Biologically Inspired Methods for Agile Command and Control (BIO C2)

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Abstract: In a dynamic and complex environment, agile command and control responses are needed to handle both conventional and asymmetric challenges. Agile command and control is particularly difficult due to the necessity of cross-scale interaction. The technical idea is to develop biologically inspired methods based on individual behavior to population response dynamics to facilitate cross-scale interaction or coupling. The goal is to determine "markers" that can be placed in the environment, which can be "read" at multiple scales to produce a more agile response. Agent-based approaches will be used to investigate optimal coupling or exploitation methods between scales, including (1) uncoordinated collaboration based on biologically inspired methods; (2) coordinated collaboration or peer-to-peer methods; and (3) hybrid methods, including uncoordinated, coordinated, and/or hierarchical approaches.

Problem Statement: In a dynamic and complex threat environment, agile command and control responses are needed to handle both conventional and asymmetric threats (Cabana et al., 2006). Agile command and control is particularly difficult in such systems due to the necessity of cross-scale interaction. For example, in the Netted Sensor *Enterprise*[1] shown in Figure 1, the sensor mote field (squares on ground) is at one scale and the aerial assets, Air and Space Operations Center (AOC), and aggregated mote field information (A) are at a second scale. In addition, the AOC has Air Tasking Orders (ATO) being developed every 72 hours and Time Critical Targeting (TCT) happening on the order of 10 minutes. These vastly different mission planning time scales draw on the same Netted Sensor assets creating negative implications for command and control responses to threats.

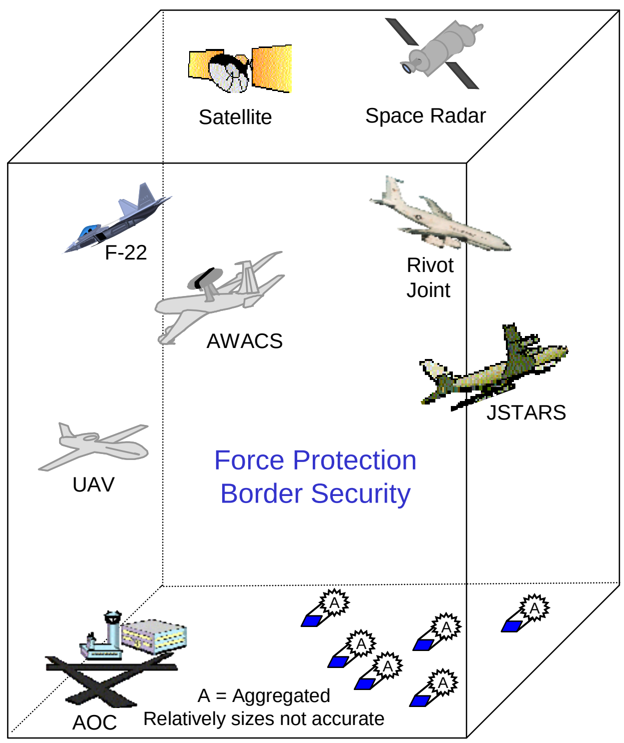

Figure 1: The Netted Sensor (NS) Enterprise—the Air and Space Operations Center (AOC), aerial sensor assets, and bases protected by mote fields.

Technical Idea/Research Hypothesis: The technical idea is to develop biologically inspired methods based on individual behavior to population response dynamics to facilitate cross-scale interaction or coupling. There are many scales in biological systems, including molecular, cellular, organism, population, and ecosystem. Biological coupling between scales will be emulated in the Netted Sensor (NS) Enterprise—an important problem for our sponsors. Sensor networks offer an individual behavior (sensor) to population response (*red force tracking*[2]) analogy that is promising, and thus was selected as the initial case study. Agent-based approaches will be used to map specific threats in the NS Enterprise to an optimal scale coupling method, including those based on biology (e.g., uncoordinated) and more traditional methods (e.g., hierarchical and peer-to-peer). The goal is to increase the agility of the response to the threat while minimizing the effect of cross-scale interaction. Therefore, biologically inspired methods are hypothesized to facilitate multiple scale interaction.

Technical Approach: The first step in the approach is to discover and adapt multiple scale, biologically inspired methods. A proof-of-concept has been explored using bacterial cell-to-cell communication to develop an algorithm for detecting threats in an acoustic sensor mote field (Mathieu et al., 2006). The method is based on bioluminescent (light-producing) bacteria. The bacteria both produce and sense a chemical that diffuses into the environment; when a threshold concentration is reached, light production is up-regulated or turned on (Ward et al., 2001; Miller et al., 2005. Camilli and Bassler, 2006). This concentration is often related to a certain density of bacteria, so the response is referred to as quorum sensing and the chemical is called a quorum sensing molecule (QSM). In this example, a bacterium "marks" its environment using the QSM, which is sensed or "read" by neighboring bacteria in the population to produce a population-wide response (light production).

In extending the method to the sensor mote field, each acoustic node has a calculated QSM or information sharing level (the "marker"), which is based on the non-linear dynamics observed in the biological system. This level is available to be "read" by neighboring nodes to calculate their QSM level. The mathematics used for the QSM algorithm were based on population scale differential equations; however, there are many studies available that have extended the mathematics to the individual, agent-based scale that is needed for algorithm development. For example, extensive research has been done on schooling fish (Vabo and Nottestad, 1997; Kunz and Hemelrijk, 2003; Zheng et al., 2005). Biologically inspired methods will be mapped to command and control challenges and made available on the Web in a searchable format. This Web service design was modeled after a similar capability for using biology to design physical systems (Vincent et al., 2001).

The second step in this approach is to develop agent-based models of the various scales in the NS Enterprise. The two scales in the AOC will be modeled as individual agents that interact with the aerial assets (e.g. AWACS, space radar, etc.) and the aggregated values from the mote fields. The QSM algorithm can be applied to the NS Enterprise as well. For example, assume that the JSTARS and a UAV both detect a threat moving on the ground. These assets would then assign a threat value to the specific area where the threat was detected. This threat value is the "marker" and the rest of the NS Enterprise can "read" that marker. In addition, the QSM can be viewed more traditionally as a token of information being passed from the JSTARS to the UAV. In summary, an agent-based approach will be used to investigate optimal coupling strategies for specific NS threats: (1) uncoordinated collaboration based on biologically inspired methods; (2) coordinated collaboration based on passing tokens between assets; and (3) hybrid methods including combinations of uncoordinated, coordinated, and even hierarchical approaches.

In the first two years, this approach will be applied to the NS Enterprise. In the final year, the approach will be extended to another domain. Possible domains include: disaster response, data sharing, distributed operations, etc. Based on the White House Report (2006) for Hurricane Katrina, there was a 56-hour period in which local, state, and federal agents had time to prepare for the disaster. The existing plan was for the most part executed well—unfortunately, the plan was not sufficient. Since national disasters are impossible to rehearse, local rehearsals are the only means of obtaining information on the adequacy of disaster plans. However, it is very difficult to aggregate the results from local rehearsals into a national disaster plan. A simulation environment, as described above, provides a means to aggregate the results from local exercises. For instance, in Hurricane Katrina, local responders marked houses that had been inspected and "marked" with Xs. This "marking" is equivalent to the QSM. The "marking" was available for other first responders to "read," as well as agents from other scales such as state and federal agents driving a boat or truck, as well as flying in helicopters through the neighborhoods. The agent-based simulation environment can be used to experiment with how to "mark" and "read" the environment to best facilitate cross-scale interaction.

Impact: Threats in the Netted Sensor Enterprise will be mapped to the optimal coupling or exploitation method.

- Uncoordinated Collaboration (e.g. biologically inspired)
- Coordinated Collaboration (e.g. peer-to-peer)
- Hybrid Method (uncoordinated, coordinated, hierarchical approaches)

Based on the selection of the Netted Sensor Enterprise case study, sponsor transition opportunities exist in domains where agile functionality for conventional and asymmetric threats are needed, including Sensor Networks, Air and Space Operations Center (AOC), and Netcentric Enabled Command and Control (NECC). The techniques developed will be beneficial for many multiple scale enterprise challenges, including disaster response, distributed operations, and data sharing—one will be explored extensively in the third year.

In addition, this research supports the corporate thrust in Enterprise System Engineering through the development of multiple scale analysis techniques, which is of interest to all of our sponsors (DoD, Intelligence, DHS, DHHS, etc.). This work draws extensively on mathematical biotechnology and addresses the area of agile command and control, which is needed for an optimal biosecurity response—both of which are corporate thrust areas.

A searchable biological strategies Web service applied to command and control challenges will be developed and maintained on the external MITRE website to facilitate the exchange of ideas in this area. The report "Towards 2020 Science" (Emmot, 2006) states, "Big challenges for future computing systems have elegant analogies and solutions in biology, such as the development and evolution of complex systems, resilience and fault tolerance, and adaptation and learning." Publications will be pursued in refereed journals and conference proceedings in, potentially, three distinct research areas: sensor networks, agent-based approaches, mathematical biology.

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Notes

[1]*An Enterprise is defined here as a decision making entity that has a homeostatic environment (e.g. internal equilibrium) and contains autonomous agents.*

[2]*Blue force tracking is beyond the scope of this research effort.*

[3]*An example scenario: (1) a moving target detection on the ground from JSTARS or space radar; (2) AWACS provides radio frequency emitter data for the same target (ESM); (3) Video of the target is obtained from a UAV; and (4) acoustic mote field sensors determines if the target is small or large.*

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