Internet of Battlefield Things

COLLABORATIVE RESEARCH ALLIANCE

Experimentation Overview

Research Management Board

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INTEGRATED EXPERIMENTATION

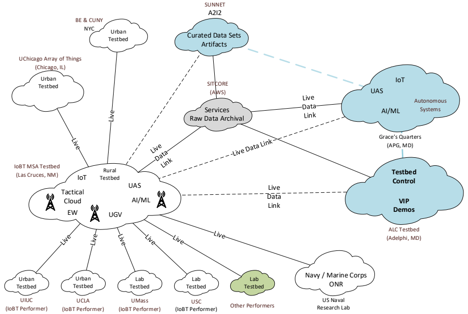
IoBT REIGN

DEVCOM ARMY RESEARCH LABORATORY

Objectives

- Establish collaborative experiments validating synergies and exposing opportunities for IoBT research
- Evaluate IoBT technology in an operational context with full decision cycles
- Drive academic-government collaboration and technology transition

Distributed Virtual Proving Ground



Environment for live, physically distributed experimentation

Rapid assessment and learning of emerging capabilities

Multimodal Reconnaissance in Resource-Constrained Environments

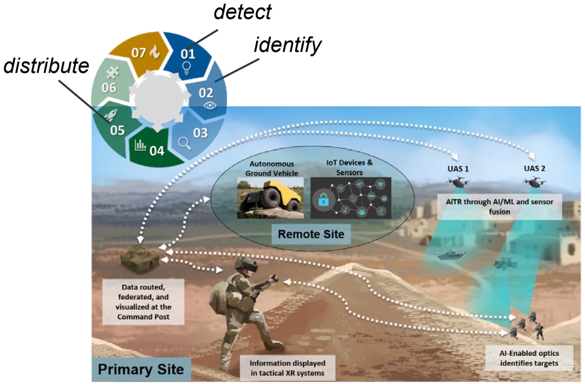
Target identification

Distributed processing

Detection verification

Compressed communications

Full MDO Decision Cycle Applications



Integration with ongoing experiments for decision cycle evaluation

THE DISTRIBUTED VIRTUAL PROVING GROUND (DVPG)

IoBT REIGN

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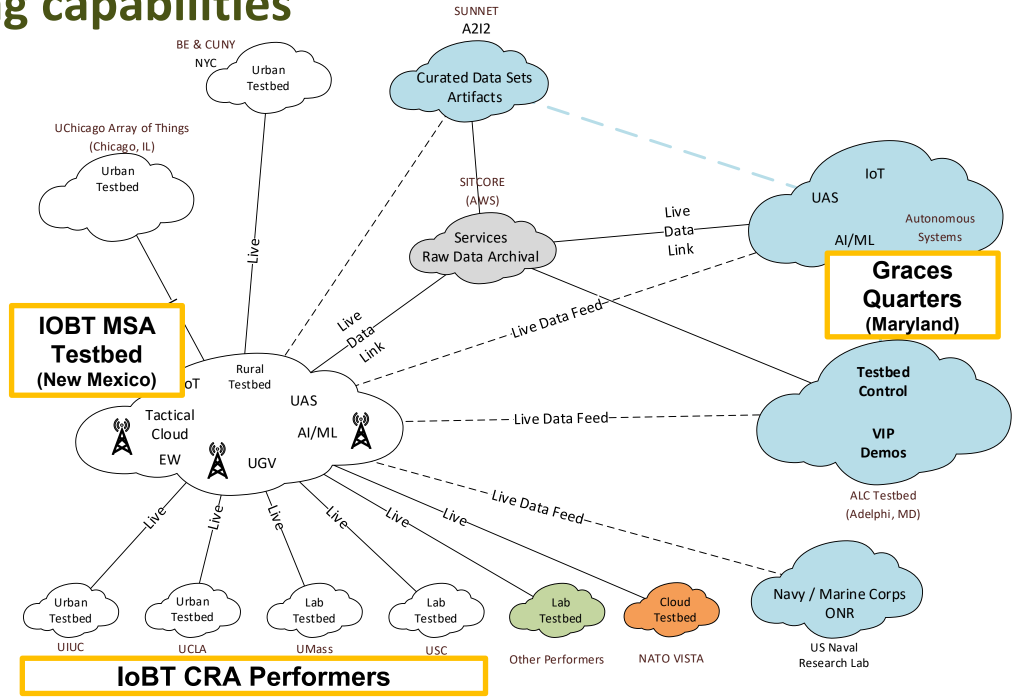
The DVPG is a nationwide virtual experimentation facility designed to allow rapid assessment and learning about emerging capabilities

Goals:

- Empirically evaluate basic research at IoBT scale with real-time access
- Leverage existing investments in research and experimentation infrastructure including across services
- 1000+ heterogeneous intelligent devices and autonomy transparently interoperating within a common operating environment
- Allow repeatable experimentation, including hybrid “physical + emulation” capabilities
- Enable cross-institution collaborative experimentation without co-locating
- Develop insights to drive future research problems

Press release: https://www.army.mil/article/249319



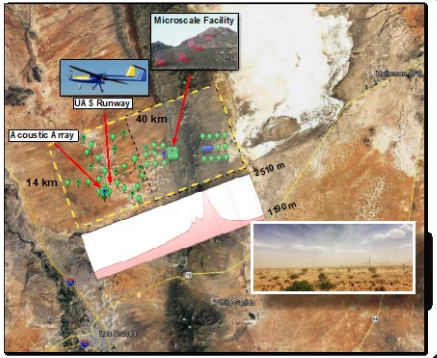
Developed with resources from IoBT to advance research and enable empirical experimentation

DVPG & IOBT EXPERIMENTATION

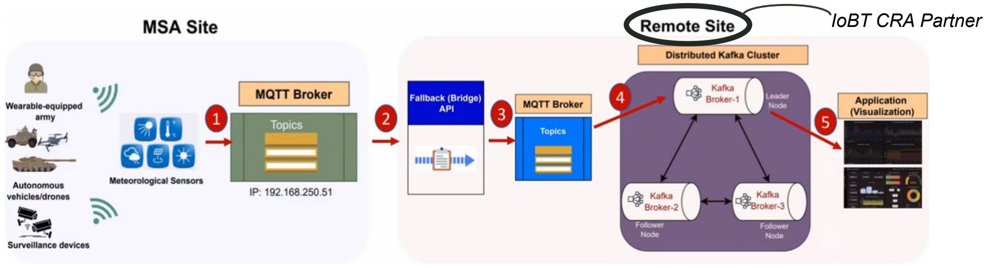
IoBT REIGN DEVCOM ARMY RESEARCH LABORATORY

ARL's Multi-Purpose Sensing Area (MSA)

- 14km x 40km, ARL shared-owned facility
- Can operate UxVs & low power spectrum effects
- Natural characteristics for contested austere environment and MDO Effect Loop evaluation
- Fifty-one 30ft towers with 15-20 heterogeneous sensors per tower and edge processing capabilities



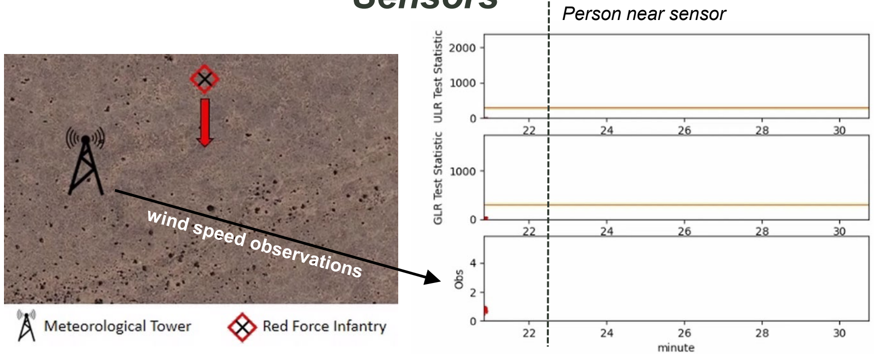
Resilient Data Distribution Infrastructure



Unified abstraction over underlying protocols for data transfer provides robustness to failure

Demo video available: [Resilient Publish-Subscribe Architecture]

Quickest Change Detection from Environment Sensors



Full demo video available: [Fast Anomaly Detection]

DVPG & IOBT EXPERIMENTATION

IoBT REIGN

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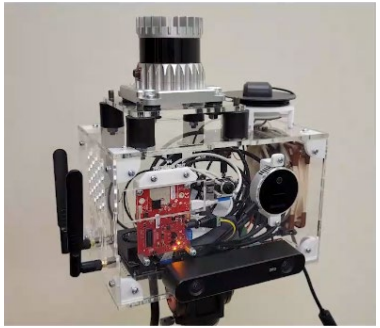
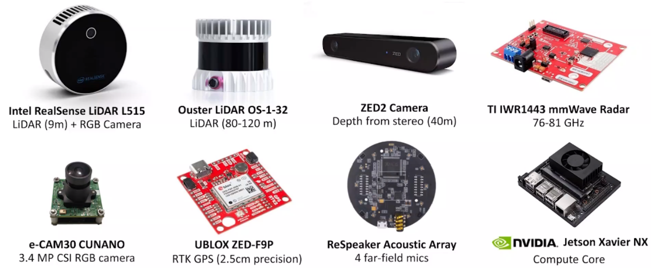
ARL's Robotics Research Collaboration Campus (R2C2) at Graces Quarters

- 3 km x 1.5 km controlled space
- MOUT (Military Operations on Urban Terrain) site - mock urban environment with nice buildings made from shipping containers
- Can operate air and ground autonomy
- MOUT site is being outfitted with IoBT relevant heterogeneous sensors and edge processing capabilities

Multi-Modal Data Collection Node





R2C2 MOUT Site

Multi-modal nodes constructed to collect multi-vantage data for research in intelligent multimodality and distributed analytics

Nodes are being replicated at R2C2

Demo video available: [Multi-Modal Data Collection]

EXAMPLE VALIDATION EXPERIMENTS

IoBT REIGN | DEVCOM ARMY RESEARCH LABORATORY

Question: How do IoBT "Edge Efficiency" Innovations Improve Decision Cycle?

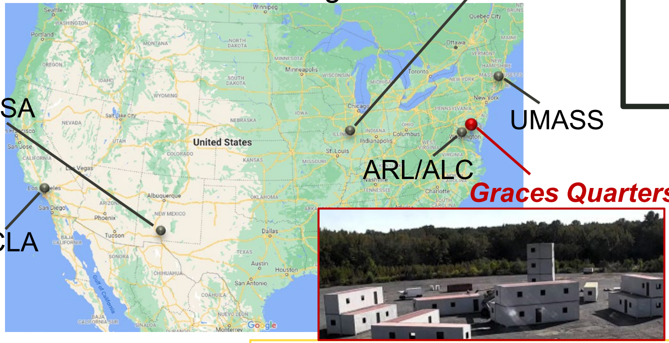
Experiment: Deploy an IoBT multimodal target detection/identification pipeline at GQ site. Run vehicles. Evaluate performance.

Empirical Results:

- Fine-grained target classification at the point of observation.
  - Within seconds
  - Accuracy up to 99% (trade-off with latency)

Full demo video available: Improving Edge Efficiency

DVPG Linkages



Multimodal Reconnaissance in Resource-Constrained Environments

Target identification

Distributed processing

Detection verification

Compressed communications

Question: How do IoBT "Unconventional and Multimodal Sensing" Innovations Improve Situational Awareness?

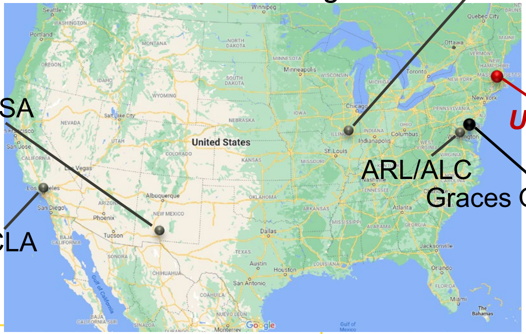
Experiment: Deploy multiple multimodal (RF, EO, thermal) sensors at an urban location with human targets. Evaluate performance.

Empirical Results:

- Multi-modal human detection & monitoring
- Dynamic processing under resource constraints

Full demo video available: Multimodal Sensing for Human Monitoring

DVPG Linkages



Experimental vignettes motivated by FCC collaboration (with MAJ Adam Taliaferro, FCC)

CLASSIFICATION AT THE POINT OF OBSERVATION

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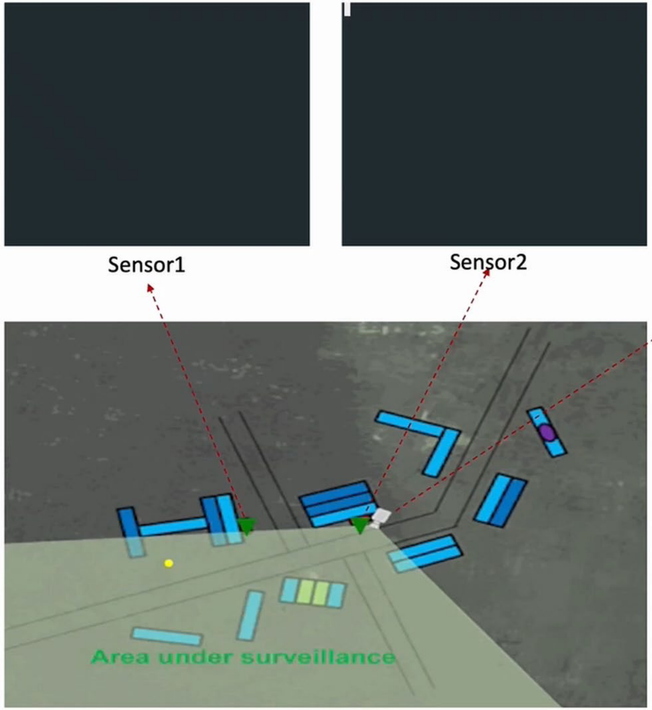
Fine-grained *on-sensor* classification



Ground-truth View

Camera

Mission Objective: keep silent, but report when specific target is *identified*

Target:
Warthog Robot

Results:

- ***New capability:*** In-situ *fine-grained* target classification. Improves stealth – sensor does not need to send data elsewhere for *fine-grained* classification; can identify target (e.g., vehicle type) at point of observation
- ***Performance advantage:*** Improved classification latency/accuracy trade-off; Reduced reliance on network; Reduced communication

Battlefield Anti-Intrusion System (BAIS)	IoBT Experiment
 Personnel, Wheeled Vehicle, Tracked Vehicle	
Coarse-grained	**Fine-grained**

Fine-grained on-sensor classification using acoustic/seismic sensing, followed by visual confirmation if the right target is found

Full demo video available: [Improving Edge Efficiency]

MULTIMODAL HUMAN MONITORING

IoBT REIGN

remote processing cluster

Resource Status:

- Multimodal, multi-view outdoor sensors available
- Resource-constrained onboard sensor processing
- Remote processing available via WIFI

Mission Objective: maintain situational awareness of humans in the environment both outside and inside buildings

Multi-view human detection via distributed prediction (onboard sensor & remote processing)

Results:

- ***New capability:*** Commodity RF sensing; distributed prediction accounting for dynamic bandwidth
- ***Performance advantage:*** Improved classification latency; sensing in high interference settings

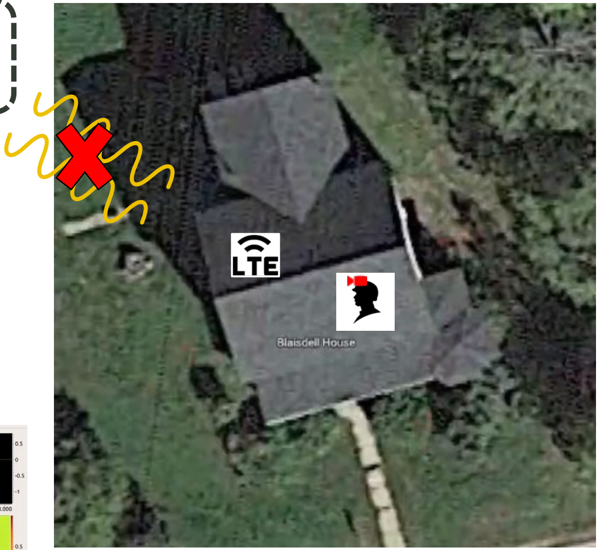
NLOS (through walls) human movement monitoring

MULTIMODAL HUMAN MONITORING

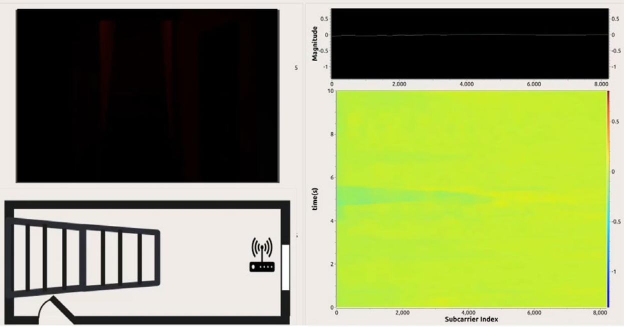
remote processing cluster

Resource Status:

- Multimodal, emplaced and Soldier worn sensors available
- Resource-constrained onboard sensor processing ***only***
- ***Remote processing unavailable***



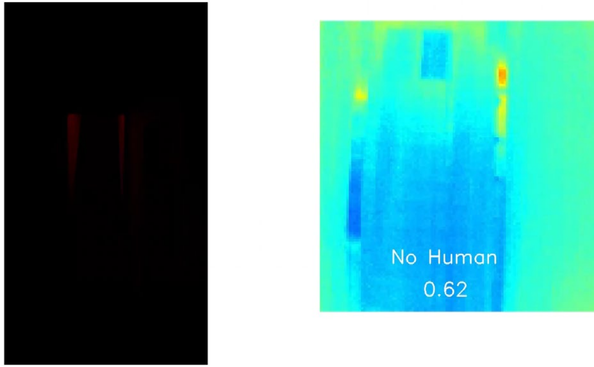
Mission Objective: confirm human presence in building with multiple available sensing assets



Human detection in the dark via LTE motion sensing

Results:

- ***New capability:*** Disconnected operations; commodity RF sensing
- ***Performance advantage:*** Improved resilience to disrupted communication and reduced visibility



Confirmation of LTE sensing via human detection modal trained on thermal images

Dynamic operation mode selected based on local compute energy availability

Full demo video available: [Multimodal Sensing for Human Monitoring]

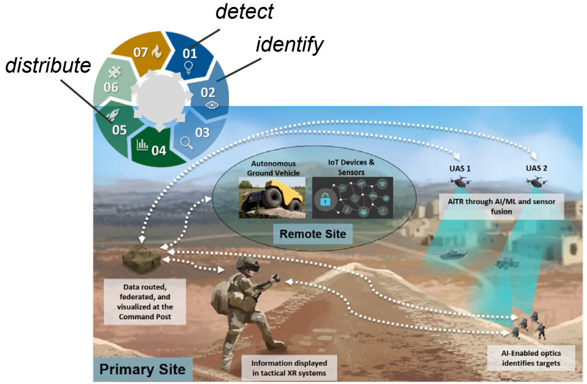
MDO DECISION CYCLE APPLICATIONS

Objective: Inject mature IoBT CRA technology into existing ARL and DoD experimentation efforts to evaluate capabilities in operationally-relevant settings with Army target sets to inform continued technology development

Three Experimentation Routes

1. ***PC2x:*** Joint, MDO decision cycle applications
   Note: *IoBT technologies were tested in* ***PC21 Experiment Excursion ACROPOLIS*** - compression algorithms running on UGV and UAS for target detection; use of DVPG
2. ***DARTS***: Possible validation path for in-situ acoustic/seismic target identification with uncertainty quantification
3. ***TTCP AISC***: Coalition, MDO decision cycle applications - Compressed and distributed prediction for tactical edge processing

Full MDO Decision Cycle Applications



Integration with ongoing experiments for decision cycle evaluation

Research Questions:

1. How do IoBT innovations improve mission-centric performance metrics?
2. Which computational performance enhancements contribute the most to decision advantage?
3. What “science-in-the-dirt” lessons are learned that inspire new directions in IoBT research?

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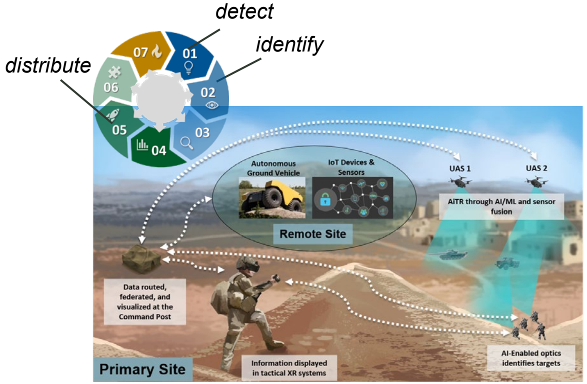

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PC21 EXPERIMENT EXCURSION: ACROPOLIS

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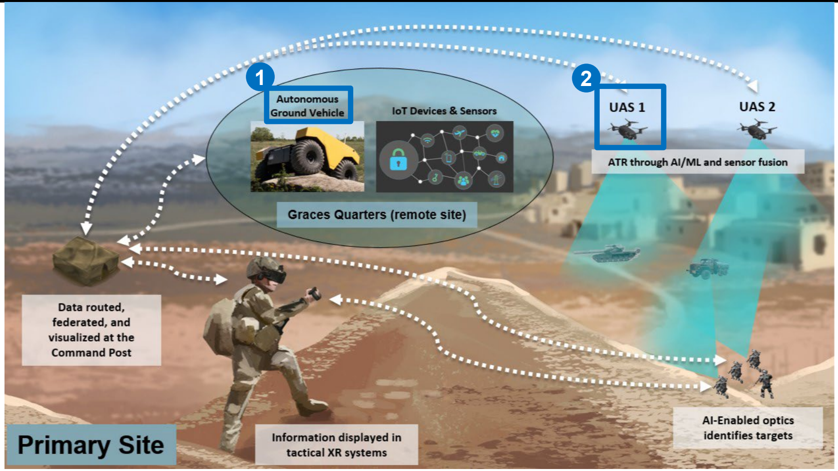
IoBT CRA Experiment Contributions

Compressive Offloading 1

- **ACROPOLIS Task:** Small ground vehicle executing exploration and reconnaissance – human detection using camera sensor
- **Shortcomings:** 1) Onboard GPU too small to fit detection model, 2) Using CPU to run detection model prohibited the exploration and mapping to run efficiently
- **IoBT Innovation:** Asymmetric encoder/decoder for compressive offloading to provide low latency data transfer to edge server where detections are executed without compromising the ground autonomy stack

Neural Network Model Compression 2

- **ACROPOLIS Task:** UAS executing target detection with camera sensor
- **Shortcomings:** UAS is overprovisioned with large GPU, increasing its SWaP factor
- **IoBT Innovation:** Compressor-critic framework reduces UAS neural network size with minimal degradation in performance, making smaller on-board computing hardware adequate



ARL Excursion for PC21 explored three key functions:

- ***Collaborative target localization:*** Small UAV platform(s) with onboard AI/ML analytics feed full motion video and detected targets into COP for geolocalization, correlation and simulated effects
- ***Autonomy:*** UGV at remote site (Graces Quarters) but linked into the COP takes single-point goals and fully autonomously navigate to objective, then capture surveillance information and return data along with analytics output to the COP
- ***COP visualization & interaction:*** Display the heterogeneous platform data and target information to the users, allowing for interactive visualization and enable users to set new goals or waypoints for the UxVs

Connected via the DVPG

TTCP AISC EXPERIMENT INTEGRATION

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The Technical Cooperation Program (TTCP) AI Strategic Challenge (AISC) Approach:

- Develop, implement, and integrate AI algorithms, associated data, and software solutions to enhance the performance of a variety of military systems (capability pillars)
- Study how well FVEY Nations' technology interact and interoperate in military operational contexts while performing experiments structured to examine cross-cutting themes

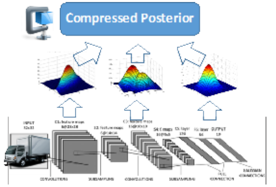
AISC Capability Pillars

Tailored AI at the Tactical Edge (TATE)	Soldier Interactions with AI-Enabled Systems (SIAS)	AI for Operations & Planning (AIOP)	Transfer of Tactical Control of AI-Enabled Systems (ToTC)	Opposed AI (OA)
AI for derivation of actionable information from complex, multimodal, unstructured data	AI to enhance effectiveness at the tactical level	AI to enhance decision making quality and speed to support complex, high tempo collation Amphibious Access missions	AI to enhance resource sharing efficiency across a multination collation in high temp operations	AI vs AI in an opposed environment to deliver resilient AI systems

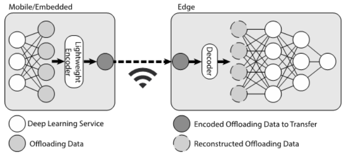
Joint Experimentation Fall 2022 (TATE, SIAS)

TTCP AISC events allow IoBT CRA innovations to be experimented with Coalition POR systems

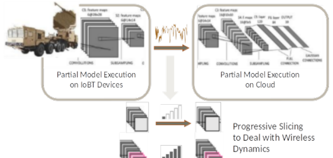
IoBT Technologies for Fall Experimentation



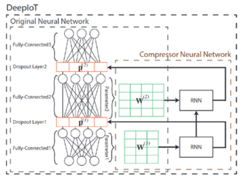
Compressed Uncertainty Quantification



Compressive Data Offloading



Distributed Inference



Compressed Model Inference

INTEGRATED EXPERIMENTATION

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What did we learn?

Practical bottlenecks:

- *Example:* Battery power is a significant limiting resource for the viability of tactical edge analytics. Scaling in time (i.e., longevity) is a key challenge
- *Example:* Real data are noisy, scarce, and hard to label. Resiliency to poor "ground truth" is important

Misaligned assumptions*:*

- *Example:* Effect mechanisms and assessment sensors are not collocated. Feedback linking effects and measurements (for learning systems) needs careful coordination

Underestimated challenges:

- *Example:* Fast/robust reconfiguration is needed more often than originally believed (due to environmental dynamics)

What can we do now?

On site and virtual, repeatable experimentation for cross-domain operations to support rapid technology integration and refinement

What will we do in the future?

Continued experimental activities with direct transition targets

Questions?

To view full demo videos of discussed research visit:
https://abdelzaher.cs.illinois.edu/RMB22-Demos.html

To view read-ahead material visit:
https://iobt.illinois.edu/RMB22-Readahead