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An Agent-based Model Simulation of Multiple Collaborating Mobile Ad Hoc Networks (MANET)

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Abstract

The paper presents a preliminary result of using cognitive- and behavior-based modeling framework to simulate a network of MANETs (Mobile Adhoc NETworks) as intelligent agents in a tactical battlefield. We demonstrate the efficacies of an agent-based modeling and the need for developing formal methods for multi-agent simulations from a system of systems (SoS) perspective. The development of our model framework informs the need to describe behaviors and relationships of actors and objects in the context of a mission space, and 2) to provide a foundation for modeling agent behaviors in a way that is plausible with respect to human behavior, a specially from the standpoint of human-system interactions.

1.0. Introduction

The surge in the human dependency on Mobile Ad hoc NETworks (MANET) in various task scenarios (battlefield, emergency response, social network, etc.) is growing exponentially. For example, modern battle command is populated with network-centric physical assets; predominant among these are constellations of MANETs that are used to aid tactical, collaborative communications during real-time battlefield operations. MANETs represent a class of battlefield tactical communication networks that are highly mobile and adaptive with respect to applications. MANETs support robust and efficient battlefield operations, routing, communicating, and distributing information functionalities across their mobile nodes.

Stations in MANETs are usually laptops, Personal digital Assistants (PDAs) or mobile phones. These devices feature Bluetooth and/or IEEE 802.11 (WiFi) network interfaces and communicate in a decentralized manner. Mobility is a key feature of MANETs. Because of their high cost and the lack of flexibility of such networks, experimentation is mostly achieved through simulation.

In the operational environment, MANETs are vulnerable to enemy attacks, failures caused by engineering devices, and occasional degradation due to technology. All these factors require that some enabling tools be developed to support an effective fielding of MANETs for command and control (C2) purposes. It also requires that engineering analysis be conducted to monitor performance over time. Metrics of performance may include vulnerability, resiliency, reliability, trust between users, trust in MANETs, and so on.

MANETs constitute a special class of networks that embrace humans and machines, leading to what may be described as cognitive socio-technical systems (CSTS). This increases the complexities involved how interactions occur in systems: human-human, human-machine, or machine-machines. These qualities demand that MANETs be designed to acquire certain human traits similar to how human interact and behave in dynamic task situations. This is the motivating factor for considering agent models for MANETs. This consideration forces us to look at important human traits such as perception, cognition, behavior, collaboration, and team work. Our agent-based simulation model incorporates these characteristics.

2. Intelligent Agents

Consider a simplified battlefield tactical communication networks shown in Figure 1. We may need to know how agents perceive the environment based on MANET information load (voice, data, voice + data); how humans make decision based on the tactical requirements and supported by MANET; how multiple humans and multiple MANET users interact; and how such interactions enable performance. Answers to these perceptual, cognitive, social, and behavior questions lead to our interest in embodied definitions of specialized cognitive agents for human-mobile network interaction. It is possible to discover new behaviors as a result of many interacting agent behaviors.

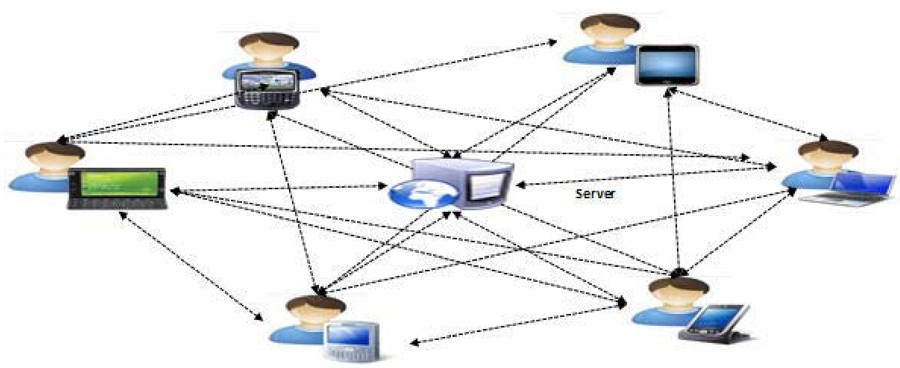


Figure 1. A simplified MANET topology.

Intelligent agents can then be defined as a human or a MANET device that can recognize its environment information, make sense of the context, perform plausible reasoning, and decide on courses of action while collaborating with other agents. In the battlefield environment, the agents should be able to predict the enemy states and plan courses of action to minimize the MANET vulnerability during operations. In concert with these assertions, our agent concept is to develop methods for understanding how MANET operators exploit information in opportunistic domains with adaptive and dynamic windows of decision opportunities; study how agent interactions between MANET and humans, human and human, or MANET to MANET nodes, orchestrate coping strategies during unexpected attacks, uncertainties, information sharing, and how they collaborate to redefine new goals during system agitation states. Table 1 gives an anectodal view of some of the methods for collaboration by agents.

Table 1: Possible agent collaboration modalities

	MANET device	Human
MANET device	Instructions and rules	Model-based predictions and look-up table
Human	User-interface, visual tools	Social-based: dialogs and communication

Drawing from many definitions and requirement studies in the agent community (Wooldridge, 1995), SoS (Wegner, et al., 2006), M&S (Bernstein, et al., 2006) ,social sciences and cognitive psychology, an intelligent is likely to possess at least one of the following properties:

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

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

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

(4) Self-organized—the notion that agents that have intelligent 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 (Ntuen, 2006);

(7). Agitative states—the notion that MANET agents in the battlefield 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.

Intelligent agents must be able to learn (through various methods such as reinforcement, Bayesian, feedback, imitation, etc). They must exhibit certain levels of expertise based on level of assigned experience on a task, demonstrate intelligent or ignorance of a subject matter, and be vulnerable to intentional bias (Kahneman, Slovic, and Tversky, 1999). Premised on these human-like characteristics, a MANET node is considered to represent an agent of human and device entities. Thus a node can exhibit behaviors of various forms—from passive to active, static to adaptive, and be capable of demonstrating selfish-, collaborative-, and participative-, leadership-, and followership-behaviors. A learning agent is also constructed to have situation awareness capability while interacting with its environment. Hence, an agent can monitor the behavior of other agents, take commands from a command and control (C2) agent, understand its roles and when to perform them, learn personal and organization level preferences, and be able to predict future actions. The objective of this work is to incorporate these capabilities to the MANET agents

3. A Cognitive Model of MANET Agents

The core technical challenge of our work involves tackling cross-disciplinary issues of dynamic network protocol and multi-agent system design. An obvious approach is to build an agent out of two (or more) subsystems: a deliberative one, containing a symbolic world model, which develops plans and makes decisions in a rational manner; and a reactive one, which is capable of reacting to events that occur in the environment without engaging in complex reasoning. Often, the reactive component is given some kind of precedence over the deliberative one, so that it can provide a rapid response to important environmental events. Rather than the classical approach of symbolic reasoning, it is assumed here that agent's dynamic behavior is a result of interaction with other agents and the environment in which it works. The agent's ability to reason is not necessarily a sufficient condition for sensemaking, but the resultant behaviors arising from interactions—socially and ecologically.

One novel approach to representing intelligent behaviors to MANET agents is to use the OODA(Observe, Orient, Decide, Act) model. This is shown in Figure 2 for a four-node MANET system. The OODA model was developed by Boyd (1987) to address the concerns of military decision-making processes that consider uncertainties. In the OODA model, the "Orient" sub-model attempts to capture the cognitive processes involved during sensemaking—although it was never addressed as such. The components describe the human cognitive tasks with feedback and feed-forward loops. Boyd describes the sensemaking process in four stages with the orientation stage being the stage at which most of the sensemaking process takes place.

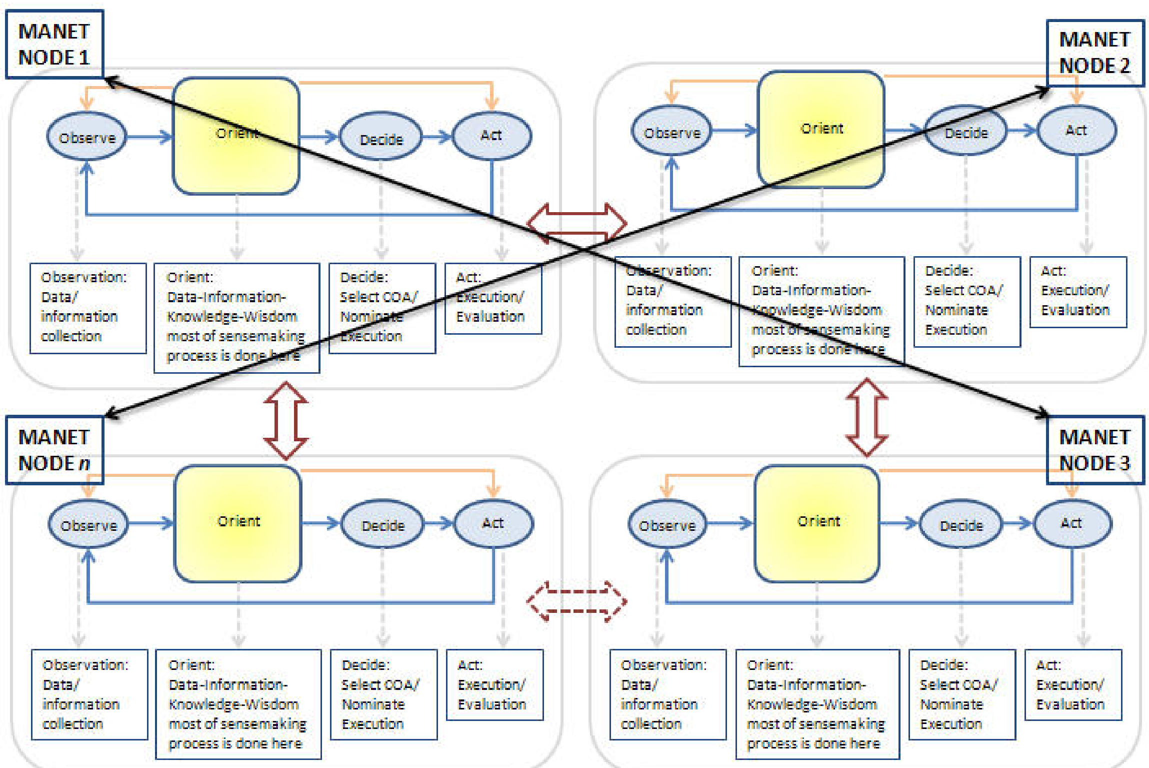


Figure 2. Multiple connected OODA for MANET agents

The multiple connected OODA network is modeled as a propositional network. According to Black [5], propositional networks are sets of entities illustrated by their interrelated relations and properties. It is similar to concept map in that they both represent knowledge structures and contents in a declarative way. The causal relations in concept map can also be represented as a series of condition-action or if-then rules.

The model framework is based on shared ontology. Ontology is often defined as an "explicit specification of a conceptualization" (Fox & Gruninger, 1997; Gruber, 1993). It is used to define and organize knowledge concepts in a system. Thus, ontology can be regarded as a tool for information network management. The ontology approach for the multiple OODA network is simple: *When we perform actions, we do so after a careful selection, often through rational model, of interrelated activities*.

The spatial connection or relationship of nodes (with each node with agent properties) and their intentional forms a network, referred to here as a Knowledge Action Network for Agents (KANA). KANA is a construct similar to Black's propositional network, except that KANA allows for representation of retrospective, current, and prospective sensemaking schemata for agents so as to enable reflexive and envisioning reasoning behaviors. KANA also allows representation for agents to collaborate during a reasoning process to manage uncertain system resources to achieve intended system-level actions. KANA is designed to capture and build behavior relations between agents employing well matured cognitive tools such as activity theory, cognitive task analysis, behavior analysis, functional requirement specification, and operation tracing and mapping. For example, social behavior ontology should be able to represent: how interactions occur among agents; how collaborations take place; how agents negotiate and reach consensus; and how leaders are selected among agents. A more global ontology may represent how variability in agent behaviors are captured over time (temporal), space (spatial), location of activity (situational), and effect of workload (conditional). KANA also addresses human dimensions, conditions and rules for behavior representations, autonomy, and intention (shared and individual), and characteristics of SoS at different platforms and design hierarchies (e.g., soldier, tank, platoon, etc.) as explicated on the battlefield (Cioppa, Lucas, & Sanchez, 2004).

We consider MANET agents to learn and understand the human user actions. These agents should be able to **P**redict, **E**nvision, **A**nticipate, **R**eason, and **L**earn (PEARL). This leads to the concept of **PEARL** as a high-level meta-agent for supervising the behaviors of other agents. They can use what they have learned from interactions to determine what to do in the future within its environment. The learning agent watches out for themselves, enforcing their own individual preferences and taking advantages of others preferences and biases. PEARL has a three-stage interacting layer: a currency layer which has some or all information about the current state of the system; a retrospective sensemaking layer which has some or all the pertinent information about the past system behaviors and performance measures, including, e.g, beliefs either about the external world or the system's internal state; and prospective (envisioning) state which has models of a system and its agent behaviors. The success of PEARL lies on how information is shared between agents. Thus, PEARL allows agents the ability for perceptual-control of dynamic actions through learning, shifting system goals, time pressure, information dynamics, complex battlefield operations requiring adaptive courses of actions, skill acquisition, adaptive and self-organizing behaviors, visualizing problem space, and hierarchical multilayer interaction of command and control tasks between and among agents (human and software) performing tasks, sharing resources, and self organizing--including exchanging leadership roles in the cell—such as switching roles and building redundancy systems (self-satisficing solutions) during high workload in the SoS; and autopoiesis--a self-production - maintenance of a living organism's form with time and flows.

4. SAMPLE SIMULATION

We are developing two agent-based environments. The first is a constructive simulation based on network and graph theory. Here the user can create arbitrary number of MANET nodes and conduct the simulation experiment over a stipulated use time. This is shown in Figure 3a. For each node, the user assigns the agent roles such as scouting, security operation, etc., node potential failure mechanisms, a list of potential vulnerable factors (e.g., jamming, disruption, spoofing, attack, fake routing message, interceptions, etc.) and the risk factors for each events. The collection of agent properties is shown in Figure 3b. The simulation can produce statistics as queried by the user. For example, in Figure 4, statistics on C2 manager (from PEARL agent) is produced. In Figure 4 PEARL agent can produce situation watch statistics such the net intrusion (89.3%), device failures (33.8%), communication failure (85.5%), and discrepancy in messages (38.8%). PEARL also identifies enemy spying into the network (91%), listening to communication (20%), and attempted attacks on the network (61%). PEARL agent uses cause-effect and pattern mapping to predict the network behaviors. For instance, the simulation showed that loss of information was detected 30.3%, information degraded about 73.7%, and there were critical changes in node behaviors (83.7%). The consequences for these actions are identified. For instance, loss of safety occurred 73% of the time these events happen. The vulnerability of the network in this example is 66.8%--meaning that the network is vulnerable to outside incursions or likely to fail in performing its duty 66.8 percent of the time.

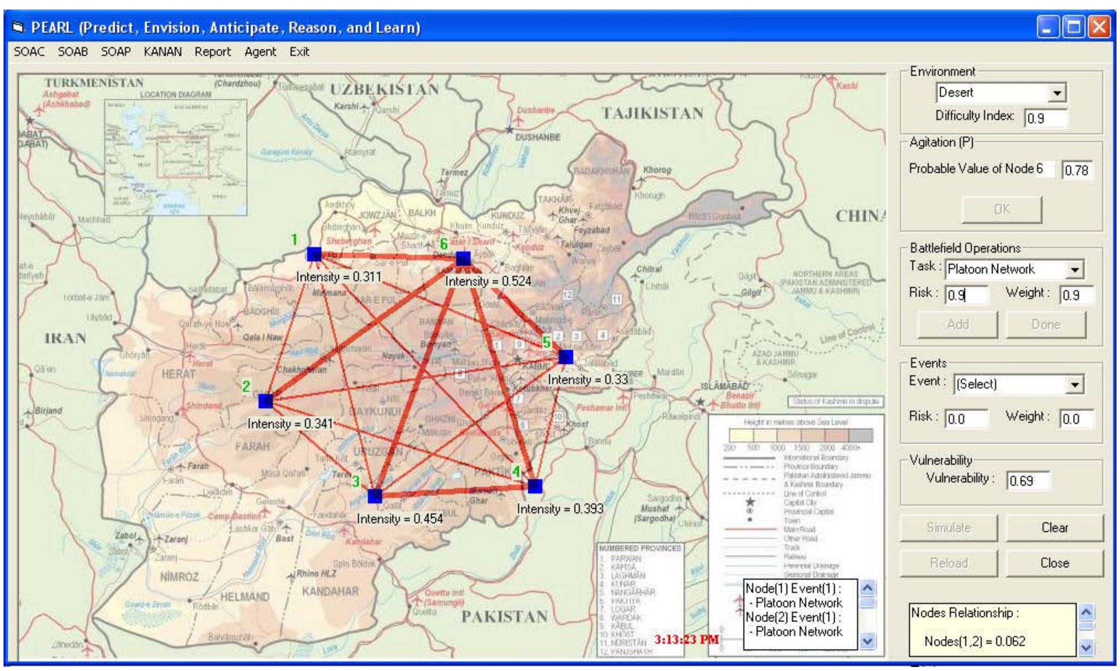


Figure 3a. Sample MANET nodes

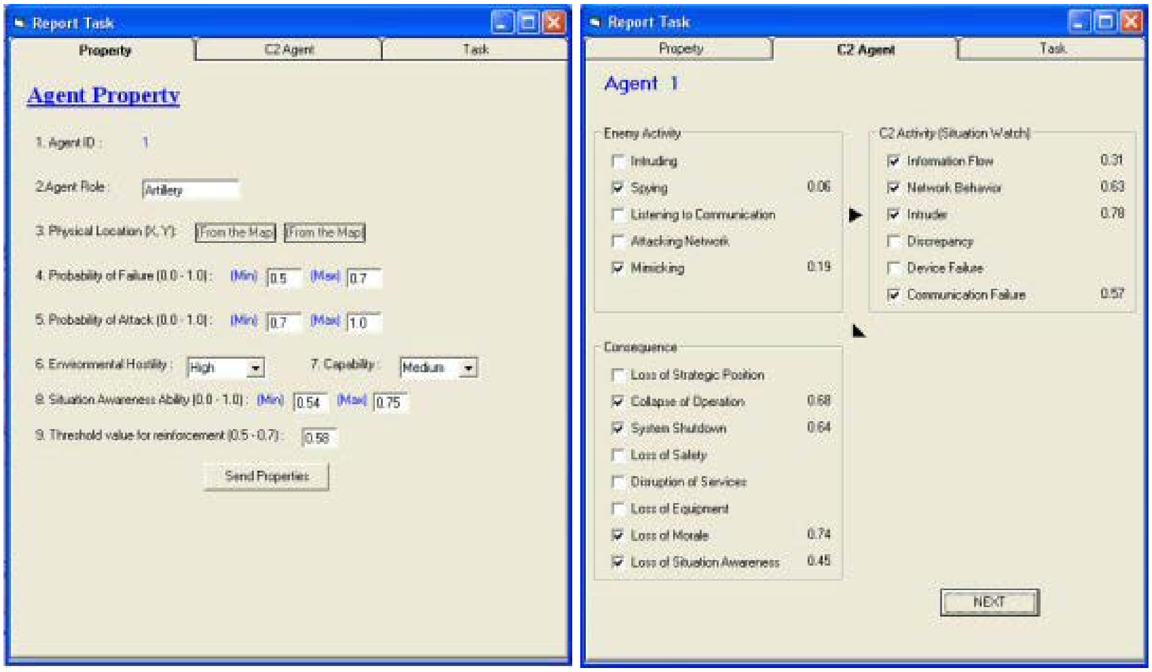


Figure 3b. A window to capture agent properties

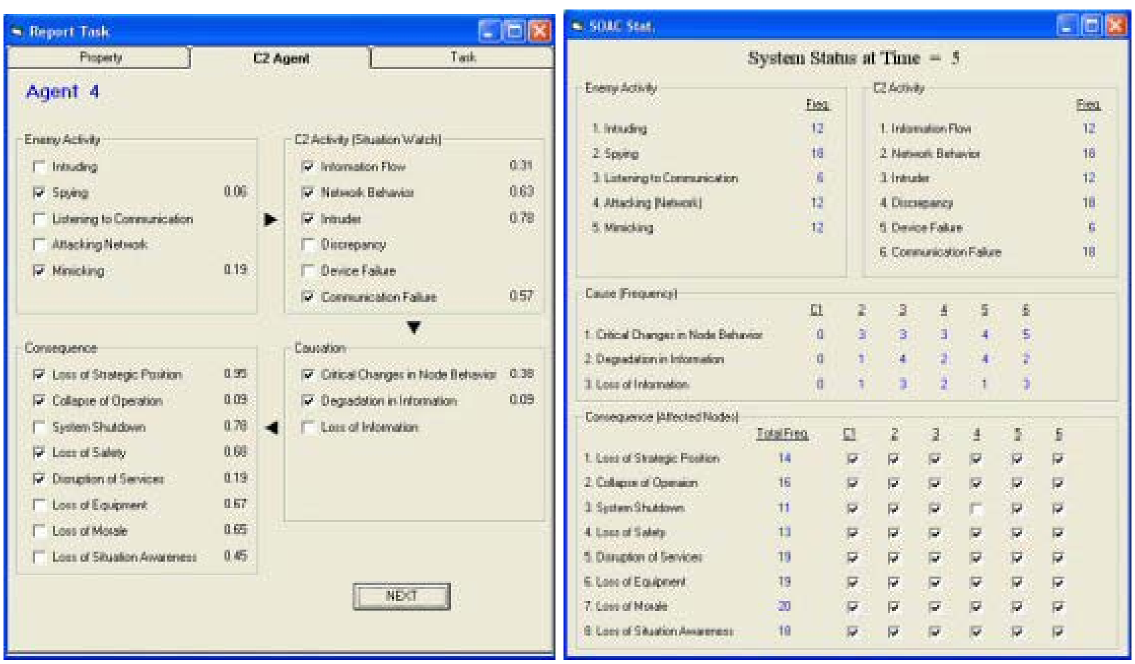
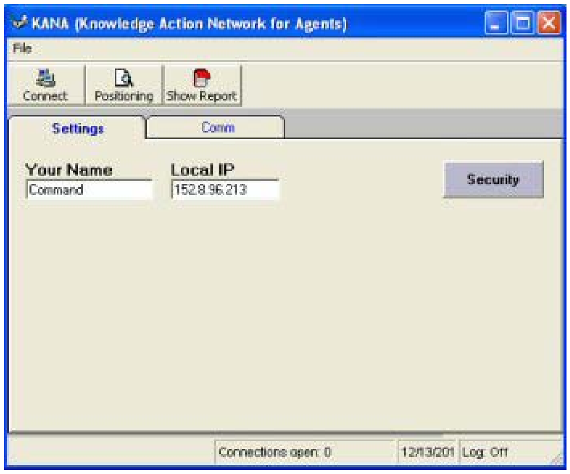
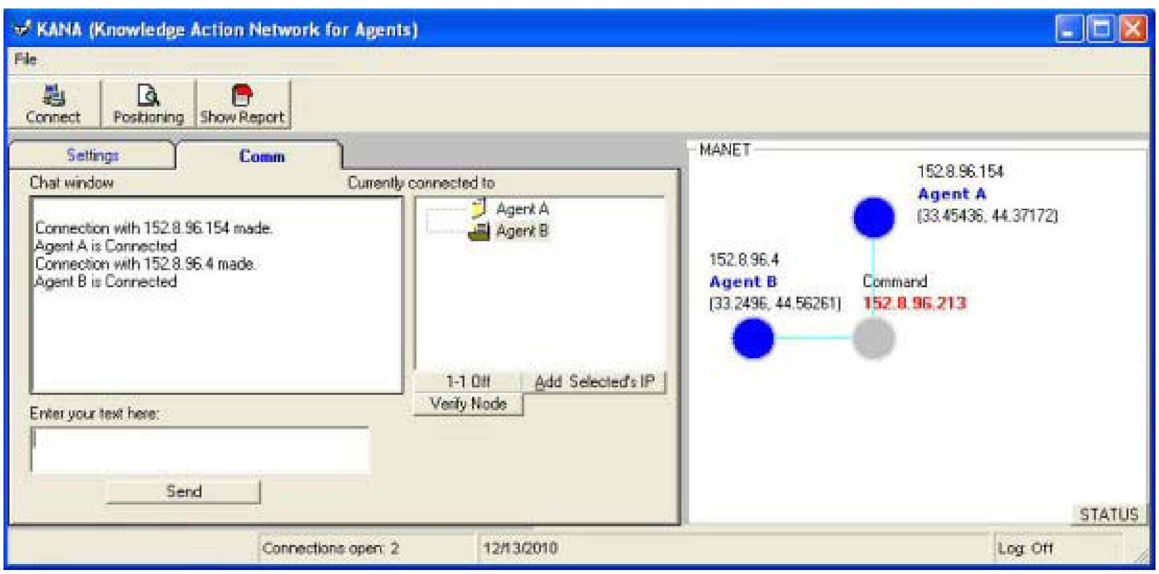


Figure 4. Sample output statistics from PEARL agent

4. Performance Evaluation of a Battlefield Visualization Tool

The second part of the project is the experimental domain which seeks to mimic MANET behaviors using a collaborative sensemaking software system (S3) developed by Ntuen, Park, and Kim (2008). Here, we allow up to three users and computers that are remotely (geographically dispersed) within our laboratory to serve as different MANET nodes. The purpose of this is to enable real-time technology transfer. At the present time, Figure 5 shows and example experimental simulation for direct and active MANET configuration. In Figure 5, two MANET nodes (users) and C2 (PEARL) are configured as shown on the upper part of the Figure 5. The lower part of Figure 5 shows sample window that captures agent (Node) information in real-time information. Figure 6 shows an example of how PEAR recognizes intruder by asking for node entry verification.





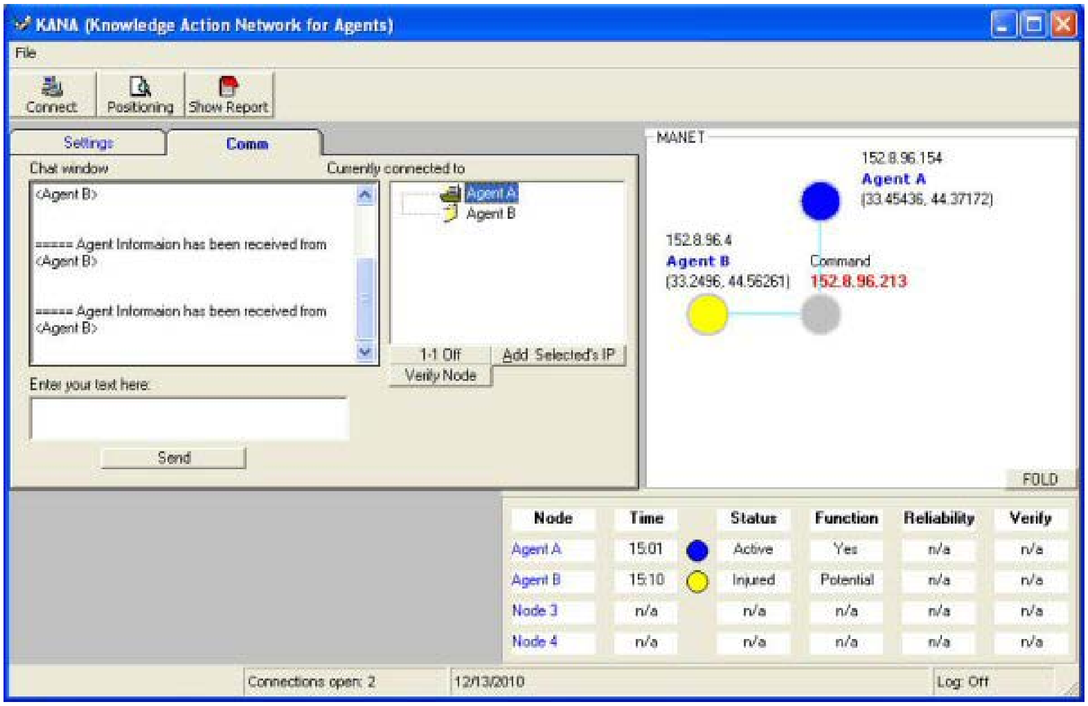
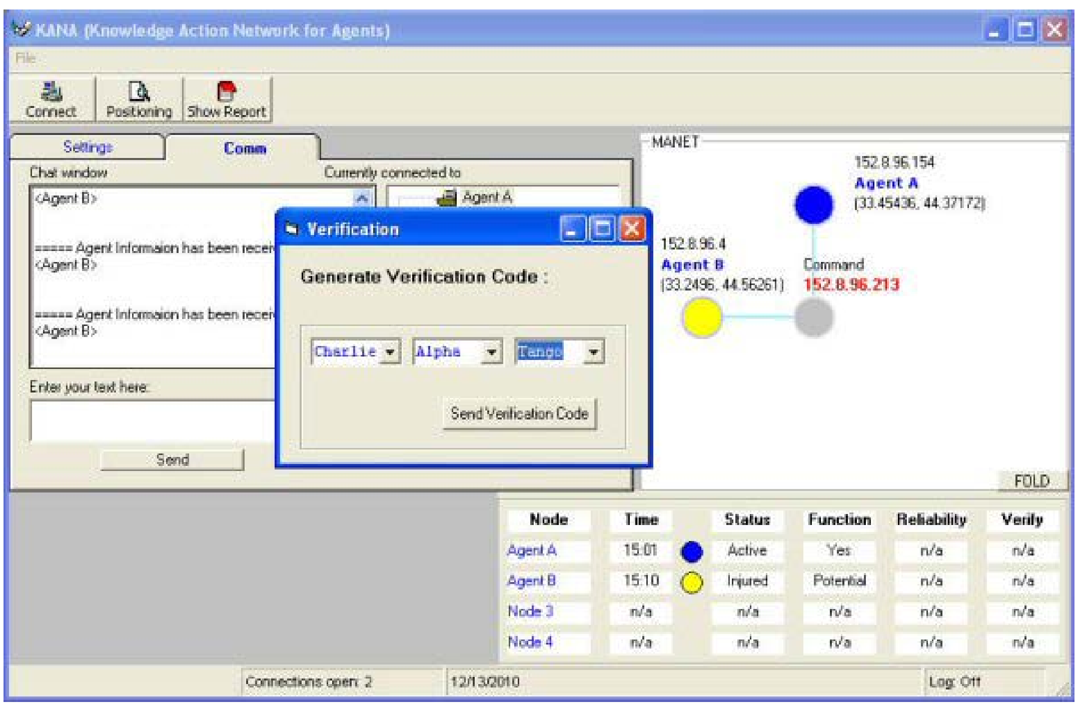


Figure 5. Sample MANET agent experimental frame.



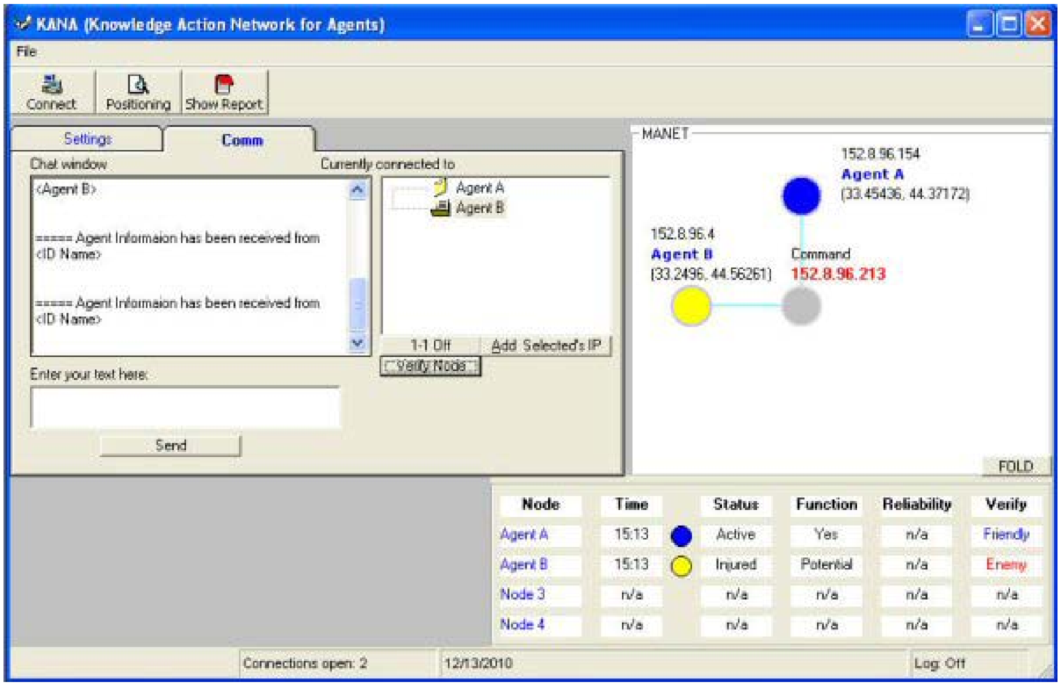


Figure 6. Network intrusion detection and verification by PEARL agent

4. Summary and Conclusion

MANETs constitute a special class of networks that embrace humans and machines, leading to what may be described as cognitive socio-technical systems (CSTS). This increases the complexities involved how interactions occur in systems: human-human, human-machine, or machine-machines. Modeling MANET from the standpoint of system of systems is the focus of our on-going project. The current results are anecdotal with respect to scale-down properties scoped for demonstration of the efficacy of agents in a system of systems (SoS) MANETs. From our pilot study, two fundamental meta problems are constraints to realistic cognitive modeling and representation of agent properties. The first is dealing with adaptive behaviors as a consequent of information changes from battlefield tasks and the supporting mobile wireless communication networks. KANA knowledge manager in our system is designed to manage this kind of situation in large-scale complex networks. The second challenge is reducing complicated and complex human observable behaviors to simple qualitative rules for agents to learn. We achieved this by using decoupled OODA models.

In our simplified experiments with PEARL agent, we can compute useful MANET network properties such as vulnerability, resiliency, and reliability. We are not dealing with the typical network statistical characteristics such as centrality. Hence, there are other human-centric agent properties to be added. These include, but are not limited to, how agents believe each other as a function of stereotypical and bias knowledge, social affinity as a function of team situation awareness and collaboration, how agents bind problems in context and provide solutions when faced with uncertainties and surprise, how agents learn (e.g., what important factors make an agent to use, say, reinforcement learning as opposed to imitation learning), the kinds of emerging behaviors when an agent interacts with other agents in context, and the level and probability of self-organization by agents when a network is attacked. These issues are critical to the survivability of MANETS in battlefields.

Our simplified simulation further inform that: (a) if decision making in a dynamic battlefield problem solving environment is to be driven by simulation, it is necessary to develop real-time models than can self organize in response to new information; (b) SoS simulation inherits special properties of advanced distributed simulation which requires rapid information processing and manipulation of extremely large information; and (c) when multiple entity behaviors interact, it is possible to derive latent intelligent behaviors that make the functioning of SoS scalable across different echelons of information abstraction and control. These are the basic research problems our agent-based environment will address as an on-going research.

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