Command and Control of Autonomous UxV’s

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- University-Based Applied Research and Development Laboratory
- Focus on National Security
- Major Effort in Space Science and Technology
- Partner in Johns Hopkins Commitment to Education and Medicine
- ~3,350 Staff
Future Unmanned Battlespace

• Thousands of UxV’s and stationary unmanned sensors
• Hundreds of flavors of UxV’s and sensors (heterogeneous environment)
• Significant increase in automation required
• Human operators will provide high-level goals to UxV’s for autonomous operation
Challenges

• To achieve the future unmanned battlespace:
  – Autonomous vehicles
  – Sensor and UxV’s coordination
  – Robust to failure (communications, hardware, peer)
  – Long operational periods
  – Decentralized control

• APL areas of work:
  – Autonomy
  – Simulation
  – Decentralized Communications
  – Command and Control
Decentralization

- New techniques in control of Unmanned Vehicles and a decentralized computing environment require rethinking of C2
  - Decentralized AI
    - Behavior Based System
    - Swarming
  - Decentralized computing environment
    - Mesh networks
    - Service Oriented Architectures
  - Decentralized Command and Control
    - Heterarchical organization
Decentralized AI

- Swarming as AI Solution
- Biological systems provide insight on problems
- Swarm of ants
  - Decentralized control
  - Massively distributed
  - Robust to failures
  - Self-organizing, Self-regulating

- Ants maintains own “world model”
- UxV are agents in the swarm
Swarm AI Behavior

**Stigmergy** – “a method of communication in decentralized systems in which the individual parts of the system communicate with one another by modifying their local environment.”

Examples: Flock of Birds, Wolf Packs, Foraging Ants
# Platform Evolution

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<tr>
<th>Catch Phrase</th>
<th>3/N-Tier</th>
<th>Net Apps</th>
<th>Net Services</th>
<th>Next</th>
<th>After that</th>
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<tbody>
<tr>
<td>The Network Is the computer</td>
<td>Objects</td>
<td>Legacy to the Web</td>
<td>The Computer Is the Network</td>
<td>Network of embedded things</td>
<td>Network of Things</td>
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- **Scale**: 100s, 1000s, 1000000s, 100000000s, 1000000000s
- **Leaf Protocol(s)**: X, +HTTP (+JVM), +XML, Portal, +RMI
- **Directory(s)**: NIS, NIS+, +CDS, +LDAP (*), +UDDI
- **Session**: RPC, XDR, +CORBA, +CORBA, RMI, +SOAP, XML
- **Schematic**: SLID 2004-0258

*Unknown*

**Note**: Additional details and information are provided in the diagram and table.
Decentralized C2

• Historical Examples
  – Napoleon during Ulm Campaign
  – Japanese in Kamikaze Attacks
  – Germans in Battle of Atlantic

• Organizations operate most efficiently when command structure match their mission environment.
  – Decentralized AI
  – Decentralized Computing
Swarming as a C2 Solution

• For C2 environment to match mission environment, we must move from Hierarchical to Heterarchical Control

• Benefits of Heterarchical C2
  – Ability to perform a task is independent the organizations size
  – The decision loop is less than that in hierarchical C2 systems
  – The group as a whole is more survivable
High-Level Goals

- Protect Moving Convoy
- Deny Access to Basin
- Patrol Roads in Area of Interest
- Protect HQ
- Identify Mines in Surf Zone

Warfighter Ground Station

3/12/2003
<table>
<thead>
<tr>
<th>Automation Level</th>
<th>Description</th>
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Propagation Network

• Platform Independent
  – UGV, UAV, Windows Laptop, Handheld
  – Humans or sensors can provide input to network
  – Supports multiple operators simultaneously
  – Future embedded devices….

• Decentralized

• Robust in an unreliable environment
• Modeled after insect behavior
  – Observations about the world are translated into beliefs (pheromones)
  – Collection of beliefs constitute world model.

• Heterogeneous Swarm of Vehicles
  – Real and simulated robots working in concert

• Opportunistic Communications

• Heterarchical C2 environment
• Variation on classic AI paradigm of: Sense, Plan, Act
  – Sensor-based Observations are used to generate…
  – Belief about the current state of the world which in turn is used to devise an appropriate…
  – Behaviors to satisfy group goals and objectives. Behaviors are then used to generate…
  – Actions which translate into real world movements of the robot.
Conclusions

- Large Scale deployment of Unmanned Vehicles will require a rethinking of C2
- C2 environment should match mission environment
  - Heterarchical vs. Hierarchical Organization
  - Decentralized AI
  - Decentralized Computing Environment
  - Decentralized Command and Control