Why the Navy Needs TSUNAMI

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Abstract

Admiral Jay L. Johnson, Chief of Naval Operations, U.S. Navy, in his address at the U.S. Naval Institute Annapolis Seminar and 123rd Annual Meeting, in Annapolis, Maryland, on April 23, 1997, said the military is in the midst of "a fundamental shift from what we call platform-centric warfare to something we call network-centric warfare." The Tactical Sensor and Ubiquitous Network Agent-Modeling Initiative (TSUNAMI) directly supports this shift. The Navy Warfare Development Command (NWDC) and Argonne National Laboratory's Center for Complex Adaptive Systems Simulation (CCASS) are collaborating to develop TSUNAMI to support several key NWDC initiatives related to network-centric warfare; expeditionary maneuver warfare; operational maneuver from the sea; and ship to objective maneuver. The goal is to exploit the potential benefits of initiatives such as the Expeditionary Sensor Grid and the capabilities of programs of record such as the Joint Strike Fighter and the Amphibious Assault Vehicle. The NWDC and CCASS are applying agent-based modeling and simulation computing advances to allow TSUNAMI to simulate battle space motion and interaction over real terrain maps; clone sensors and sensor fields; apply rule sets to simulate message traffic; simulate quality of service protocols; and simulate exercise data management choices on a case by case basis to model realistic traffic loadings and network overheads. TSUNAMI agents model interacting blue, red, and neutral forces with complex behaviors and a variety of attributes including varying communications equipment; varying sensing capabilities; varying mobility; varying memory; and varying fuel and battery lifetimes. These agents and their simulated environment will be described in detail; and example model results will be presented.

1 INTRODUCTION

Complex adaptive systems (CAS) are sophisticated collections of interacting components that modify their behavior to match changing environments (Holland, 1998; Nadel and Stein, 1993). CASs exhibit coherence under change in spite of constant disruptions and limited central planning. CAS components are diverse in both form and capability. These components change their structure and methods of interaction based on their experiences.

The complex interactions and interdependencies between CAS components are much like those studied in Game Theory (Picker, 1997). Unfortunately, the interactions and adaptation exhibited by many CAS components is often too complex to be conveniently

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modeled using standard Game Theoretic techniques. Agent-based modeling and simulation (ABMS) offers appealing extensions to traditional Game Theory.

ABMS applies agents and a framework for simulating their decisions and interactions to study CAS (Epstein and Axtell, 1996). ABMS is related to various other simulation techniques, including discrete event simulation and distributed artificial intelligence or multiagent systems (Law and Kelton, 2000; Pritsker, 1986). Although many traits are shared, ABMS is differentiated from these approaches by its focus on achieving "clarity through simplicity" as opposed to deprecating "simplicity in favor of inferential and communicative depth and verisimilitude" (Sallach and Macal, 2001).

An agent is a software representation of a decision-making unit. Agents are self-directed objects with specific traits. Agents typically exhibit bounded rationality, meaning that they make decisions using limited internal decision rules that depend only on imperfect local information. Emergent behavior is a key feature of ABMS. Emergent behavior occurs when the behavior of a system is more complicated than the simple sum of the behavior of its components (Bonabeau et al., 1999).

Several powerful ABMS tools have been developed, including Swarm and the Recursive Agent Simulation Toolkit (RePast) (Burkhart et al., 2000; Collier and Sallach, 2001). These and other ABMS tools have been used to construct successful simulations of a wide range of CAS as varied as computer networks (Triantafyllopoulos, et al. 2001), electric power infrastructures (Bower and Bunn, 2000; North 2000a), foreign exchange (Yang 2000), integrated economies (Epstein and Axtell, 1996), and interwoven electrical power and natural gas infrastructures (North 2000b, and 2001).

2 THE SHIFT

TSUNAMI directly supports the Navy's shift to network-centric warfare. Admiral Jay L. Johnson, Chief of Naval Operations (CNO), USN, in his address at the U.S. Naval Institute Annapolis Seminar and 123rd Annual Meeting, in Annapolis, Maryland, on April 23, 1997, said the military is in the midst of "a fundamental shift from what we call platform-centric warfare to something we call network-centric warfare." The Tactical Sensor and Ubiquitous Network Agent-Modeling Initiative (TSUNAMI) directly supports this shift.

TSUNAMI is being developed to support several key Naval initiatives. TSUNAMI will directly support the Naval Warfare Development Command (NWDC) in the following areas:

- Network-centric warfare.
- Expeditionary maneuver warfare.
- Operational maneuver from the sea.
- Ship to objective maneuver.

The goal of the TSUNAMI program is to allow the navy to exploit the potential benefits of several programs of report:

- The Expeditionary Sensor Grid
- The capabilities of programs of record such as the Joint Strike Fighter and the Amphibious Assault Vehicle

3 SETTING GOALS

TSUNAMI will directly support the development of future Naval communications architectures. The Navy's future communications architectures must be:

- Ubiquitous and thus available everywhere all the time.
- Dynamic and thus constantly changing to match the world.
- Self-forming and thus automatically setup and configured.
- Self-healing and thus virtually maintenance free.
- Heterogeneous and thus diverse.
- Transparent and thus easy for users.
- These characteristics are difficult to model using traditional techniques.

TSUNAMI washes away the limits of traditional techniques using agent-based modeling and simulation (ABMS). TSUNAMI uses Repast ABMS to provide many capabilities:

- TSUNAMI has the ability to simulate battle space motion and interaction.
- TSUNAMI has the ability to clone sensors and sensor fields.
- TSUNAMI has the ability to apply rule sets to simulate message traffic.
- TSUNAMI has the ability to simulate quality of service protocols.
- TSUNAMI has the ability to simulate exercise data management choices on a case by case basis to model realistic traffic loadings and network overheads.

TSUNAMI agents apply dynamic network management and traffic loading protocols in simulated disadvantaged environments. TSUNAMI links explicitly model the uncertain nature of the unreliable paths.

4 THE BATTLE SPACE

TSUNAMI agents represent battle space objects:

- TSUNAMI agents include blue forces such as boats, airplanes, tanks, trucks, missiles, and sensors.
- TSUNAMI agents include red forces such as boats, airplanes, tanks, trucks, missiles, sensors, and weapons of mass destruction.
- TSUNAMI agents include neutral bystanders.

As shown in Figure 1, each TSUNAMI agent has one or more properties:

- Each agent has a location.
- Each agent has an ability to move.
- Each agent has a current heading.
- Each agent has fuel or battery levels.
- Each agent has a memory.
- Each agent has a communications routing capability with specific protocols.

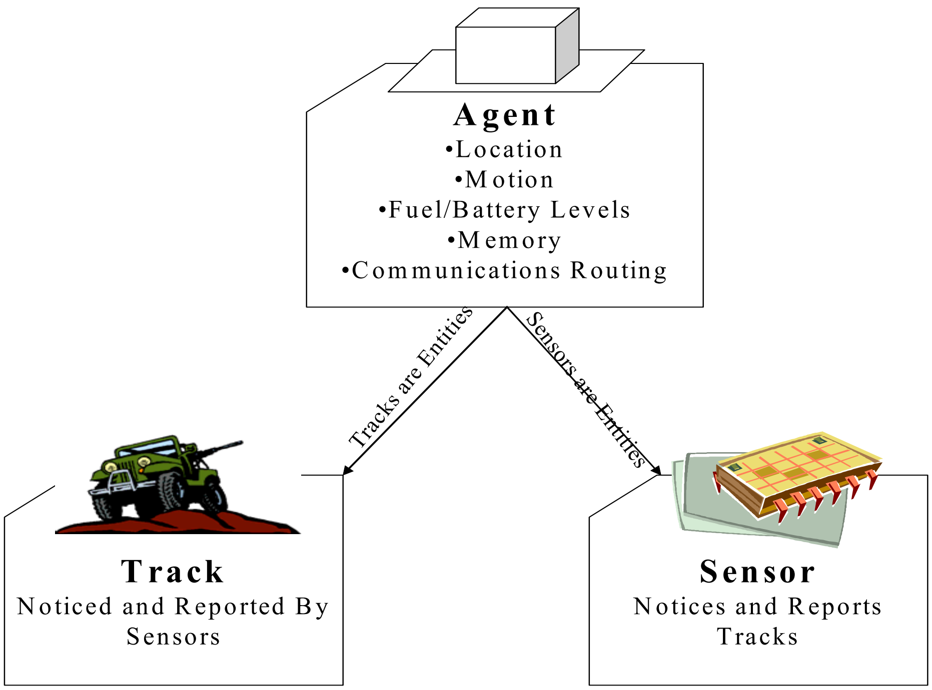

Figure 1: TSUNAMI Agents

TSUNAMI agent behaviors model battle space interactions. TSUNAMI agents have three types of basic behaviors:

- TSUNAMI agents have the ability to move.
- TSUNAMI agents have the ability to sense their surroundings.
- TSUNAMI agents have the ability to communicate.

Each of these basic behaviors have appropriate variations that add appropriate detail and fidelity. TSUNAMI agents move throughout the simulated battle space in three different ways:

- TSUNAMI agents can exhibit responsive motion to fight, follow, or flee other agents.
- TSUNAMI agents can exhibit scripted motion defined by the model users before a simulation run.

- TSUNAMI agents can exhibit random motion when no other options are available.

The TSUNAMI interface indicates the current state of the battle space as shown in Figure 2. The current battle space background is green to increase the readability of the figure. TSUNAMI is designed to display and use real map data as required. Allied forces are blue circles. Fixed sensors are dark blue. Mobile agents are light blue. Hostile forces are red. Neutral bystanders are white boxes.

Several graphs indicate key battle space parameters. Figure 3 shows the TSUNAMI average effective communications range graph. Figure 4 shows the TSUNAMI the average bandwidth for allied and hostile forces graph.

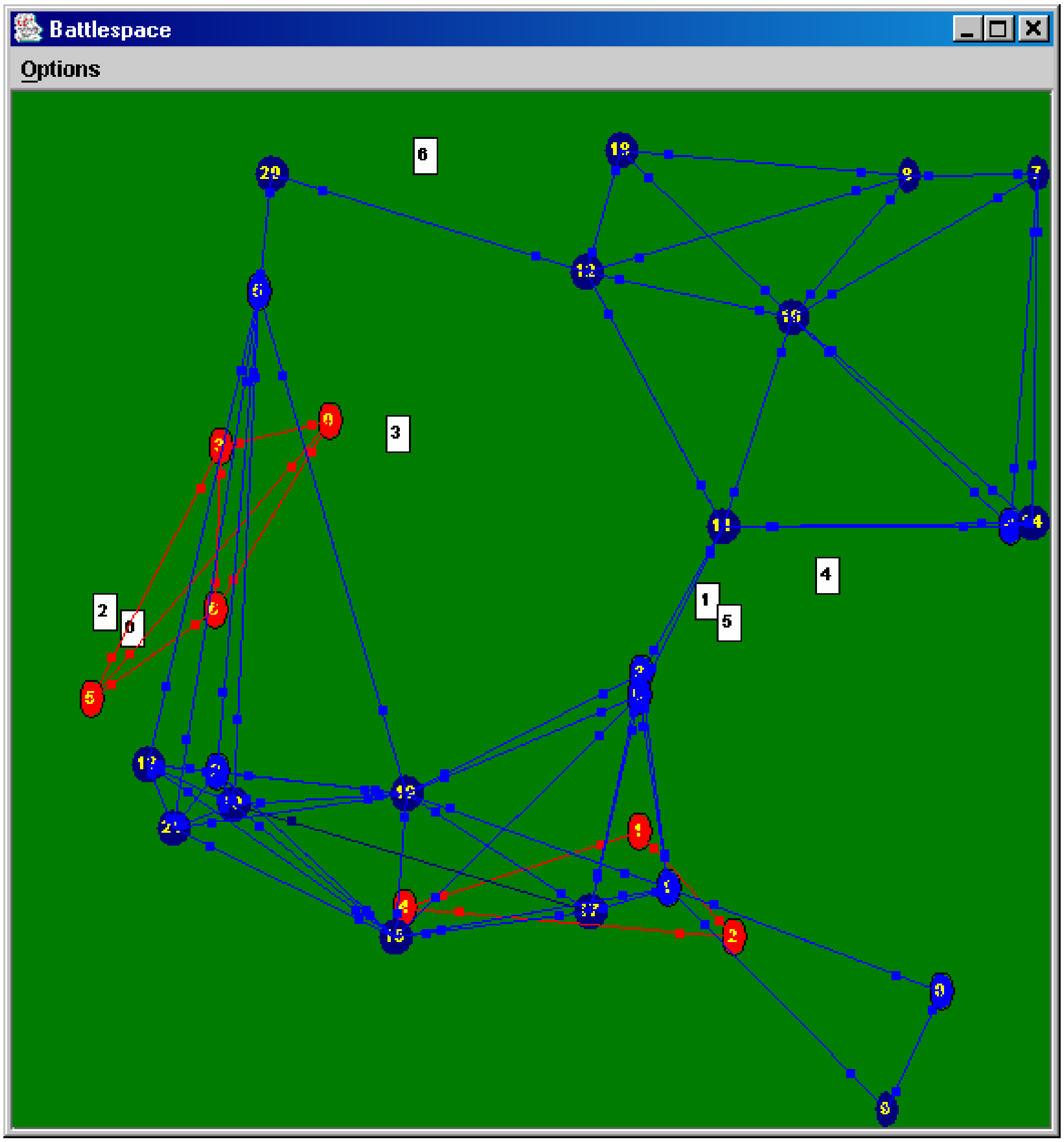

Figure 2: The TSUNAMI Interface

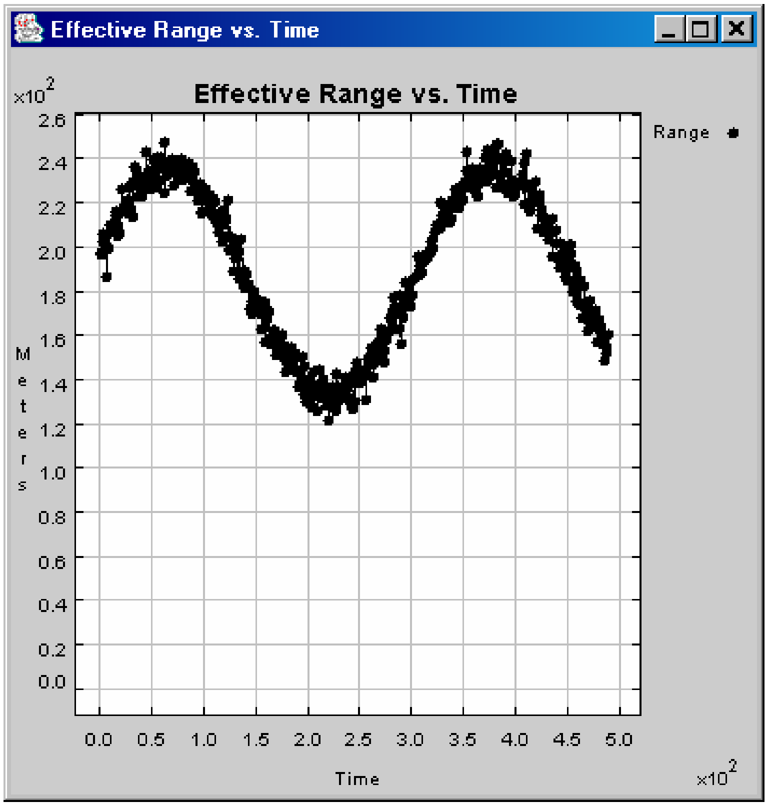

Figure 3: The TSUNAMI Average Effective Communications Range Graph

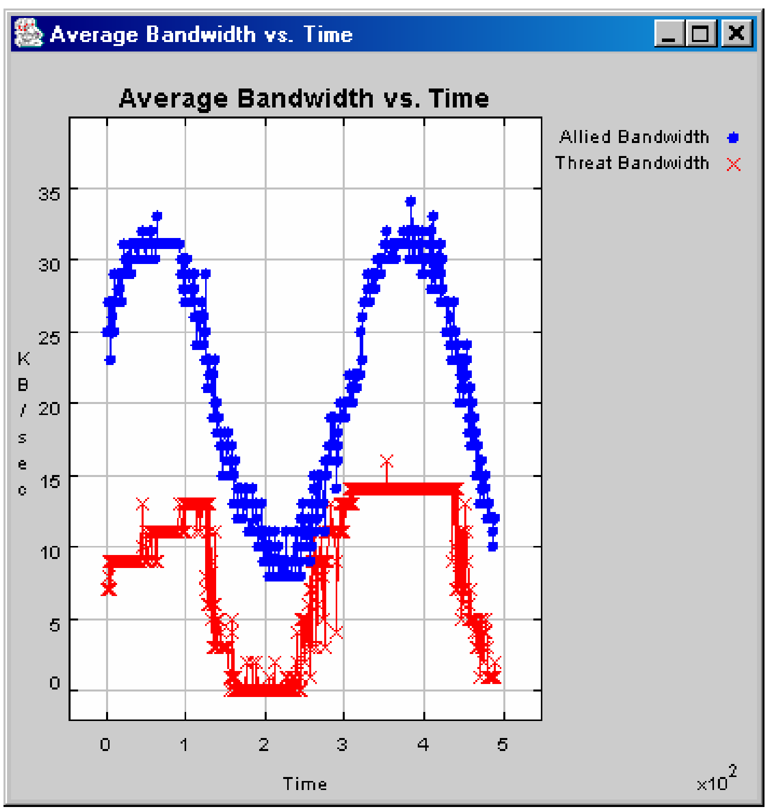

Figure 4: The TSUNAMI Average Bandwidth Graph

5 Simple Example Protocol

TSUNAMI can model many possible communications architectures and protocols. To consider several extremely simple examples, TSUNAMI can model peer-to-peer routing that is accomplished by allowing each agent to select the most appropriate next step for each received message based on several criteria:

- TSUNAMI agents can use their previous experience with each available choice to make new choices.
- TSUNAMI agents can use the current usage of each available choice to make new choices.
- TSUNAMI agents can use the each message's quality of service priority to make new choices.

These simple examples are intended to indicate some of the basic flexibility inherent in TSUNAMI's design. The actual protocols that are modeled can be much more complex.

6 CONCLUSION

The military is in the midst of a shift from platform-centric warfare to network-centric warfare. TSUNAMI directly supports this shift by providing the capability to model future communications architectures. The NWDC and CCASS are collaborating to develop TSUNAMI to support several key NWDC initiatives related to network-centric warfare; expeditionary maneuver warfare; operational maneuver from the sea; and ship to objective maneuver. The goal is to exploit the potential benefits of initiatives such as the Expeditionary Sensor Grid and the capabilities of programs of record such as the Joint Strike Fighter and the Amphibious Assault Vehicle. The NWDC and CCASS are applying agent-based modeling and simulation computing advances to allow TSUNAMI to simulate battle space motion and interaction over real terrain maps; clone sensors and sensor fields; apply rule sets to simulate message traffic; simulate quality of service protocols; and simulate exercise data management choices on a case by case basis to model realistic traffic loadings and network overheads. TSUNAMI agents model interacting blue, red, and neutral forces with complex behaviors and a variety of attributes including varying communications equipment; varying sensing capabilities; varying mobility; varying memory; and varying fuel and battery lifetimes.

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