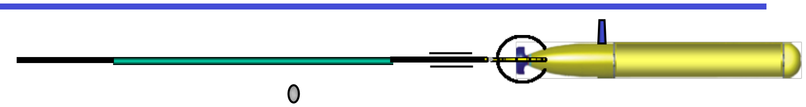


MOOS-IvP Payload Autonomy Virtual Sensing Platform

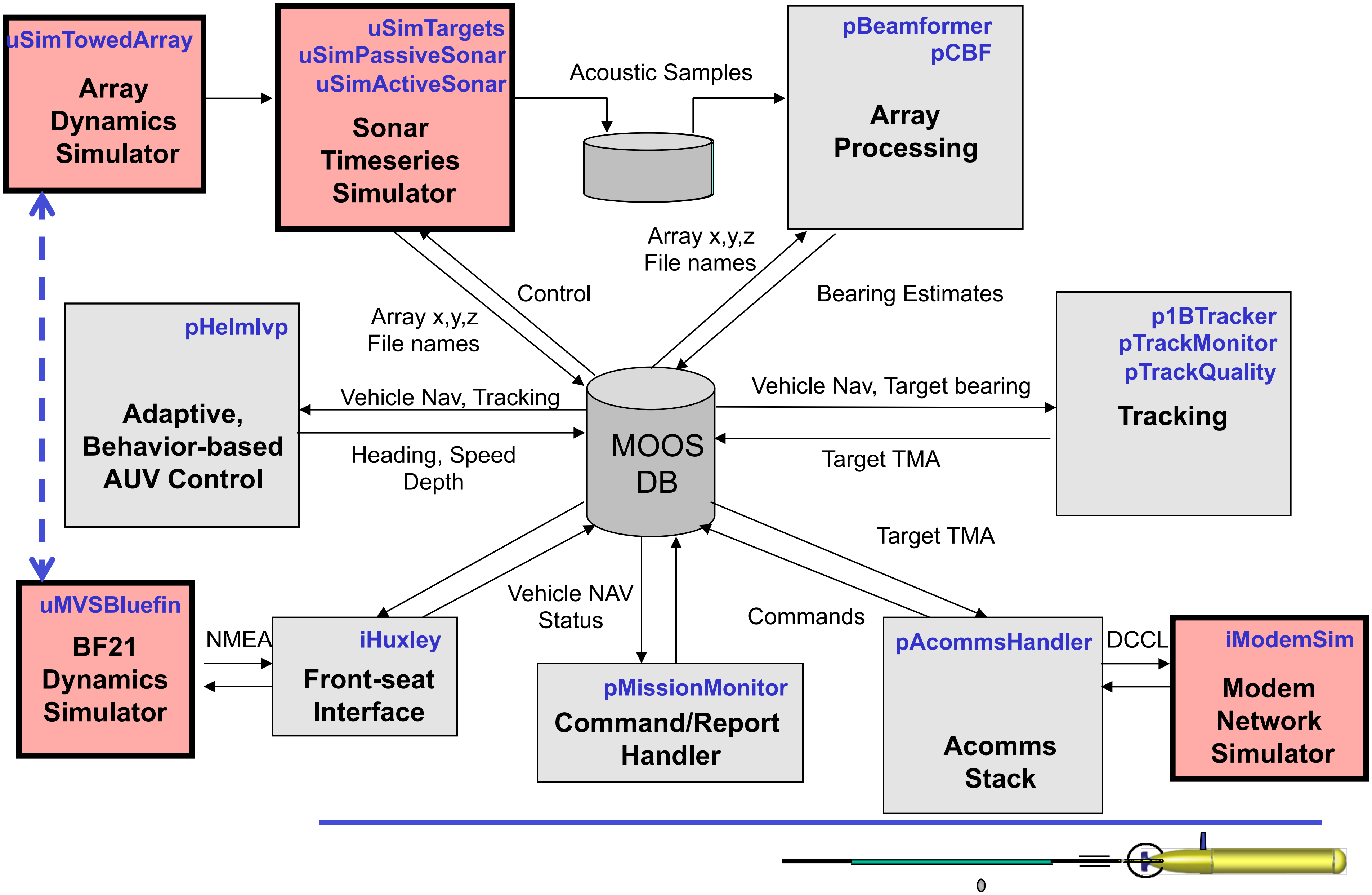


MIT-LAMSS
Acoustic Sensing Autonomy System





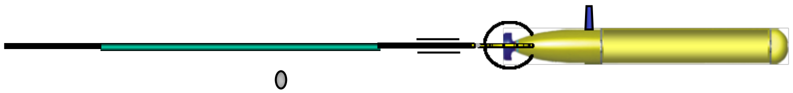
MIT-LAMSS
Virtual Acoustic Sensing Autonomy System



Massachusetts
Institute of
Technology

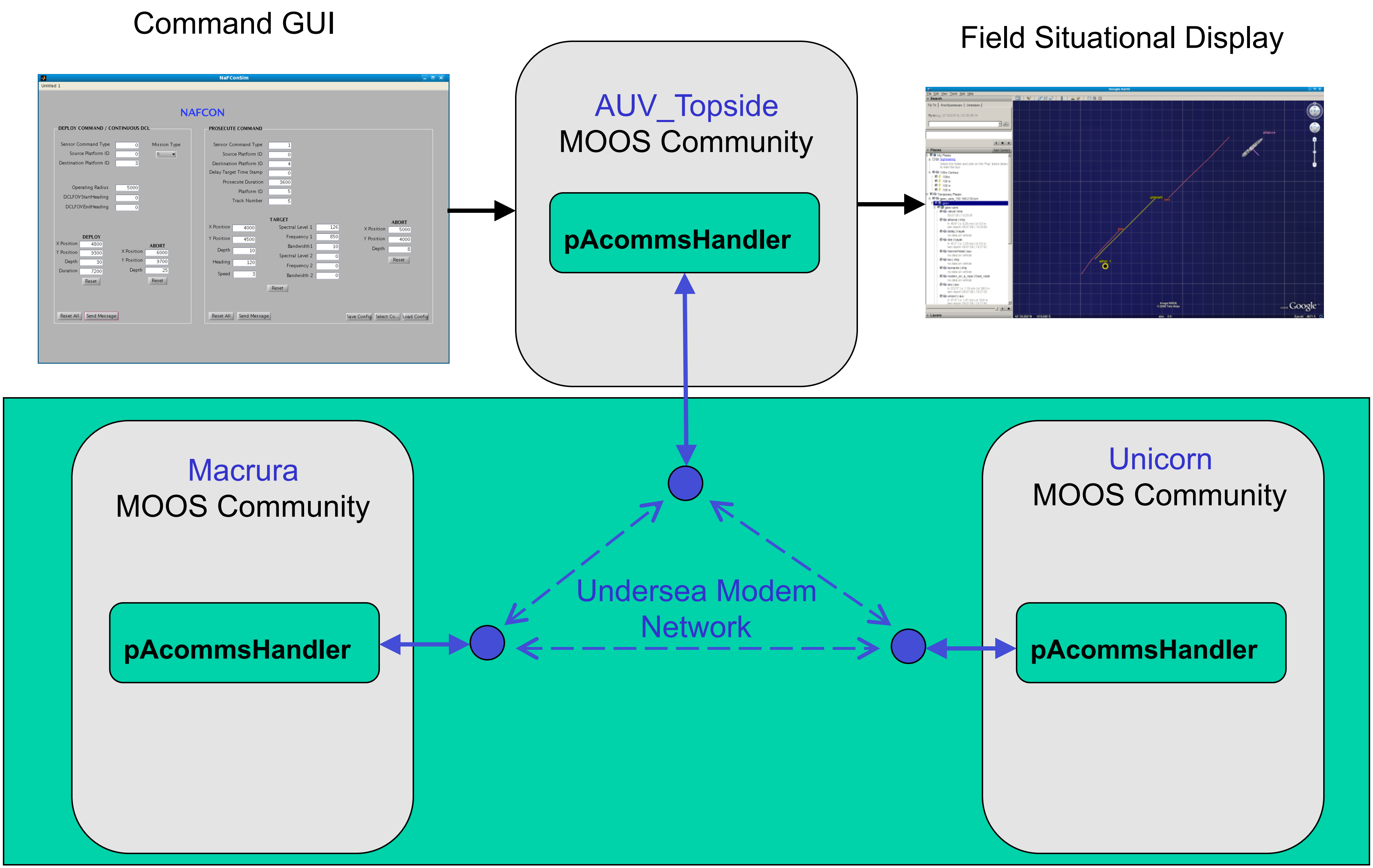
MOOS-IvP
Acoustic Sensing Simulator Modules

- ‘Frontseat simulation
  - uSimMarine: generic platform dynamics simulator
  - uMVSBluefin: HiFi platform dynamics of BF21
  - iChauffeur: New generic interface to MVC or separate frontseat simulator
- Communication networking
  - iModemSim: Virtual underwater modem network
- Navigation
  - pSimLBL: Long-baseline navigation system simulator
  - uSimGPS: GPS simulator
- Environment simulators
  - uSimBathy: Bathymetry simulator
  - uSimCTD: CTD sensor simulator
  - iMseas: Interface to CTD data from MSEAS circulation models
  - iMseasbathy: Interface to bathymetry data from MSEAS
- Environmental acoustic simulators
  - uSimtargets: Dynamics of arbitrary number of acoustic targets
  - uSimTowedarray: Physics-based towed array dynamics model
  - uSimPassiveSonar: Passive sonar simulator
  - uSimActiveSonar: Active sonar simulator
  - iBellhop: interface to embedded Bellhop acoustic propagation model
  - uSimTargetBearings: Low-fidelity target bearing simulator (ground truth with noise)

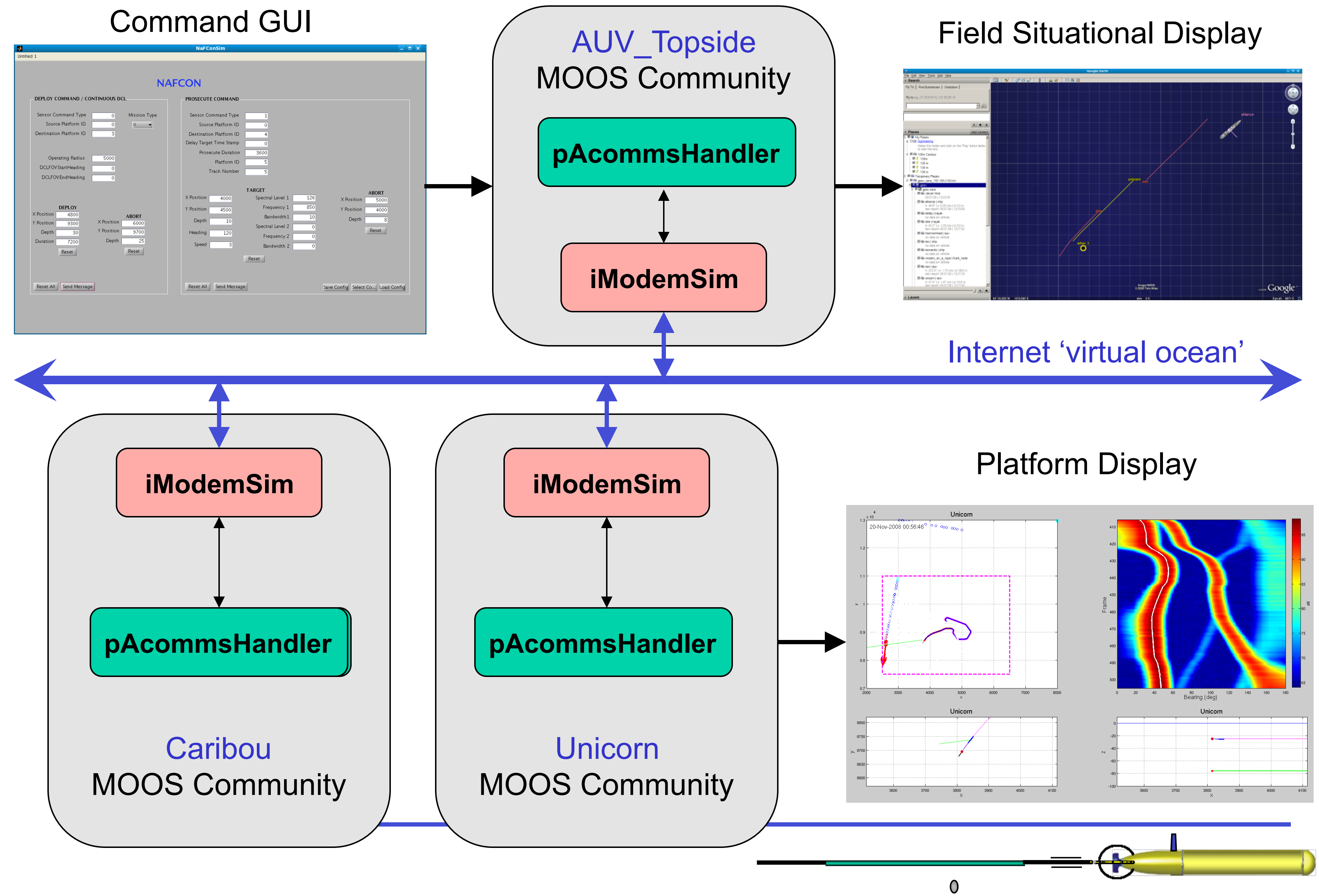


Massachusetts Institute of Technology

MIT-LAMSS
Undersea Communication Infrastructure

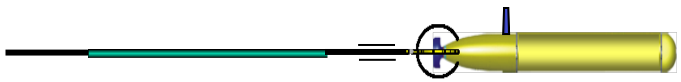


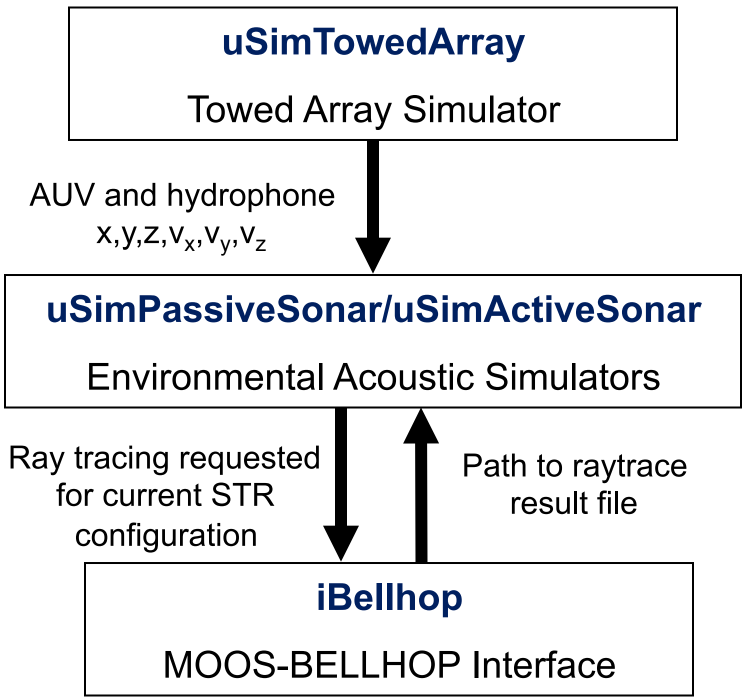
MIT-LAMSS
Virtual Communication Infrastructure



MIT-LAMSS
Passive Acoustic Sensor Simulator

Massachusetts Institute of Technology



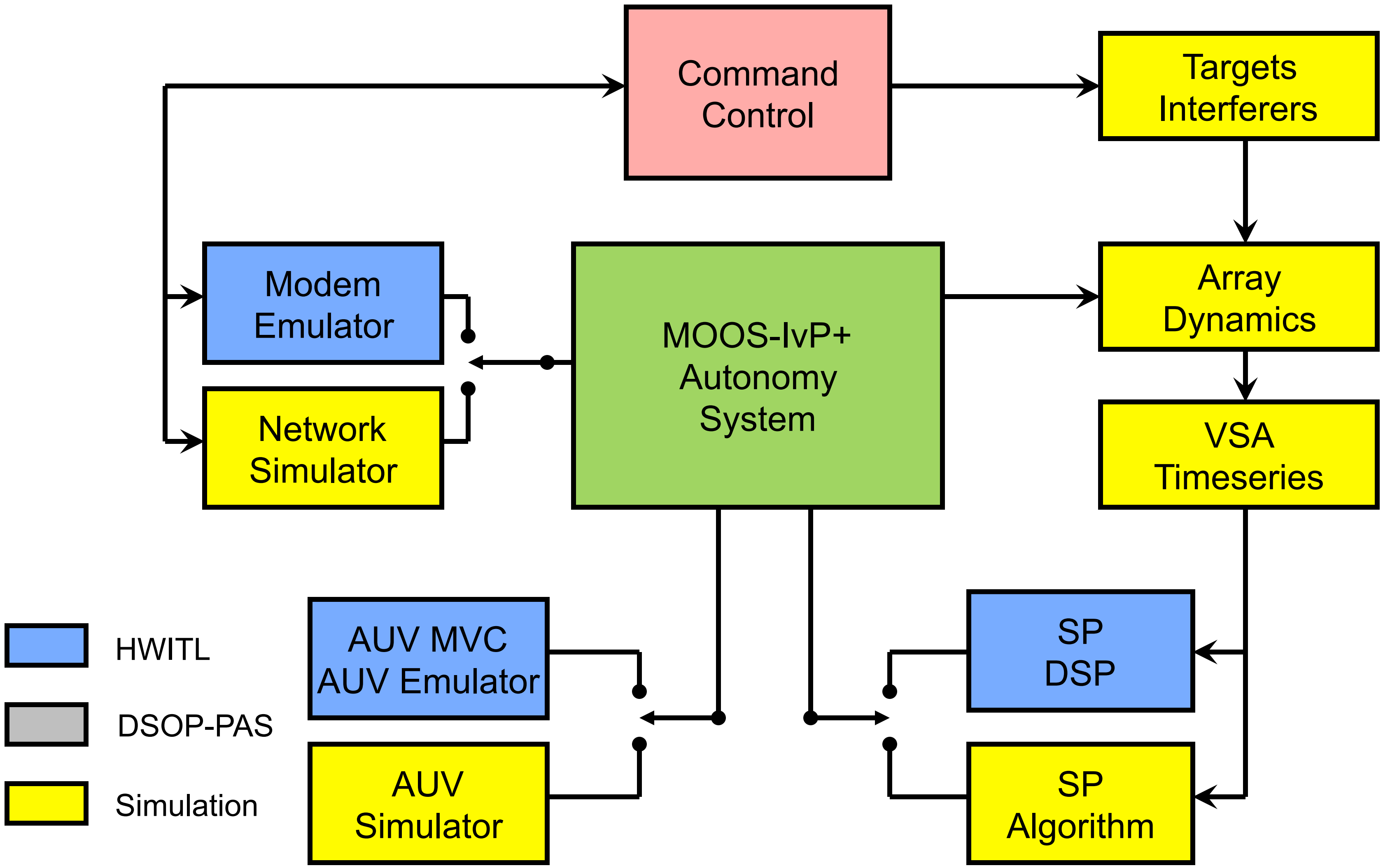


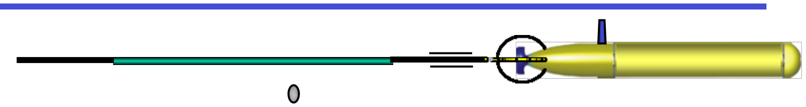
MIT-LAMSS
MOOS-Embedded Environmental Acoustic Simulator

1. Environmental data in mission configuration dynamically fused with in-situ CTD data
2. Handles dynamically changing number and configuration of sources, targets and receivers.
3. Inherent local plane wave expansion allows efficient adaptation to situational dynamics
4. Consistent simulation of all onboard acoustic systems
5. Unified MOOS process iBellhop provides standardized interface to legacy raytracing code BELLHOP.
   - Request eigenray travel time, intensity and phase
     - iBellhop automatically handles environmental updates
     - Current source/target/receiver configuration
     - Frequency band, beam width etc.
   - Returned results used to compute active or passive time-series, written to data file

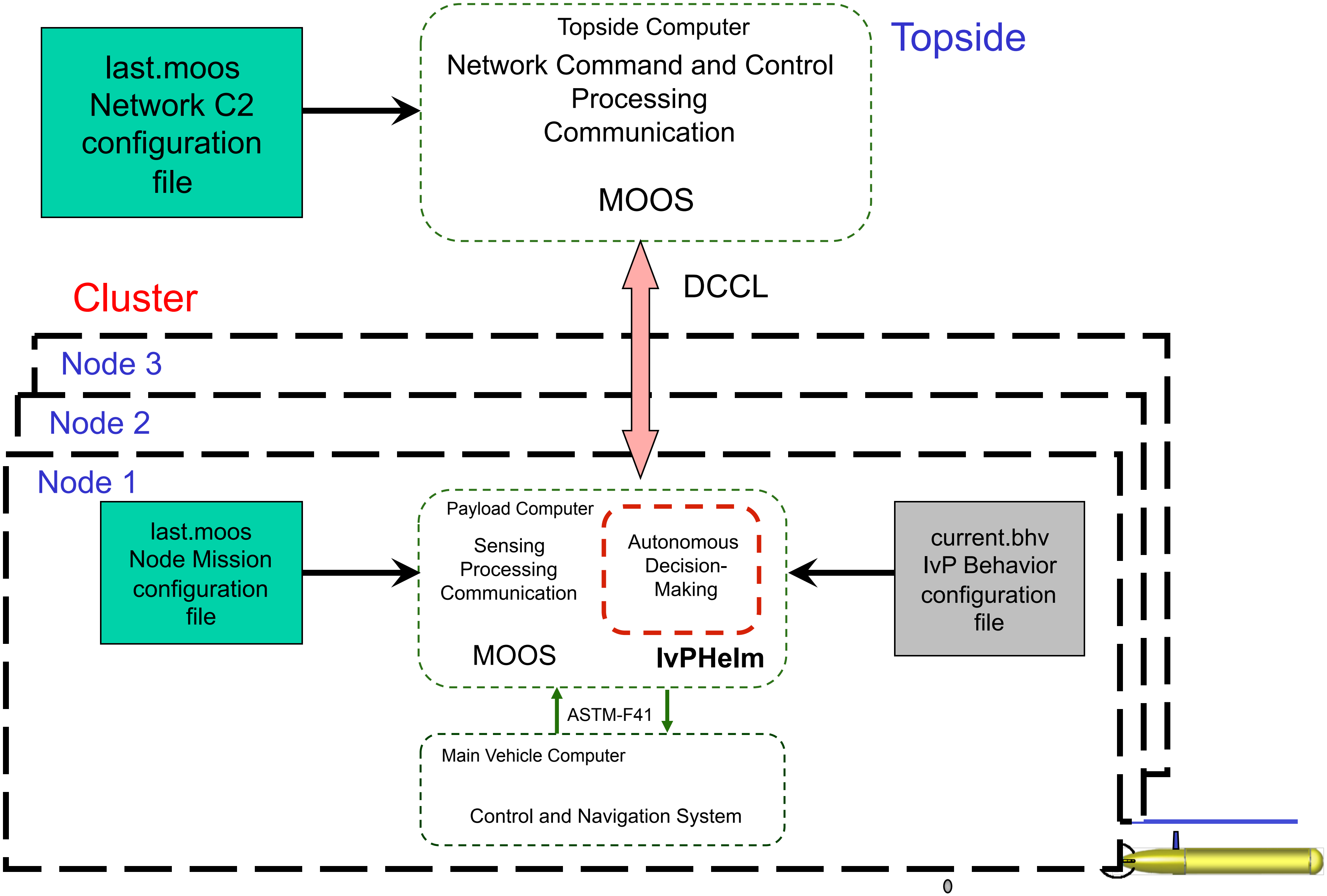
Massachusetts Institute of Technology

MIT-LAMSS
Hybrid HWITL Acoustic Sensing Node Simulator

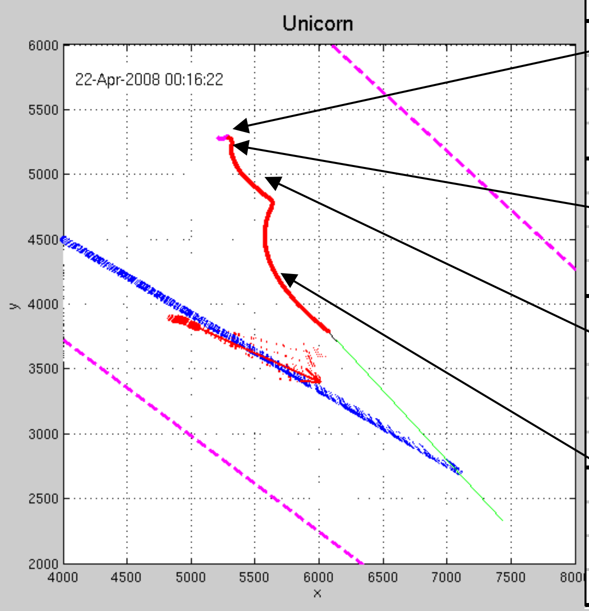




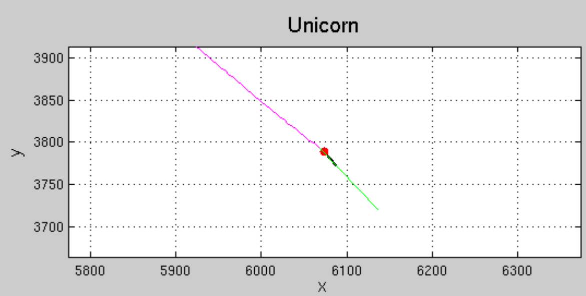
MOOS-IvP
At-sea/Virtual Undersea Network Architecture

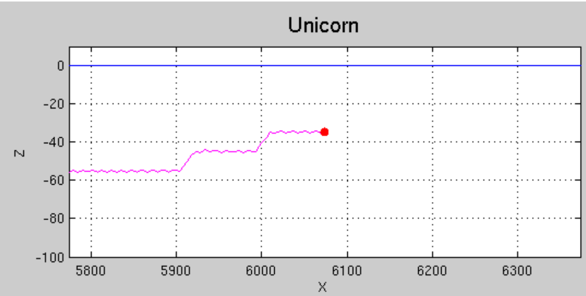


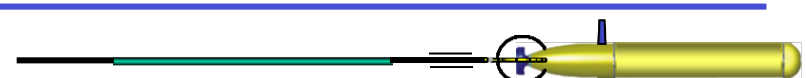
MIT Acoustic Network Simulator
Adaptive DCLT Target Prosecute



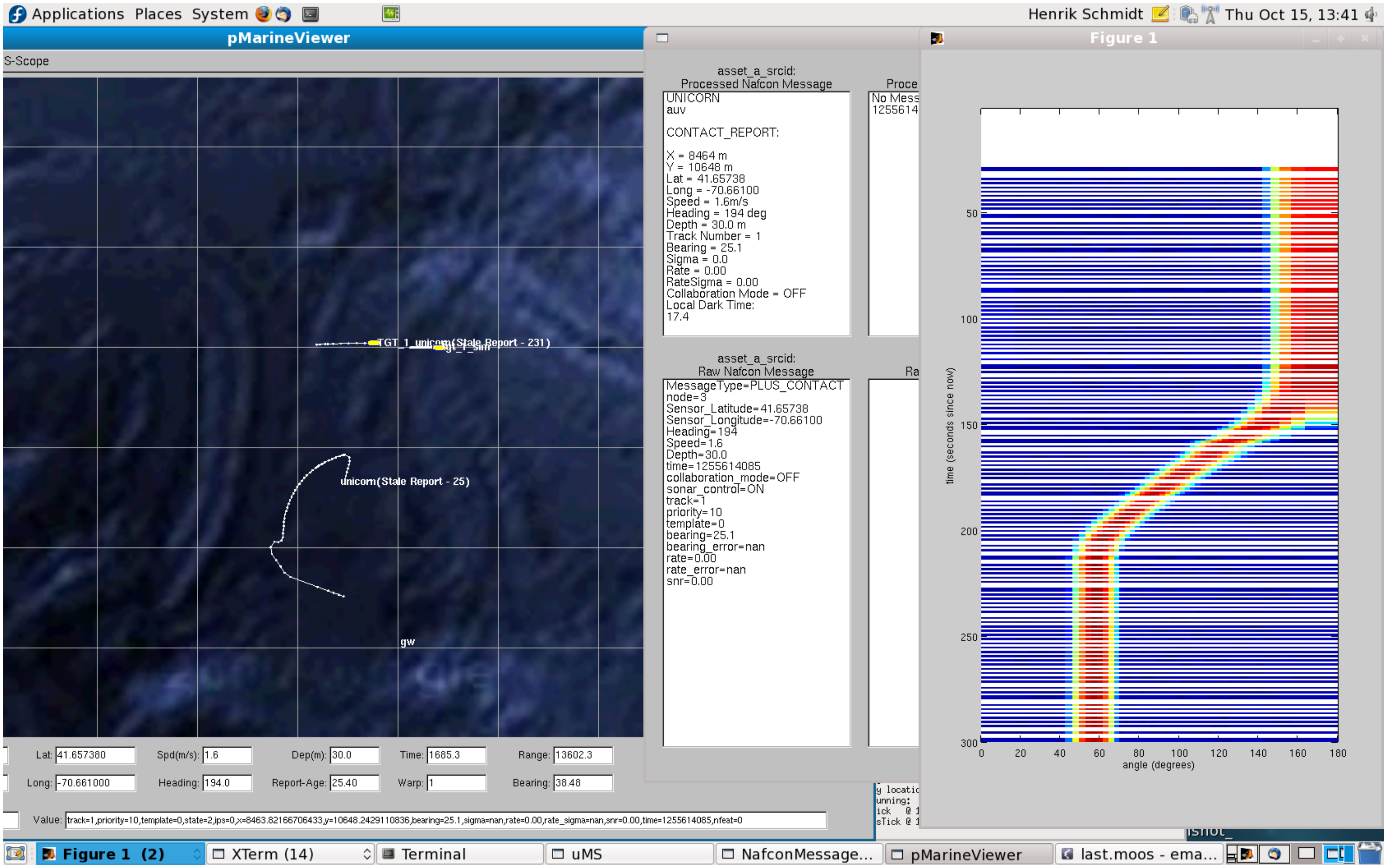
Sub State	Cluster Control	State Control	Signal Processing	Helm Behaviors
Search	pTargetOpportunity	pSearch	pBearingTrack	Attractor
	pClusterPriority			RubberBand
				ConstantDepth
				TurnMemory
Ambiguous			pBearingTrack	ArrayTurn
				ConstantSpeed
				ConstantDepth
				TurnMemory
Track	pMBTracker	p1HTracker	pBearingTrack	Attractor
		pMBTracker	p1HTracker	ArrayAngle
		pTrackQuality	pMBTracker	CollaborativeTracking
			Nodestar	ConstantDepth
				TurnMemory
Classify		pTrackQuality	pBeamform	Attractor
			pSubindex	ClassifyYoyo
				ConstantSpeed
				TurnMemory



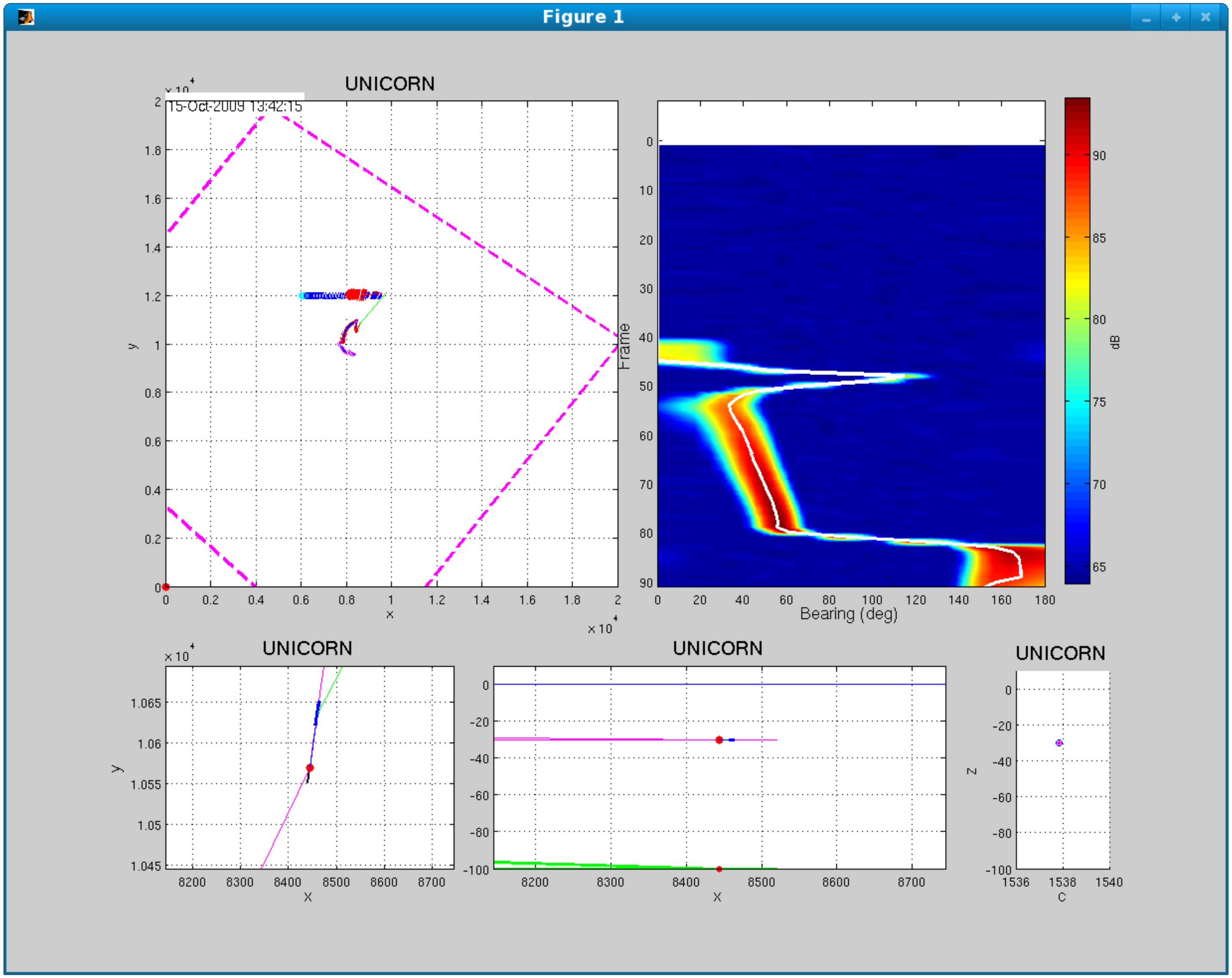




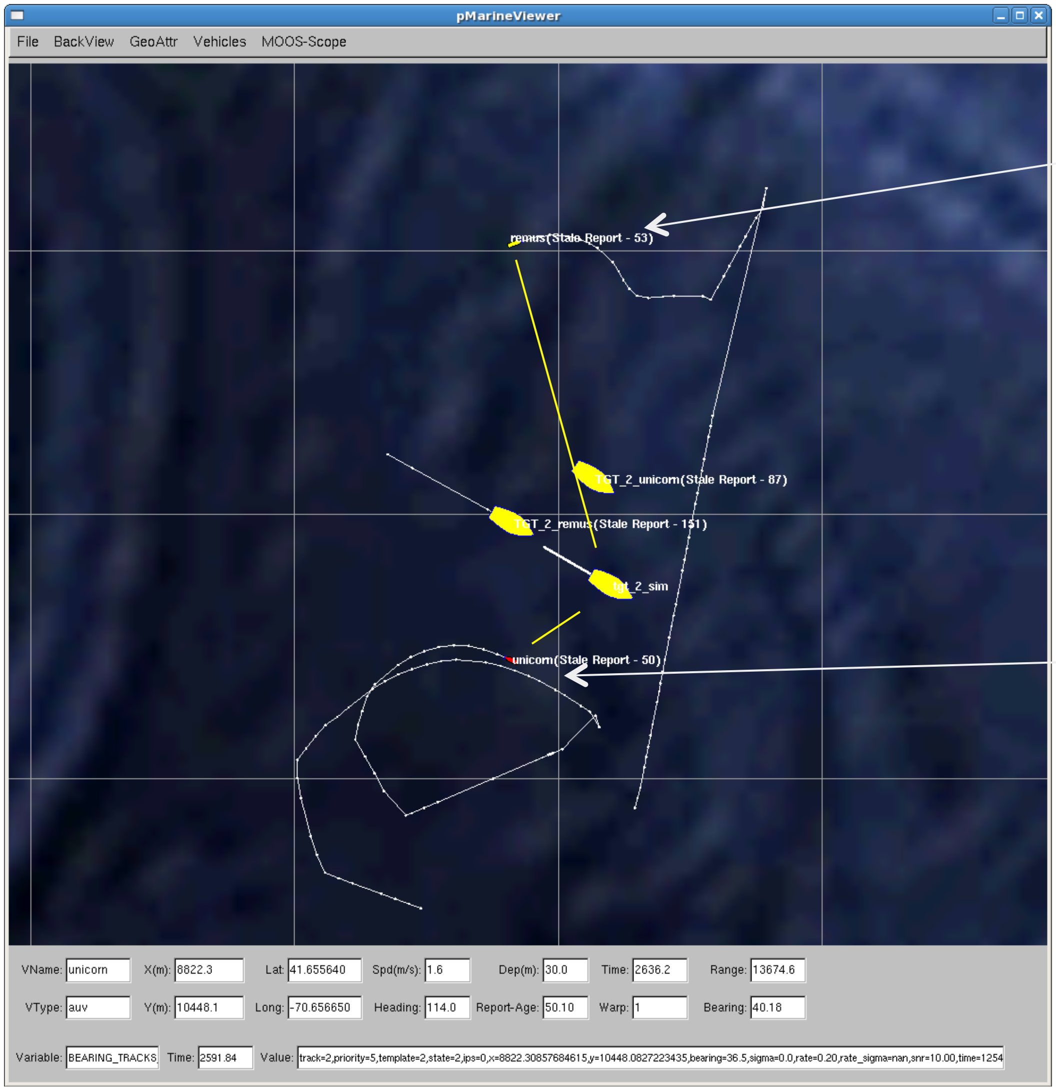
Virtual Experiment
Status, Contact and BTR packed into PSK Messages



MIT Acoustic Network Simulator
Node Level Visualization (small_uVis.m)



Virtual Experiment
Collaborative, Adaptive Tracking



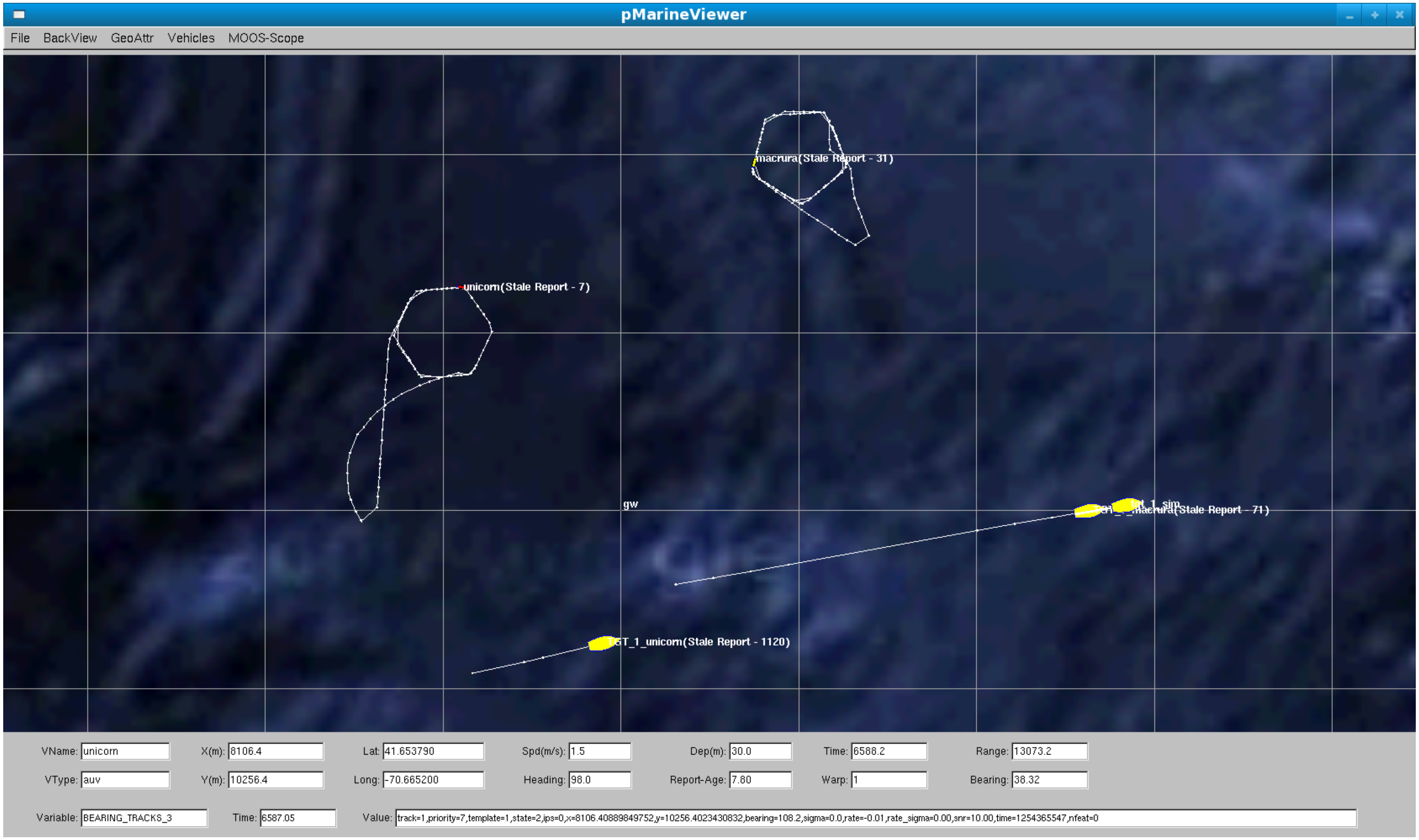
Remus

- Remus Emulator
- Array dynamics simulator
- Acoustic simulator
- Bearing tracker
- Geo-tracker
  - Single/Multi bearing

Unicorn

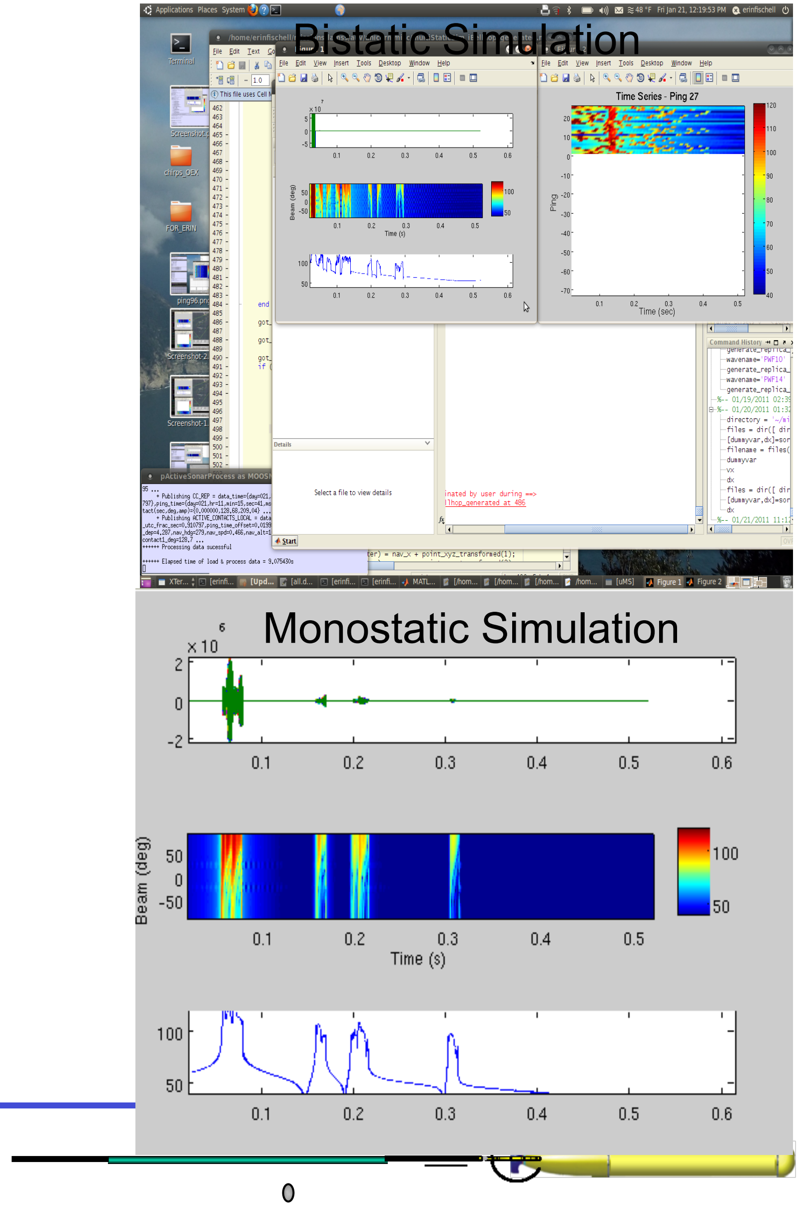
- Bearing simulator
- Geo-tracker
  - Single/Multi bearing

Virtual Experiment
Collaborative, Adaptive Tracking - Target hand-off

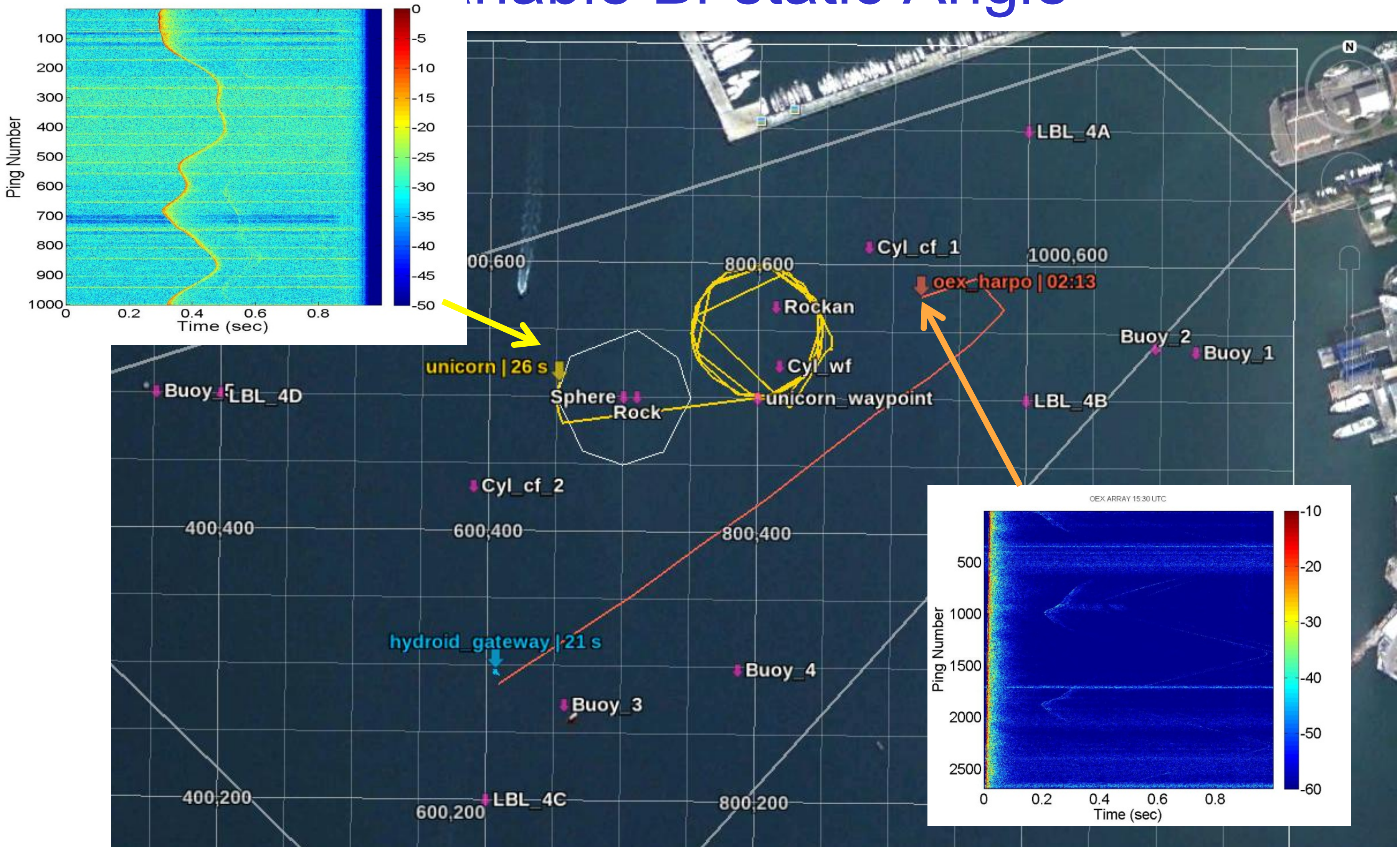


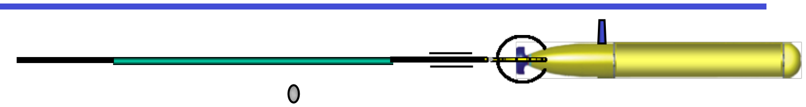
uSimActiveSonar

- Multi-Pathing active acoustic simulator
- Bistatic or monostatic
- Uses Bellhop to simulate environmental losses and multipathing
- Generates a file containing a time series with same format produced by arrays
- Output file used by beam former

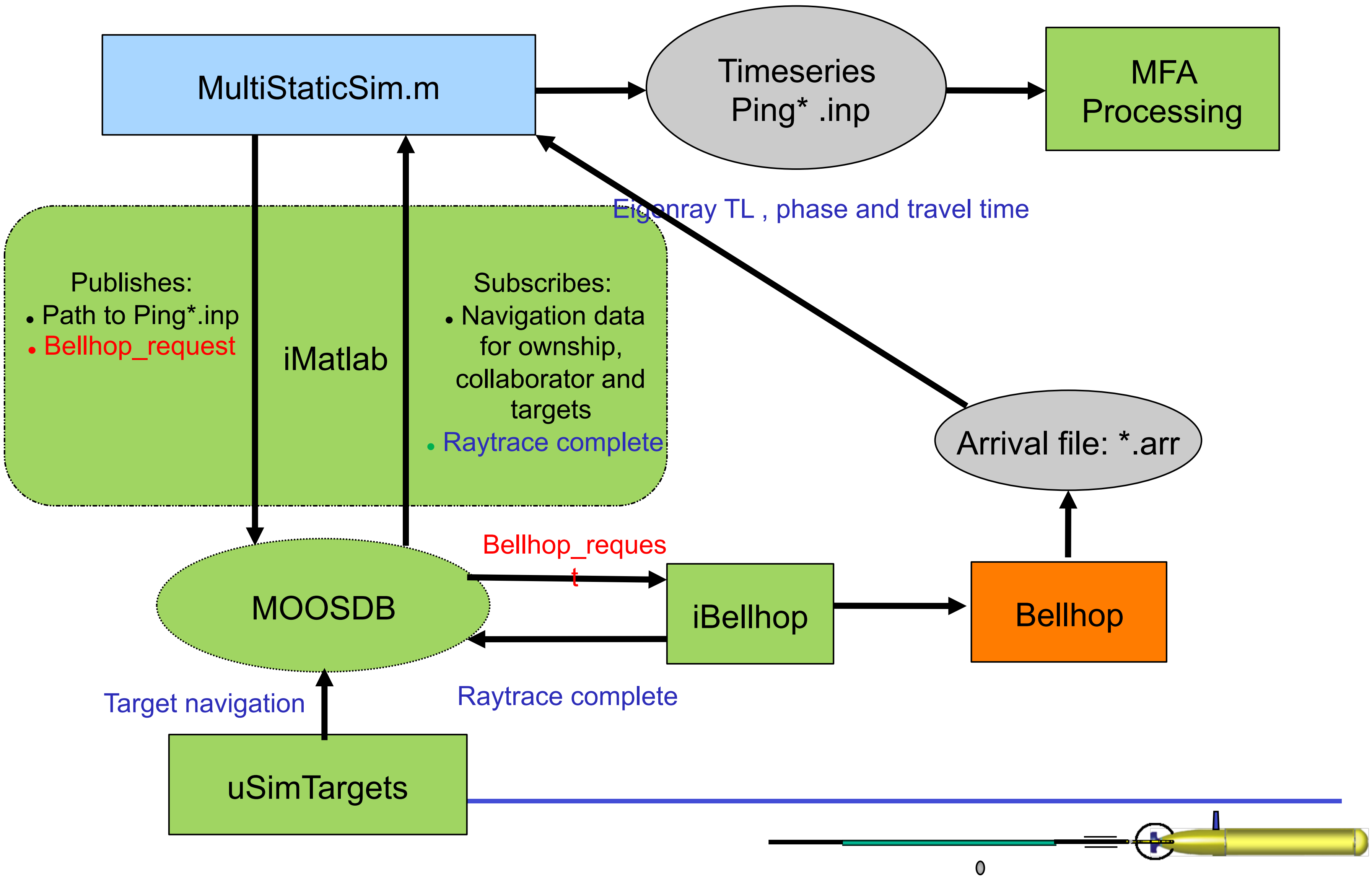


SWAMSI'11 Mono/Bistatics
Variable Bi-static Angle



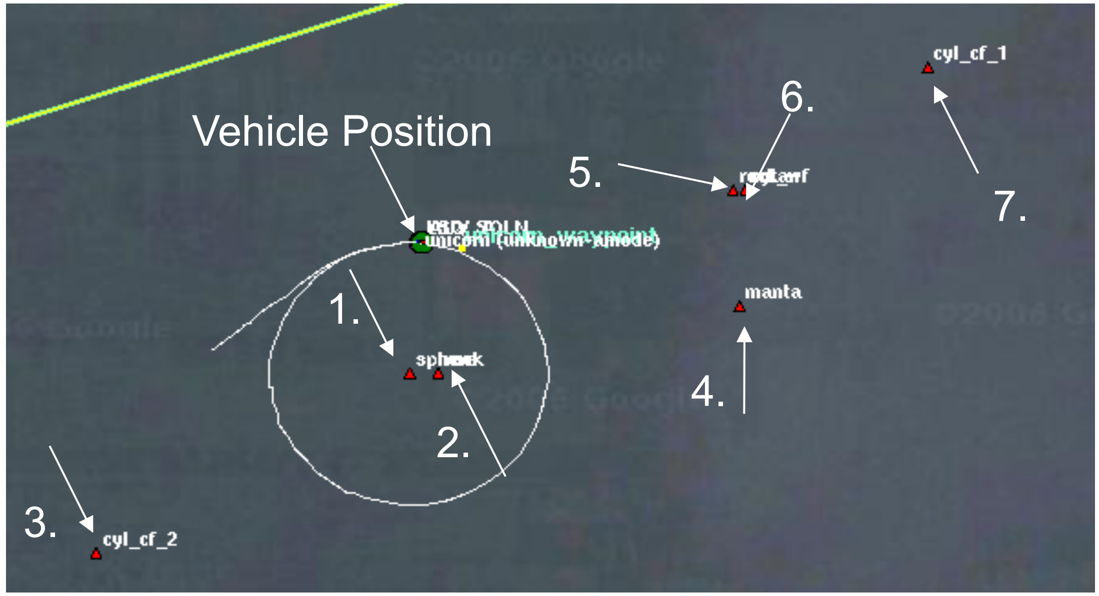


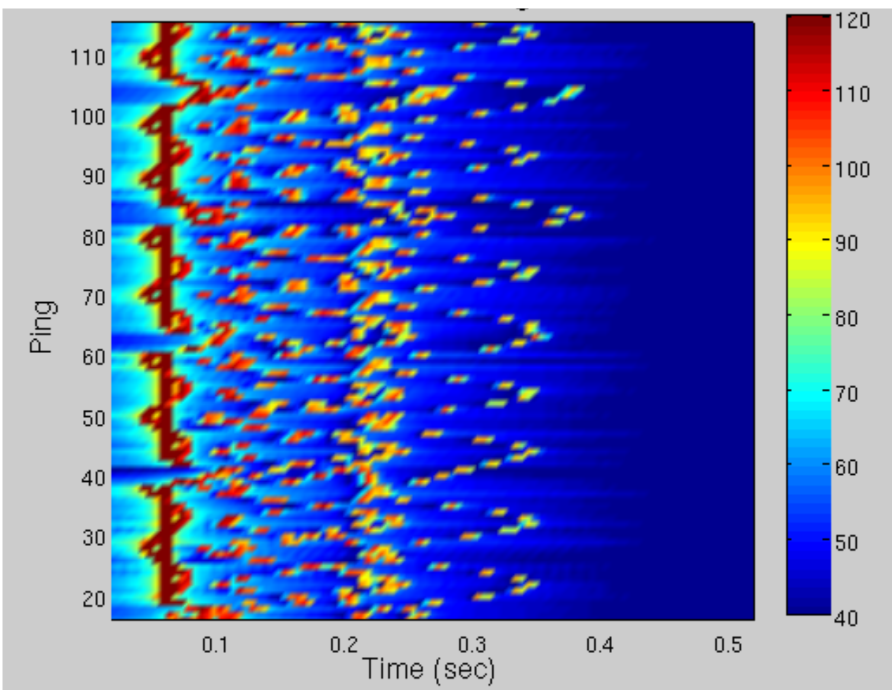
Multistatic Active Sonar Simulator Architecture

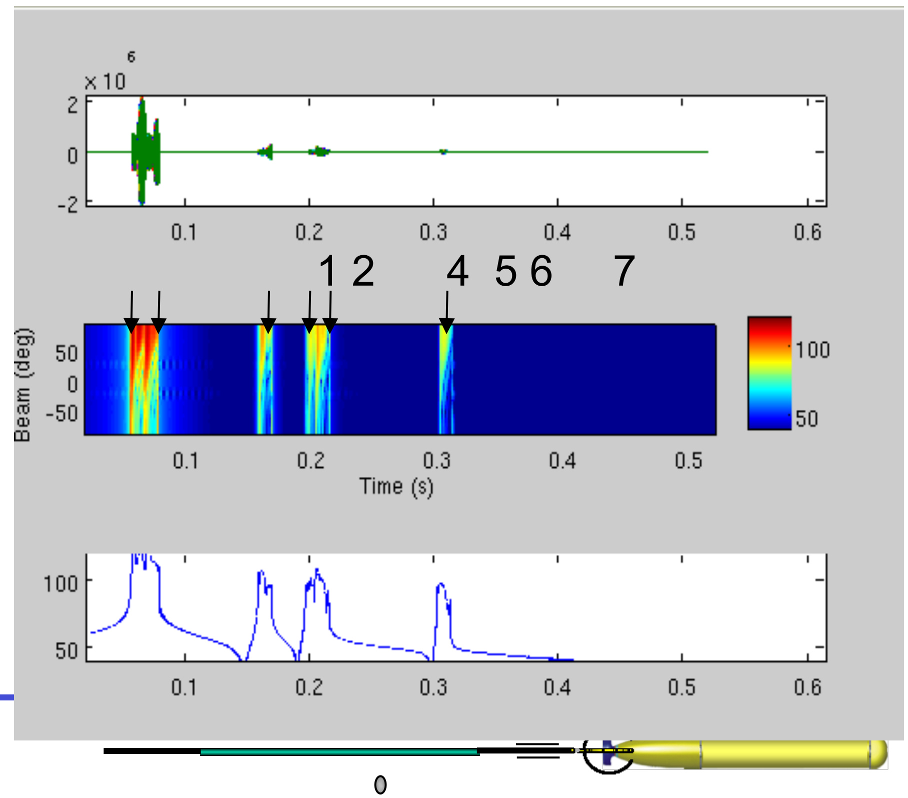


Massachusetts
Institute of
Technology

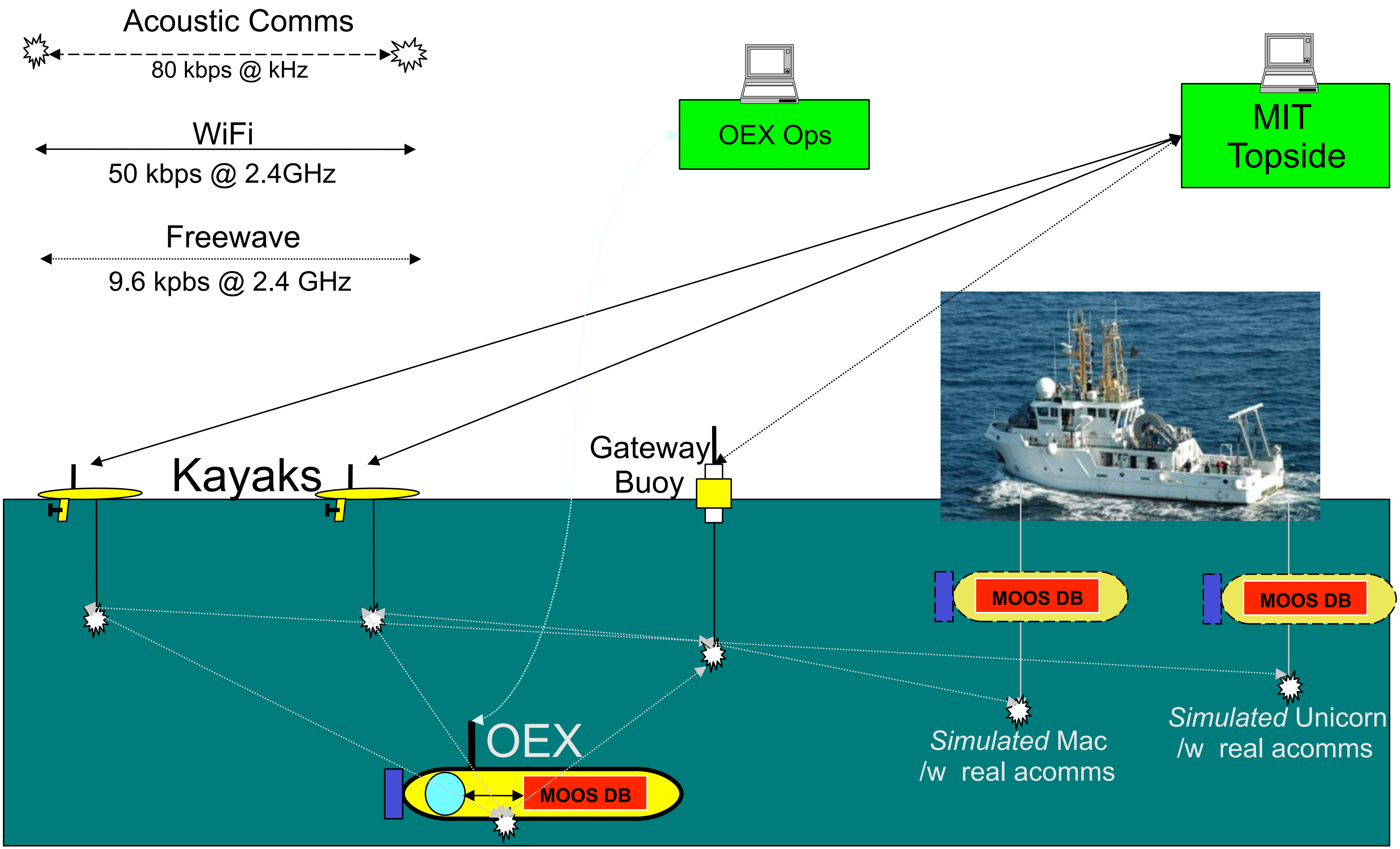
1. Sphere
2. Rock
3. Cyl_cf_2
4. Manta
5. Rockan
6. Cyl_wf
7. Cyl_cf_1







CCLNet'08
Hybrid At-sea/Virtual Autonomous Network



Track-and-Trail Autonomy
Collision avoidance

Cluster Priority Autonomy Hybrid Real/Virtual Network

At-sea Nodes

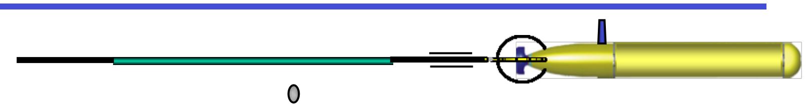
AUV:
- oex

Kayaks:
- bobby
- dee

Virtual Nodes

AUV:
- unicorn

Kayaks:
- xulu
- yolanda
- zero



Summary

- Intelligent autonomy is crucial to the performance of distributed undersea sensing systems
  - Adaptation and collaboration may compensate for less capable sensing capabilities
  - Communication channel capacity many orders of magnitude lower than for air-and land-based systems
  - Full integration of sensing, modeling, and control required so mission can be accomplished with no or intermittent communication
  - Behavior based autonomy key enabler for integrated sensing, modeling and control.
  - MOOS-IvP is an open-source, highly portable autonomy software supporting advanced, behavior-based, adaptive and collaborative autonomy.
  - High-fidelity acoustic simulation linked with autonomy system is a key tool for development of distributed autonomy
    - Historically >100 hours of virtual tests for each hour of at-sea mission