AN AGENT-BASED MODEL SIMULATION OF MULTIPLE COLLABORATING MOBILE AD HOC NETWORKS (MANET)

<table>
<thead>
<tr>
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<tbody>
<tr>
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<td>RTP, NC</td>
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Presentation Outline

1. Background
2. Research Motivation
3. Approach
4. Modeling & Simulation
5. Simulation Results
6. Summary and Conclusions
MANET: A popular acronym for Mobile Ad hoc NETwork

- A MANET is an autonomous collection of mobile users that communicate over relatively bandwidth constrained wireless links.
- Since the nodes are mobile, the network topology may change rapidly and unpredictably over time.
- The network is decentralized, where all network activity including discovering the topology and delivering messages must be executed by the nodes themselves, i.e., routing functionality will be incorporated into mobile nodes.
- A hybrid of human-machine- or machine-machine- system
BACKGROUND

• Mobile
  – Random and perhaps constantly changing

• Ad-hoc
  – Not engineered

• Networks
  – Elastic data applications which use networks to communicate

Ad hoc networks:
  Do not need backbone infrastructure support
  Are easy to deploy
  Useful when infrastructure is absent, destroyed or impractical

• Interconnected collection of wireless nodes
• Nodes enter and leave over time
• Nodes also act as routers; forward packets
• No pre-established network infrastructure
• No centralized administration
• Communication using BlueTooth and WAP
Envisioned Evolution of Network Technology

- Self-configuring
- Self-organizing
- Self-healing
- Self-managing

Increasing Capability

Technology Development

- Self-configuring
- Self-organizing
- Self-healing
- Self-managing

- Auto-configuration
- MANET Routing
- Distributed Applications
- Peer-to-Peer
- Robust, persistent data transport
- Disruption Tolerance
- Human Interaction ("man on the loop")
- "Network-aware" Agent-based Systems
- Distributed Autonomy

What human characteristics are transferred?

From: Brian Adamson, NRL
Many Applications of MANET

• Personal area networking
  – cell phone, laptop, ear phone, wrist watch
• Military environments
  – soldiers, tanks, planes
• Civilian environments
  – taxi cab network
  – meeting rooms
  – sports stadiums
  – boats, small aircraft
• Emergency operations
  – search-and-rescue
  – policing and fire fighting
Military applications

- Combat regiment in the field
  - Perhaps 4000-8000 objects in constant unpredictable motion…

- Intercommunication of forces
  - Proximity, function, plan of battle

- Special issues
  - Low probability of detection
  - Random association and topology
Challenges in Mobile Environments

- **Limitations of the Wireless Network**
  - packet loss due to transmission errors
  - variable capacity links
  - frequent disconnections/partitions
  - limited communication bandwidth
  - Broadcast nature of the communications

- **Limitations Imposed by Mobility**
  - dynamically changing topologies/routes
  - lack of mobility awareness by system/applications

- **Limitations of the Mobile Computer**
  - short battery lifetime
  - limited capacities
Challenges Continue

- Dynamic Topologies and node memberships
- Bandwidth constraints
- Many Transmission Errors
- Energy-constrained operation
Community Attention to Manets

- Routing/ packet scheduling
- Reliability
- Lethality
- Energy consumption and longevity
- Vulnerability
- Mobility
- Security
- Survivability
Motivation

• MANET as a human-machine system

• MANETOLOGY: Develop a network theory for human-machine system (with MANET = machine)

2. Allows for representation framework for CSTS
3. Advance cognitive network theory for modeling and simulation

Question: Does agent-based MANET performance (measured by vulnerability) affected by human traits like behavior, perception, and cognition abilities?
INFLUENCING FACTORS FOR MANETOLOGY

(1) Emergence – the notion that the interaction of a technological, cognitive, social, and ecological system will give rise to a collective pattern of behaviors that differ remarkably from the presumed behaviors from each of the sub-systems;

(2) Dynamic – the notion that behavior change is situated in time and space giving rise to temporal and spatial behaviors, respectively;

(3) Spiral model – the notion that due to the interaction of multiple behaviors, resultant system behaviors are non-linear, and understanding information flow and their functions are mediated through a continuous spiral feedback model;

(4) Self-organized – the notion that agents that have intelligence can adapt and re-organize their behaviors for planning during contingencies;

(5) Distributed cognition – the notion that each agent in the system share, the same goal and seamlessly distribute what they know with each other;

(6) Sensemaking – the notion that agents can reduce equivocal information to a common metric for use in an intended goal execution, and collectively seek prospective information for coping with future state changes (Huang & Chang, 2006);

(7) Agitative states – the notion that agents for military M&S will operate under stress levels which have the effect of diminishing the full functioning of the agent’s performance such as reduction of awareness and attention.
At each node, the human activities are to Observe, Orient, Decide, Act

<table>
<thead>
<tr>
<th></th>
<th>MANET device</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANET device</td>
<td>Instructions and rules Automated behaviors</td>
<td>Model-based predictions and look-up table</td>
</tr>
<tr>
<td>Human</td>
<td>User-interface, visual tools</td>
<td>Social-based: dialogs and communication</td>
</tr>
</tbody>
</table>
The OODA model was developed by Boyd (1987)
APPROACH—MANET AS A COGNITIVE SOCIO-TECHNOLOGY SYSTEM (CSTS): Why Agents

(a) cope with complex interaction of multiple behaviors;
(b) capable of analyzing complex adaptive information;
(c) cope with contingencies under emergence behaviors and events;
(d) recognize opportunities in a spatio-temporal manner;
(e) seek satisficing and plausible (good enough) solutions when confronted with unexpected situations with uncertain and equivocal information;
(f) represent as much as is feasible the various dimensions of expert knowledge in the domain problems.
Assume the basic principle of a Rational Agent: For each possible percept sequence, a rational agent should select an action that is expected to maximize its performance measure, given the evidence provided by the percept sequence and whatever built-in knowledge the agent has.
Approach: Agents in MANET

Agents can perform actions in order to modify future percepts so as to obtain useful information (information gathering, exploration).

Each agent interacts (directly or indirectly) with one or more aspects of an environment.
APPROACH: Modeling Representation

Agent Environments
- Fully vs. Partially Observable (Accessible vs. inaccessible)
- Deterministic vs. Stochastic (non-deterministic)
- Episodic vs. Sequential (non-episodic)
- Static vs. dynamic
- Discrete vs. continuous

Modeling Perceptual Attention in Virtual Humans

Randall W. Hill, Jr.
Variability in human behavior most often arises from complex interactions among the many mental and

Variability in Human Behavior Modeling for Military Simulations

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A Computational Model on Surprise and Its Effects on Agent Behaviour in Simulated Environments

Robbert-Jan Merk
APPROACH: Considering Behavior

Modeling Human Behavior for Virtual Training Systems

Yohei Murakami and Yuki Sugimoto and Toru Ishida
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Variability in Human Behavior Modeling for Military Simulations

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An agent is completely specified by the agent function mapping percept sequences to actions. We use a model-based reflex agent function paradigm for the prototype simulation.
An agent function can have one or all of:

- **Simple reflex agents:** If the world is X then action Y
- **Model-based reflex agents:** what representation describes the situation?
- **Goal-based agents:** For situation X what should I do to achieve Y?
- **Utility-based agents:** If I do X for situation Y, my satisfaction is $Z \geq \Omega$
SAMPLE Behavior Adaptation Algorithms

1. **Agent ID**

2. **Time**: The time agent’s properties reported to the command node.

3. **Roles**: Agent’s role assigned by Command Node.

4. **Physical Location (X,Y,Z)**: Agent’s Current Location on the Real Map (Google Map). (Z= Zoom level)

5. **Behavior_F**: get from ‘probability of failure’ received from agent node \(( \text{min} + (\text{max} – \text{min})\times\text{rand()} )\).

6. **Behavior_A**: get from ‘probability of attack’ received from agent node \(( \text{min} + (\text{max} – \text{min})\times\text{rand()} )\).

7. **Behavior_AD**: Adaptability when there is enemy attack.
\[
y_{\text{adap}} = \left( \frac{2}{1+e^{-kf(h,c)}} \right) - 1
\]
\(k = 1, \quad f(h,c) = \text{Trapezoidal Fuzzy Number using hostility(h) and capability(c) level}
\)

   - if \(y_{\text{adap}} < 0\) then : Agent is Not **Adaptive**
   - if \(0 \leq y_{\text{adap}} < 0.4\) then : Agent is **Sluggishly Adaptive**
   - if \(0.4 < y_{\text{adap}} \leq 1.0\) then : Agent is **Adaptive**

8. **Perception**: get from ‘Situation Awareness ability’ received from agent node \(( \text{min} + (\text{max} – \text{min})\times\text{rand()} )\).

   - if \(0.5 < \text{SA} \leq 1.0\) then : **Recognize**
   - if \(0.0 \leq \text{SA} < 0.5\) then : **Fail**

9. **Learning**: (reinforcement learning, discounted time learning)
SAMPLE SIMULATION RESULTS

Sample network topology (A MANET with 6 nodes; allowed number of nodes is arbitrary)

Input parameters

Vulnerability of network during simulation = 69%

Arc size defines frequency of node-to-node interaction

Sample node intensity (45.6%) calculated as aggregated parameter effects: task difficulty, interaction requirements, perception of environment, personality type, etc.
### SIMULATION RESULTS

#### System Status at Time = 5

<table>
<thead>
<tr>
<th>Enemy Activity</th>
<th>Freq.</th>
<th>C2 Activity</th>
<th>Freq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Intruding</td>
<td>12</td>
<td>1. Information Flow</td>
<td>12</td>
</tr>
<tr>
<td>2. Spying</td>
<td>18</td>
<td>2. Network Behavior</td>
<td>18</td>
</tr>
<tr>
<td>3. Listening to Communication</td>
<td>6</td>
<td>3. Intruder</td>
<td>12</td>
</tr>
<tr>
<td>4. Attacking (Network)</td>
<td>12</td>
<td>4. Discrepancy</td>
<td>18</td>
</tr>
<tr>
<td>5. Mimicking</td>
<td>12</td>
<td>5. Device Failure</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Communication Failure</td>
<td>18</td>
</tr>
</tbody>
</table>

#### Cause (Frequency)

<table>
<thead>
<tr>
<th>Issue</th>
<th>C1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Critical Changes in Node Behavior</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Degradation in Information</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>3. Loss of Information</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Consequence (Affected Nodes)

<table>
<thead>
<tr>
<th>Issue</th>
<th>Total Freq.</th>
<th>C1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Loss of Strategic Position</td>
<td>14</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>2. Collapse of Operation</td>
<td>16</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>3. System Shutdown</td>
<td>11</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>4. Loss of Safety</td>
<td>13</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>5. Disruption of Services</td>
<td>19</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>6. Loss of Equipment</td>
<td>19</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td>7. Loss of Morale</td>
<td>20</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>8. Loss of Situation Awareness</td>
<td>18</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
SIMULATION RESULTS: Sample Output – Agent 1

**Agent Property**
- Agent ID: 1
- Agent Role: Artillery
- Physical Location X, Y: From the Map
- Probability of Failure (0.0 - 1.0): Min: 0.5, Max: 0.7
- Probability of Attack (0.0 - 1.0): Min: 0.7, Max: 1.0
- Environmental Hostility: High
- Capability: Medium
- Situation Awareness Ability (0.0 - 1.0): Min: 0.54, Max: 0.75
- Threshold value for reinforcement (0.5 - 0.7): 0.58

**Agent Characteristics**

**Agent 1**

**Agent's Observation**
- Behavior: 0.3475 → 0.4
- Cognition: 0.3937 → 0.8
- Learning: 0.1095 → 0.2
- Perception: 0.5168 → 0.6

**Event-Action Matrix (%)**

<table>
<thead>
<tr>
<th>Event</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>0.32</td>
<td>0.45</td>
<td>0.23</td>
</tr>
<tr>
<td>E2</td>
<td>0.32</td>
<td>0.45</td>
<td>0.23</td>
</tr>
<tr>
<td>E3</td>
<td>0.32</td>
<td>0.45</td>
<td>0.23</td>
</tr>
<tr>
<td>E4</td>
<td>0.32</td>
<td>0.45</td>
<td>0.23</td>
</tr>
<tr>
<td>E5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>E6</td>
<td>0.32</td>
<td>0.45</td>
<td>0.23</td>
</tr>
<tr>
<td>E7</td>
<td>0.32</td>
<td>0.45</td>
<td>0.23</td>
</tr>
</tbody>
</table>

**Expected Action Probability**
- Call for Fire: 0.57
- Secure Perimeter: 0.8
- Contact Next Agent: 0.4
SIMULATION RESULTS: Agent Learning Profiles

Forgetting is triggered by task conditions that disable rational and deliberate mental models – forcing the agent to ignore (or forget) routine processes.

Positive reinforcement is earned by an incremental credit awarded to an agent for routinely achieving an intended goal.
APPLICATION OF SIMULATION RESULTS

A prototype 3-node MANET with 1 C2 Server
2 field MANET agents
Log-in control by IP address.

A field MANET node
C2 server
APPLICATION OF SIMULATION RESULTS

Human injury reported by agent at MANET node 2

Injury report verification by C2 server to avoid enemy mimicking node 2 behavior or status
APPLICATION OF SIMULATION RESULTS

Enemy incursion confirmed
SIMULATION RESULTS (Agent 1)

**Vulnerability**
- **Vul**: -0.991
- **Percep**: 0.319
- **Behavior**: 0.54
- **Cognition**: 0.512

**Correlation for Simulated Period**
- **Pearson Correlation**
  - **Vul** vs. **Percep**: -0.991
  - **Vul** vs. **Behavior**: -0.198
  - **Vul** vs. **Cognition**: -0.512
  - **Percep** vs. **Behavior**: 0.319
  - **Percep** vs. **Cognition**: 0.509
  - **Behavior** vs. **Cognition**: 0.54

**Simulation Run (480 mins each)**

- **Vul Percep Behavior Cognition**
- **Vul**: -0.991
- **Percep**: 0.319
- **Behavior**: 0.54
- **Cognition**: 0.512
SIMULATION RESULTS (Agent 1)

Radar Plot of Average Normalized % Scores (low = 0.0, high = 1.0)

- Agent cognition more influential.
- Cognition correlates positively with perception and behavior.
- Decreased vulnerability = increased scores in cognition, behavior, and perception

<table>
<thead>
<tr>
<th>Vulnerability</th>
<th>Perception</th>
<th>Behavior</th>
<th>Cognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.7</td>
<td>0.56</td>
<td>0.8</td>
</tr>
<tr>
<td>0.1</td>
<td>0.9</td>
<td>0.77</td>
<td>0.85</td>
</tr>
<tr>
<td>0.15</td>
<td>0.88</td>
<td>0.8</td>
<td>0.75</td>
</tr>
<tr>
<td>0.56</td>
<td>0.4</td>
<td>0.7</td>
<td>0.66</td>
</tr>
<tr>
<td>0.35</td>
<td>0.65</td>
<td>0.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>
SUMMARY AND CONCLUSION

1. Modeling MANET as a cognitive socio-technical system.
2. MANET players considered collaborative agents:
3. Applied network science to capture MANET nodes as cognitive agents
4. Inject human cognitive and behavioral traits into agent-based modeling and simulation
5. Use OODA model and sensemaking paradigms to drive non-deliberate behavior of agents as rational entities (model-based functions).
6. Experiment with positive reinforcement learning (with incremental gain over time), and learning with forgetting caused by task changes).
SUMMARY AND CONCLUSION

7. Baseline Research Question: Does an agent-based MANET performance (measured by vulnerability) affected by human traits like behavior, perception, and cognitive abilities?

(a) As agents gain and exhibit increasing perception of the problem situation, show positive rational behaviors, and gain expertise (cognition), MANET nodes are less likely to show high vulnerability during a mission.

(b) Agents exhibit cognition, perception and behavior traits that are positively correlated.

(c) Agents exhibit more human cognitive traits in solving problems (learning and forgetting co-exist).
SUMMARY AND CONCLUSION

8. Have demonstrated the utility of the model for use in training:
   - MANET node performance statistics.
   - Human performance as orchestrated by system interactions.
   - Levels of collaboration/ information sharing during system level mission.

9. Embellish PEARL model with other agent functional algorithms; extend to system-of-systems modeling; compare performance.

10. Conduct field test to measure effects on survivability, vulnerability, lethality, and system reliability.