MULTI-AGENT SYSTEM FOR MISSION AND SITUATIONAL AWARENESS MANAGEMENT (MASAM) FOR AIRBORNE PLATFORMS (U)

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ABSTRACT (U)

(U) This paper will describe the application of improved methods of sorting, classifying, and identifying pulsed and modulated CW command and control (C2) emitters, whether air, land, sea, or subsurface. These methods are based on Artificial Intelligence (AI) and include:

- ***Probabilistic reasoning techniques*** such as Bayesian and/or Dempster-Shafer theory for data fusion and analysis.
- ***Genetic algorithms*** for multi-dimensional search and optimization (i.e. to search for optimized maneuvering and threat-response tactics.)
- ***Fuzzy set theory***, which can be implemented with various other AI techniques. For example, fuzzy logic controllers may be coupled to genetic algorithms and knowledge based rule-generating systems to provide adaptive control mechanisms.
- ***Neural networks, to aid in solving many*** pattern recognition, decision-making, data fusion and analysis problems.

(U) We will then discuss the integration of the results from these techniques with software agents, to support the capability to continuously manage the influx of on-board sensor data with received off-board information to maintain situational awareness (the relationship between own-platform and all other observed platforms in the context of the common physical environment). Software agents are characterized as autonomous, intelligent, collaborative, and perhaps exhibit some degree of mobility, acting on a user's behalf in order to meet specific objectives. Lastly, we will define the concept of a mission management system that uses the developed situational awareness to perform targeting, avoidance, and denial (countermeasures) functions of own-platform against other-platforms, while assessing own-platform states such as weapon loads and electromagnetic combat capability. A further function of the mission management system would be to specify ingress/egress routing.

INTRODUCTION (U)

(U) This paper will describe the application of the latest information and data processing technologies[1] for airborne platforms operating in the high-connectivity future battlefield environment. This high-connectivity battlefield environment will provide individual airborne platforms access to full, real-time data which is currently accessible only by senior commanders in non-real-time. As a result of this massive data overload, information warfare becomes a major consideration. The high connectivity, enemy use of COTS technology and ready availability of easy encryption complicate the information analysis task, and the formulation of platform situational awareness functions. Requirements will exist for message traffic analysis as well as Specific Emitter Identification (SEI). In addition, various levels of association among parameters, emitters, platforms, and intentions must be performed.

(U) The EW problem presented is large and significant, as seen in Figure 1. As the modern

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[1] (U) Sciortino, J.C. Jr, et al., (2000)."The Role of Artificial Intelligence and Complex Adaptive Systems in Network-Centric Electronic Warfare", Proceedings of the 45th Joint EW Conference, 1-4 May 2000, Naval Postgraduate School, Monterey, CA.

battlefield takes shape, the solutions adopted must meet the challenges posed in such an environment. Few aircraft have the luxury of adding additional aircrew or significantly more hardware. With these constraints in mind, it appears that the collective set of problems must be solved in either pure software (SW), or more likely in a mixture of SW and advanced processing hardware (HW) which includes small, but massively parallel processors. The software used must be adaptive to its environment, capable of changing its approach in order to analyze new problems. It may even be required to pose, analyze, and then solve certain mission related situational problems.

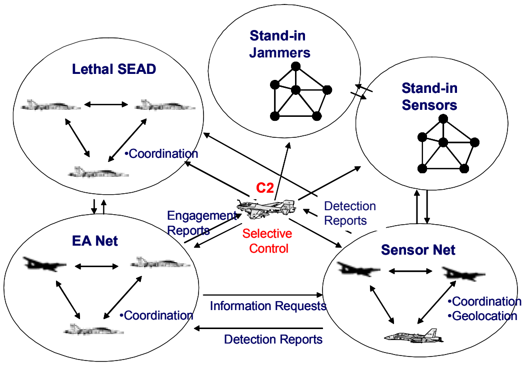

Figure 1: (U) The electromagnetic environment.

(U) Several key technologies are being exploited to provide these capabilities in the software end of the spectrum, including artificial neural networks*,* continuous valued logic, genetic algorithms[2], data fusion techniques, reasoning under uncertainty, certainty factor analysis, knowledge-based rule-generating systems (expert systems)[3] and Multi-Agent Systems[4] (MAS) (Figure 3). The collection of such technologies will be generally referred to as "autonomous intelligence technologies", or (AIT), since such technologies are being used to produce autonomous, goal-directed systems. An enabling technology that provides infrastructure support for integrating such AIT is the Control of Agent Based System (CoABS) grid (Figures 2, 3).

(U) This paper will not describe the AIT (those details can be found in the references), but rather, will focus on the CoABS grid infrastructure. We will first describe the CoABS program and the CoABS grid, as well as how the grid is being used to support the ESM problem domain by providing the necessary infrastructure support to the agents that interact with the AIT. Next, we will describe the results from our initial experiments, consisting primarily of integrating the solution from these emitter identification algorithms with the CoABS grid agents. Lastly, we will provide a brief summary and conclusion.

CoABS PROGRAM AND AGENT GRID (U)

(U) The Control of Agent-Based Systems[5] (CoABS) program was a DARPA program, aimed to develop and demonstrate techniques to safely control, coordinate, and manage large systems of autonomous software agents. CoABS has investigated the use of agent technology to improve military command, control, communication, and intelligence gathering. The military environment is dynamic, with quickly changing operations, moving hardware and software that are continually connecting and disconnecting, and bursty bandwidth availability. Inflexible stove-piped legacy

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[2] (U) Ridder, J., Oh, C. (2003). "Cooperative Control of Autonomous Stand-In Jammers," Joint Electronic Warfare Conference, May 2003.

[3] (U) Kowtha, V.C., B. Ford., M.J. Thompson and Sciortino, J.C., (2001) "Emitter Classification with CANEWS-2", Proceedings of the Joint Electronic Warfare Conference, 30 April-3 May 2001, Naval Postgraduate School, Monterey, CA.

[4] (U) Sciortino, J.C., Jr., et al (2001) "Implementation of Battlespace Agents for Network-Centric Electronic Warfare," ***SPIE Proceedings***, 4396:99-107.

[5] (U) http://coabs.globalinfotek.com

systems that were never meant to be integrated are, nevertheless, of vital importance to military planning and operations. Multiple hardware and software platforms as well as data interfaces and standards further complicate the picture. In addition, military personnel are overwhelmed by the increased data availability from the modern battlefield and suffer from information overload with no adequate tools to filter and correlate the data. A goal of CoABS was to enhance the dynamic connection and operation of military planning, command, execution, and combat support systems to quickly respond to the changing operational picture. Software agents were developed to work side-by-side with human military planners and operators to ease the burden of their daily tasks.

(U) The CoABS Grid (hereafter referred to simply as the "Grid"), developed under the CoABS program, arguably provides the most successful and widely used infrastructure to date for the large-scale integration of heterogeneous agent frameworks with object-based applications, and legacy systems (Figure 2). Based on Sun's Jini services, it includes a method-based application-programming interface to register and advertise capabilities, discover services based on those capabilities, and provides the necessary communication between services. Systems and components on the Grid can be added and upgraded without reconfiguration of the network. Failed or unavailable components are automatically purged from the registry and discovery of similar services and functionality is pursued.

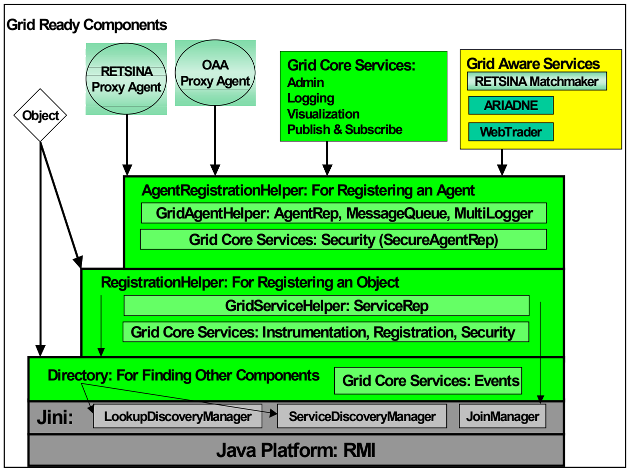

Figure 2: (U) Underlying Components of Control of Agent Based System (CoABS) Grid.

(U) The Grid supports a wide variety of applications, from simple monitoring and information retrieval to complex, dynamic domains such as military command and control. Using the Grid, agents and wrapped legacy systems can (1) describe their needs, capabilities and interfaces to other agents and legacy systems; (2) find and work with other agent components and legacy systems to accomplish complex tasks in flexible teams; (3) interact with humans and other agents to accept tasking and present results, and (4) adapt to changes in the application domain, the task at hand, or the computing environment. The Grid does this by providing access to shared policies and ontology (mechanisms for describing agents' capabilities and needs), and services that support interoperability among agents and legacy systems with simple or rich levels of semantics—all distributed across a network infrastructure.

(U) Although most agent frameworks partially support interoperability and other services that the Grid provides, each framework typically supports specialized constructs, communication, and control mechanisms. This specialization is desirable because particular systems can use mechanisms appropriate to the problem domain/task to be solved. The Grid is not intended to replace current agent frameworks but rather to augment their capabilities. The Grid provides helper utility classes that are local to an agent and hide the complexity of Jini. These classes automatically find any Look-up Services (LUS) in both the local area network and user-designated distant machines. The Grid supports agent and service discovery based on Jini entries and arbitrary predicates as well as by service type. The Grid also provides event notification when agents register, deregister, or change their advertised attributes.

MASAM ARCHITECTURE (U)

(U) An architecture, shown in Figure 3, is being developed to address the problem of situational awareness by applying AIT algorithms to both develop own-platform awareness as well as react to observed and derived platform intention. A high fidelity simulation was used to simulate the electronic battlefield, and was used to drive a set of mission agents in order to transmit critical mission parameters associated with the platforms in the scenario. At the same time, the simulation provided sensor/emitter data to the set of platform agents. These platform agents simulated platform characteristics, and provided necessary information to a set of fusion and decision agents which reacted to the simulation.

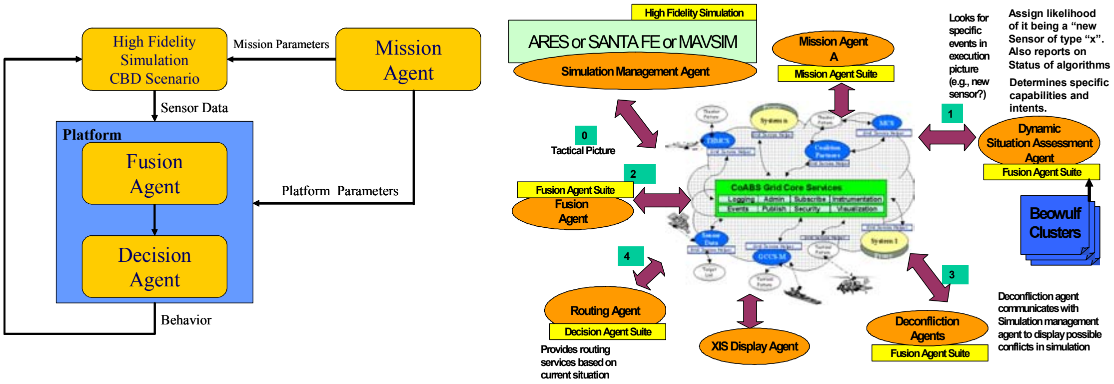

Figure 3: (U) Multi-Agent System for Mission and Situational Awareness Management (Left Panel). Use of CoABS Grid (Right Panel).

(U) Figure 3 (Left Panel) represents the architecture being pursued for MASAM. The right panel shows the "exploded view" of the software agent infrastructure associated with the platform agents as well as mission agents. As can be seen from this detailed view, the CoABS grid provides the infrastructure for these agents to communicate with each other. These agents are being developed to provide many of the support functions such as fusion and situation assessment, deconfliction and routing for airborne platforms. With reference to the detailed view, a simulation agent is being developed to provide a bridge between several ESM simulations and the grid, allowing the state of the simulated entities to be made available to other agents registered on the grid. One specific simulation is the Airborne Reactive EW simulation (ARES), used for the exploration of AEA concepts as shown in Figure 4(L). The ARES is fairly modular and parallelized (the execution thread has been ported to linux and runs on the Beowulf cluster.) This is important as most evolutionary computing methods are very computationally expensive. The simulation also takes into account terrain masking, which is mostly attributable to line-of-sight. Figure 4(R) shows the radar terrain masking effects in the simulation.

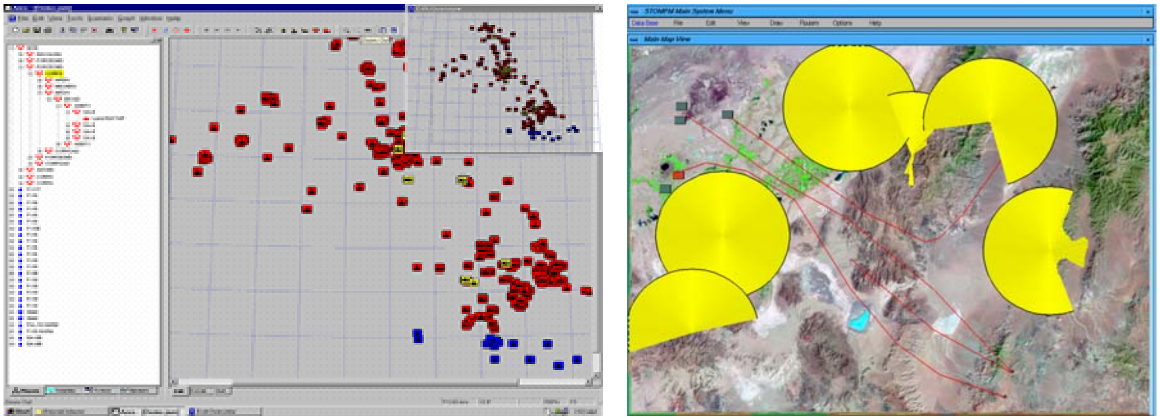

Figure 4: (U) ARES simulation (l) and Radar Terrain Masking Effects (r).

(U) The dynamic situation assessment agents will communicate with the simulation agents to assess other platform movements and intentions, in addition to fusing additional information to increase awareness. A set of deconfliction agents will determine where deconfliction[6] needs to be performed (for example, in the routing space or plan space). After this process provides increased situational awareness, a set of routing agents will perform own-platform re-routing based on other-platform criteria such as emitter capabilities and/or intentions. The routing algorithms take into consideration radar terrain masking effects and time dependencies such as repeated threat over-flights[7]. The eXtensible Information System (XIS) display agent was used primarily to interact with the XIS system to display tracks.

(U) The scenario in the simulation consisted of several aircraft flying from the Chesapeake Bay Detachment (Naval Research Laboratory-CBD, Chesapeake Beach MD) northward, with emitters placed at several locations on a nearby island. The purpose was to provide these aircraft an opportunity to passively deinterleave and identify the pulses in order to assess the situation and perform any necessary actions. A screenshot of the scenario can be seen in the simulation window in Figure 5, along with statistics collected by the situation assessment agents.

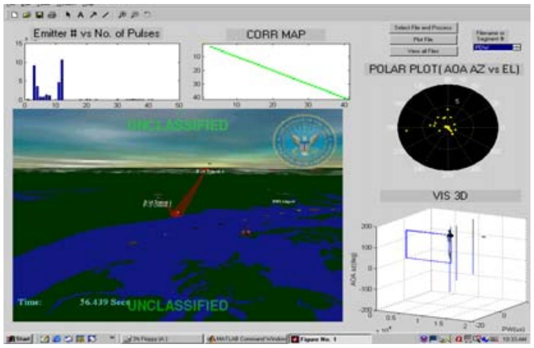

Figure 5: (U) The scenario used for MASAM and ES visualization of the processed interleaved pulses.

(U) We have developed grid-aware software agents capable of reading EW data computed on Beowulf clusters for subsequent display in XIS. The data for the EW simulation is captured onto

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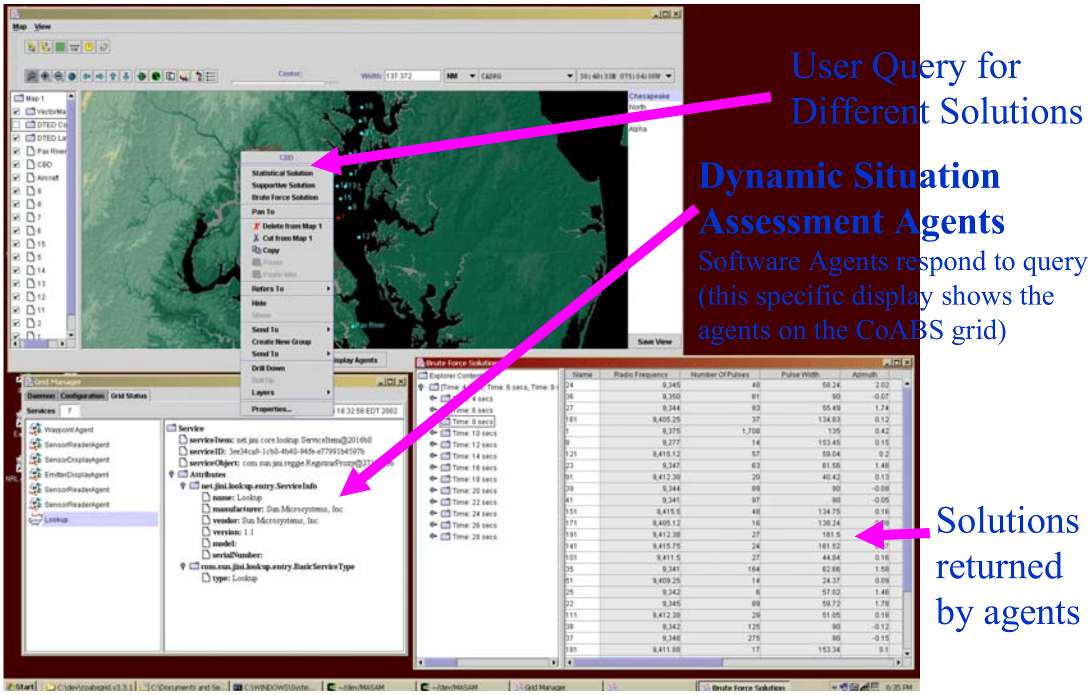
[6] (U) Mittu, R., Segaria, F., “COP/CTP Management via a Consistent Networked Information Stream (CNIS)”, Proceedings of the 2000 Command and Control Research and Technology Symposium, Monterey, CA 26-28 June 2000.

[7] (U) Zuniga, M., “Dynamic Route Optimization with Time-Expanded Graphs”, Proceedings of the 1996 SPIE Aerosense Conference.

the Beowulf clusters, where AIT algorithms reside to analyze this data. The simulation data includes the EW statistics associated with the electronic emitters in the scenario, including number of pulses, radio frequency, pulse width, azimuth, elevation, etc. Figures 5 and 6 show the visualization of the CBD Advanced Multi-Function Radar Concept Scenario emitter classification. The analysis of this data includes the use of fusion algorithms to determine the position and velocity of various platforms in the battlespace environment.[1] Bayesian networks[1], Dempster-Schafer techniques[6] and clustering algorithms[4] are used to obtain a joint estimate of platform identity. An additional use of the grid was to provide the user an intelligent interface in XIS in order to request various solutions associated with these algorithms from the single/multiple processor systems.



Service
serviceItem: net.jini.core.lookup.ServiceItem@2016b0
serviceID: 3ee34ca9-1cb0-4b40-94fe-e77991b4597b
serviceObject: com.sun.jini.reggie.RegistrarProxy@2
Attributes
net.jini.lookup.entry.ServiceInfo
name: Lookup
manufacturer: Sun Microsystems, Inc.
vendor: Sun Microsystems, Inc.
version: 1.1
model:
serialNumber:
com.sun.jini.lookup.entry.BasicServiceType
type: Lookup

Name	Radio Frequency	Number Of Pulses	Pulse Width	Azimuth
24	9,345	40	58.24	2.02
36	9,350	81	90	-0.07
27	9,344	83	55.49	1.74
161	9,405.25	37	134.83	0.12
1	9,375	1,708	135	0.42
9	9,277	14	153.45	0.15
121	9,415.12	57	59.04	0.2
23	9,347	63	61.58	1.48
91	9,412.38	20	40.42	0.13
39	9,344	88	90	-0.08
41	9,341	97	90	-0.05
151	9,415.5	48	134.75	0.16
171	9,405.12	16	138.24	[illegible]
191	9,412.38	27	161.5	[illegible]
141	9,415.75	24	161.52	[illegible]
101	9,411.5	27	44.84	0.16
35	9,341	164	62.66	1.58
61	9,409.25	14	24.37	0.09
25	9,342	6	57.02	1.46
22	9,345	69	59.72	1.78
111	9,412.38	29	51.05	0.18
38	9,342	125	90	-0.12
37	9,348	275	90	-0.15
181	9,411.88	17	153.34	0.1

User Query for Different Solutions

Dynamic Situation Assessment Agents

Software Agents respond to query (this specific display shows the agents on the CoABS grid)

Solutions returned by agents

Figure 6: (U) Use of AMRF-C Scenario on the Chesapeake Bay (Visualization on XiS) and assessment reports using the CoABS grid

(U) As the simulation was running and the algorithms were at various stages of computation, a user could also use the XIS interface (Figure 6) to request either a *statistical*, *supportive* or *brute force* solution. The *statistical* solution provided raw statistics such as PW, PRI, etc. The *supportive* solution provided a more in-depth analysis about potential enemy intent (e.g. plausibility from the Dempster-Shafer model, for example). The Brute force solution would fuse the results of each of the different classification algorithms to provide an estimate on target intentions. In the example of Figure 6, the user has requested a statistical solution (shown at the bottom right); one can also visualize the CoABS grid manager (to the bottom left) in this figure. Figure 7 shows some typical results with the plausibility of a given emitter within a library and the computation time of the solution on single and multiprocessor systems.[8] Note from the indicator an emitter was correctly matched (red) with the true emitter (maximal plausibility ranking) with some other emitters plausible (off diagonal records). The test signals reported on here included both simple and complex emitters. None of the test signals resulted in incorrect emitter identification.

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[8] (U) Kowtha, V.C., et al (2002). Signal Sorter for ES Applications. NRL Review

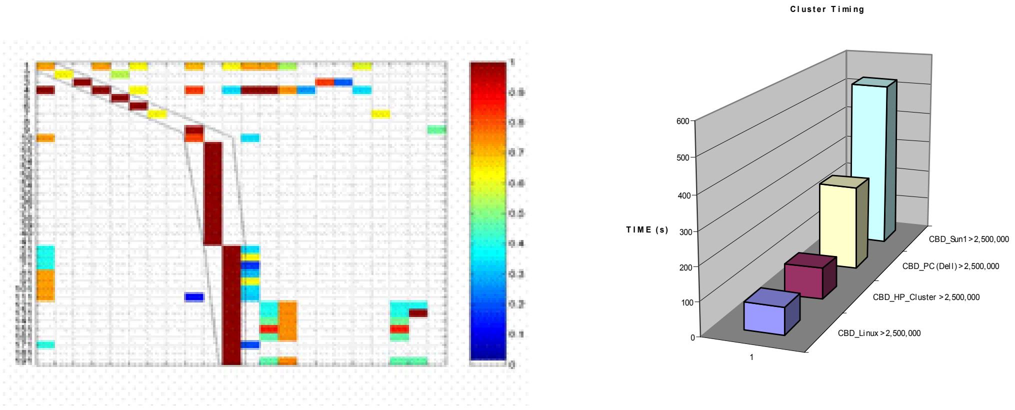

Figure 7: (U) (L) Flow chart showing path from raw pulse descriptor words (PDW's) to plausibility ordered emitter ID's. (R) The computing times on a single processor vs. distributed multiple processors.

SUMMARY AND CONCLUSIONS (U)

(U) We have applied these AIT algorithms to aid in the process of emitter identification, and described our experiment of integrating the solution from these algorithms with software agents through the CoABS grid. The objective is to improve positive ID of unknown air targets by networking and fusing ID attribute data obtained from various sensors including radar, IFF, and passive detection from the UHF through the infrared electromagnetic spectrum. The emergent sensors that enable this fruitful correlation of radar to ES attributes, (which heretofore was not feasible due to sensor performance deficiencies), are found on the SEWIP and the EP-3E Story Finder. To build ID across the network, classifier algorithms and various mathematical theories of evidence including D-S will be needed[10]

(U) At the most basic processing level, this technology is directly applicable to ESM processing. By extension it can be applied to non-cooperative ID through multi-sensor fusion with radar, IFF, or networked ESM systems. In a Network Centric ID environment, for example, the networked ESM data is correlated with radar tracks to form IDs. This can be done even when other sensors such as IFF do not respond or respond ambiguously. Other potential military application areas for which accurate emitter classification would be critical are intelligence, surveillance and reconnaissance.

(U) The nature of the problem is inherently distributed and scalable. For example, the algorithms may be geographically distributed, and hence a mechanism was needed to create a solution in which grid agents could rapidly advertise the capability of the algorithms, and agents could look-up other agents to request various solutions. The grid has been used in several experiments dealing with scalability issues. The CoABS grid has been used in the Expeditionary Sensor Grid Enabling Experiments (EEE) in order to seamlessly integrate sensor capabilities. Features associated with the use of the grid in EEE include support for hundreds of sensors, self-healing, autonomous operation and support for the ability of sensors to fade in/out from hours to minutes. The grid has also been used in the Coalition Agents Experimentation (CoAX)[9] The goal of CoAX was to demonstrate the value of software agents to construct and maintain a coalition command and control structure in support of a TTCP scenario. In this regard, the grid was used to integrate approximately seventy agents representing interfaces to coalitions systems and applications.

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[10] (U) Sciortino, J.C., Jr., Black, D. C, Altoft, J. R. (2003) "Recent Progress in Implementing a Dempster-Shafer Algorithm for Improved ESM Emitter Identification." Proceedings of the 48th Joint EW Conference, 5 –83 May 2003, Naval Postgraduate School, Monterey, CA.

[9] (U) http://www.aiai.project.ac.uk/project/coax