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Multi-Platform information fusion and management (UAV, CPF, CP-140)

13qa final report

Pierre Valin
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Defence Research and Development Canada – Valcartier

Technical Memorandum
DRDC Valcartier TM 2010-392
December 2011

Canada

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IMPORTANT INFORMATIVE STATEMENTS

Abstract

DRDC Valcartier has long been in involved data/information fusion & resource management, mostly on platforms (e.g. in 13dv "Airborne Information Fusion & Management for Tactical Picture Compilation", 2004-2007). Continuing this investigation, the ARP 13qa generalizes the problem to involve multiple platforms, such as cooperating UAVs, CPFs, and CP-140s, the latter having been studied under 13dv.

The project has expanded the scope to address distributed information fusion and dynamic resource management in Network Enabled Operations (NEOps). It has designed and implemented an open standards testbed on which algorithms can be developed, tested and validated over a wide variety of scenarios relevant to the CF. In addition to the CP-140 results which were obtained under 13dv, it has leveraged lessons learned from previous naval TDPs, such as ASCACT and COMDAT.

The project has resulted in a list of achievements, which includes a Service Oriented Architecture (SOA) testbed, on which two complex scenarios have been developed (one cooperative and the other non-cooperative), distributed information fusion (concentrating on higher level fusion), and dynamic resource management algorithms (planning and scheduling) have been tested under various dynamic network constraints and environmental conditions. Numerous scientific publications have resulted from DRDC and its industrial and academic partners.

Résumé

RDDC Valcartier participe depuis longtemps à la fusion de données et d'information, et de gestion des ressources, surtout sur des plates-formes (par exemple pour 13dv "Airborne Information Fusion & Management for Tactical Picture Compilation"). Pour faire suite à cette recherche, le PRA 13qa généralise le problème pour impliquer plusieurs plates-formes, telles des UAV, CPF et CP-140, cette dernière ayant été déjà étudiée dans le cadre de 13dv.

Ce projet a élargi l'envergure pour aborder la fusion d'information distribuée et la gestion dynamique des ressources dans les opérations réseaucentriques. Il a permis la conception et l'implémentation d'un banc d'essai basé sur des normes ouvertes, permettant le développement, l'essai et la validation sur une grande variété de scénarios importants pour les FC. En plus des résultats obtenus dans le cadre de 13dv pour le CP-140, le projet a profité des leçons apprises de PDT maritimes, tels que ASCACT et COMDAT.

Ce projet a produit une liste de réussites, incluant un banc d'essai en architecture orientée object, pour lequel deux scénarios complexes ont été élaborés (l'un coopératif et l'autre noncoopératif) et sur lequel les algorithmes portant sur la fusion d'information distribuée (surtout la fusion de haut niveau) et la gestion dynamique des ressources (élaboration des plans et des horaires) ont été testés sous diverses contraintes dynamiques de réseau et dans différentes conditions environnementales. De nombreuses publications scientifiques ont été produites par RDDC et ses partenaires industriels et universitaires.

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Executive summary

Multi-Platform Information Fusion & Management (UAV, CPF, CP-140): 13qa Final Report

Pierre Valin; DRDC Valcartier TM 2010-392; Defence R&D Canada – Valcartier; December 2011.

Introduction or background: Defence R&D Canada (DRDC) has long been involved in data/information fusion & resource management, mostly on platforms (e.g. in 13dv "Airborne Information Fusion & Management for Tactical Picture Compilation", April 2004 to March 2007). As part of this investigation, the Applied Research Project (ARP) 13qa (formerly 13db) generalizes the problem to involve multiple platforms, such as cooperating Unmanned Aerial Vehicles (UAVs), Canadian Patrol Frigates (CPFs), and airborne maritime surveillance aircraft such as the CP-140, which was studied under 13dv.

The project has expanded the scope to address distributed information fusion and dynamic resource management in Network Enabled Operations (NEOps). It has designed and implemented an open standards testbed on which algorithms can be developed, tested and benchmarked over a wide variety of scenarios relevant to the Canadian Forces (CF). In addition to the CP-140 results which were obtained under 13dv, it has leveraged lessons learned from previous naval Technology Demonstrator Projects (TDPs), such as ASCACT and COMDAT.

Results: The objectives were to investigate multi-platform information and operations management enablers for a large volume littoral surveillance (CFC-1). More precisely, the effort allowed to:

1) develop a series of littoral surveillance vignettes in a context of NEOps
2) investigate near-real-time distributed and adaptive information fusion architecture (for multiple platforms: Aurora, UAVs, Frigates, and ground stations
3) investigate the management of multiple airborne tactical pictures
4) define the implications of the NEOps concept for littoral multi-platform large volume surveillance.

All the objectives were met with success. The project has resulted in a list of achievements, which includes a Service Oriented Architecture (SOA) testbed, on which two complex scenarios have been developed (one cooperative and the other non-cooperative), distributed information fusion algorithms (concentrating on higher level fusion), and dynamic resource management algorithms (planning and scheduling) have been tested under dynamic network constraints and environmental conditions. Numerous scientific publications have resulted from DRDC in collaboration with its industrial and academic partners.

Significance: The testbed permits assessment of the effectiveness and performance of algorithms and strategies for distributed information fusion, multi-platform dynamic resource management and dynamic network configuration management.

Future plans: A follow-on ARP entitled "C2-enabled Distributed Surface Surveillance" (13qi) will leverage the existing testbed and refine all the previous algorithms, as well as add realism through proper simulation of networking protocols, more complex scenarios, etc.

Sommaire

Multi-Platform Information Fusion & Management (UAV, CPF, CP-140): 13qa Final Report

Pierre Valin; DRDC Valcartier TM 2010-392; R & D pour la défense Canada – Valcartier; Décembre 2011.

Introduction ou contexte: RDDC Valcartier participe depuis longtemps à la fusion de données et d'information, et de gestion des ressources, surtout sur des plates-formes (par exemple pour 13dv "Airborne Information Fusion & Management for Tactical Picture Compilation"). Pour faire suite à cette recherche, le PRA 13qa généralise le problème pour impliquer plusieurs plates-formes, telles des UAV, CPF et CP-140, cette dernière ayant été déjà étudiée dans le cadre de 13dv.

Ce projet a élargi l'envergure pour aborder la fusion d'information distribuée et la gestion dynamique des ressources dans les opérations réseaucentriques. Il a permis la conception et l'implémentation d'un banc d'essai basé sur des normes ouvertes, permettant le développement, l'essai et la validation sur une grande variété de scénarios importants pour les FC. En plus des résultats obtenus dans le cadre de 13dv pour le CP-140, le projet a profité des leçons apprises de PDT maritimes, tels que ASCACT et COMDAT.

Résultats: Les objectifs étaient d'étudier les catalyseurs pour l'information provenant de multiples plates-formes et pour la gestion des opérations dans le cadre de surveillance littorale sur un grand volume (CFC-1). Plus précisément, cet effort a permis de:

1) développer une série de vignettes de surveillance littorale dans le cadre NEOps
2) étudier une architecture distribuée et adaptative pour la fusion d'information, impliquant des plates-formes multiples: Aurora, UAV, frégates, et stations terrestres
3) étudier la gestion de multiples descriptions tactiques aéroportées
4) définir les implications du concept NEOps pour la surveillance littorale utilisant de multiples plates-formes sur un volume étendu.

Tous les objectifs ont été couronnés de succès. Ce projet a produit une liste de réussites, incluant un banc d'essai en architecture orientée objet, pour lequel deux scénarios complexes ont été élaborés (l'un coopératif et l'autre noncoopératif) et sur lequel les algorithmes portant sur la fusion d'information distribuée (surtout la fusion de haut niveau) et la gestion dynamique des ressources (élaboration des plans et des horaires) ont été testés sous diverses contraintes dynamiques de réseau et dans différentes conditions environnementales. De nombreuses publications scientifiques ont été produites par RDDC et ses partenaires industriels et universitaires.

Importance: Le banc d'essai a permis d'évaluer l'efficacité et la performance d'algorithmes et de stratégies pour la fusion d'information distribuée, la gestion dynamique des ressources pour de multiples plates-formes et la gestion de la configuration du réseau.

Perspectives: Le PRA suivant intitulé "C2-enabled Distributed Surface Surveillance" (13qi) utilisera le banc d'essai existant pour raffiner les algorithmes précédents, et ajoutera du réalisme grâce à une simulation des protocoles utilisés en réseau, des scénarios plus complexes, etc.

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1 Introduction

1.1 Background

The Data Fusion Subpanel of the Technology Panel for C3 (Command, Control, Communications) of the Joint Directors of Laboratories (JDL) of the Department of Defence in the USA describes data/information fusion as a "multilevel, multifaceted process dealing with the automatic detection, association, correlation, estimation, and combination of data and information from single and multiple sources". Four levels are generally agreed upon by most researchers in the field [1]:

1. Level 1 *object refinement* is often referred to as Multi-Sensor Data Fusion (MSDF) and is the most mature of all the levels. The result of this Level 1 is to provide estimates about the entities under investigation, namely tracks with their identification at some level of a taxonomy, to Level 2 Situation Refinement. The aim of Level 1 is thus to provide estimation of states of discrete physical single objects.
2. Level 2: *situation refinement*, a.k.a. Situation and Threat Assessment (STA) takes these estimated entities and aims to understand the situation, e.g. by doing clustering analyses, using contextual information, geographical data, environmental conditions, doctrinal information, etc. The resulting interpretations of the situations are then analyzed by Level 3 Impact Refinement. The aim of Level 2 is thus to provide estimation of relationships among entities.
3. Level 3: *impact refinement*, analyses the situations and aims to plan ahead a response (or many possible responses/plans) favorable to the blue force (or to the own-platform), hence the equivalent name of *threat refinement*. It provides an estimated outcome cost, including weapons used, platforms rendered partially or completely inoperative, etc. This cost is then sent to Level 4 Process Refinement. The aim of Level 3 is thus to provide an estimation of impacts (e.g. consequences of threat activities on one's own assets and goals).
4. Level 4*: process refinement* will select a response plan, including the proper use of sensors for further data gathering in order to increase the quality of the tactical picture, the movements of platforms of the blue force and the coordinated use of the appropriate weapons to achieve maximal effect on the red force, as well as deciding on the best algorithmic choice depending on context.

Additional levels [2] are sometimes found in the literature: Level 0 or "Signal/Feature Assessment" which is usually taken care of by modern sensors, and Level 5 "Human/user refinement". Note that the discussion above presents the levels as hierarchical. This is only done for clarity, as feedback loops can be present between the levels.

In the remote sensing domain, another definition has been proposed for data/information fusion, namely [3] "data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality; the exact definition of 'greater quality' will depend upon the application".

Resource management can refer to managing sensors on a given platform, to selecting trajectories of platforms, and to assigning plans and schedules in a multi-platform environment.

1.2 Previous Studies on Platform-centric Information Fusion

In the context of the Applied Research Project (ARP) 13dv “Airborne Information Fusion & Management for Tactical Picture Compilation”, three (3) reports (further described in the following 3 paragraphs) were generated, which form the airborne basis upon which 13qa “Multi-Platform Information Fusion & Management (UAV, CPF, CP-140)” can build.

The first report entitled “Information Fusion Concepts for Airborne Maritime Surveillance and C^2 Operations” [4] addressed the problematic of MSDF on-board the airborne maritime surveillance CP-140 (Aurora) aircraft. To that end, a survey of the concepts that are needed for data/information fusion was made, with the aim of improving Command and Control (C2) operations. All of the current and planned sensors were described and their suitability for fusion discussed. Relevant missions for the aircraft were listed and the focus was made on a few important ones that make full use of the Aurora’s sensor suite. For the identity information component of MSDF, a comprehensive set of *a priori* databases was constructed that contained all the information/knowledge about the platforms likely to be encountered in the missions. The most important of these was the Platform DataBase (PDB) which lists all the attributes that can be measured by the sensors (with accompanying numerical or fuzzy values), and these can be of 3 types: kinematical, geometrical or directly in terms of the identity of the target platform itself.

The second report of this series entitled “A Survey of Information Fusion Algorithms for an Airborne Application” [5] surveyed the positional fusion algorithms and the reasoning frameworks common in the artificial intelligence field for identity information fusion, and selected those which are appropriate to deal with dissimilar data coming from sensors involved in airborne data/information fusion. The Image Support Module (ISM) for the existing Forward-Looking Infra Red (FLIR) made use of many of these reasoning frameworks in parallel, and actually fused the results coming from these complementary classifiers. The Spotlight Synthetic Aperture Radar (SSAR) ISM also incorporated some of these reasoning methods in a hierarchical manner to provide multiple inputs to the MSDF module. The data used to train, validate and test the ISMs was a combination of simulated and real imagery for the SSAR, and unclassified airborne data for the FLIR.

The final report “Demonstration of Data/Information Fusion Concepts for Airborne Maritime Surveillance Operations” [6] demonstrated the achieved performance of judiciously selected information fusion and object recognition algorithms, for realistic sensor simulations in relevant airborne maritime surveillance missions. Given the scenarios tackled, a single scan associator was chosen and a single Kalman filter track update mechanism is performed for the positional fusion component. The identity was obtained through an identification fusion done by a truncated Dempster-Shafer algorithm with near-optimal truncation parameters, and a minimum for the ignorance which ensures recovery under countermeasures.

The naval component of information fusion comes mainly from the Advanced Shipborne Command and Control Technology (ASCACT) Technology Demonstrator Project (TDP), and the Command Decision Aid Technology (COMDAT) TDP.

1.3 The New Reality: Network Enabled Operations

As military and intelligence gathering operations evolve towards a global network architecture whose mandate is to maintain continuous and shared awareness through a constant, fast and timely exchange of uncorrupted information, the objective is to push forward the platform-centric data fusion capabilities developed during recent years in the direction of a network-centric data fusion capability where collaborating platforms and sensors are nodes in the global information grid that detect and track events of interest.

Thus military operations are moving from platform-centric warfare to Network-Centric Warfare (NCW), whose organizing principle has its antecedent in the dynamic of growth and competition that have emerged in the modern economy. NCW derives its power from the strong networking of well-informed but geographically dispersed forces. The enabling elements are a high-performance information grid, access to all appropriate information sources, weapons reach and manoeuvring with precision and speed of response, value-adding command and control processes — to include high speed automated assignment of resources — and integrated sensor grids closely coupled in time to shooters and C2 processes. NCW is applicable to all levels of warfare and contributes to the coalescence of strategy, operations and tactics. It is transparent to mission, force size and composition, as well as geography.

These requirements motivate a close examination of decentralized data fusion architectures, i.e., a multi-sensor system in which there is no centralized communication, coordination or control. Instead, each sensor node is empowered with the capability to process data, communicate information and make local decisions. As a consequence, a decentralized data fusion system is a collection of processing nodes connected by communication links, where each node performs a specific computing task using information from nodes with which it is linked, but where no central node controls the network. None of these nodes has knowledge about the overall network topology. The most attractive properties of such a decentralized system are:

1. Reliability: the loss of a subset of nodes and/or links does not prevent the rest of the system from functioning. In a centralized system, however, the failure of a common communication manager or a centralized controller can result in immediate catastrophic failure of the system.

2. Scalability: nodes can be added or deleted by making only local changes to the network. The addition of a node simply involves the establishment of links from one or more nodes to the network. In a centralized system, however, the addition of a new node can change the topology in such a way as to require massive changes to the overall control and communication structure.

A first attempt at the Canadianized version of NCW, called Network Enabled Operations (NEOps) was made in the report “Concepts of data/information fusion for naval C2 and airborne ISR platforms” [7] for the purpose of establishing a Maritime Tactical Picture (MTP). An MTP is, by definition, the combination of the Local Area Picture (LAP) seen by a unit (which may be part of a Task Force) using its own sensors and a Wide Area Picture (WAP) using information, not controlled by the Task Force, provided by high frequency (HF) or ultra high frequency (UHF) radios or satellites.

The present ARP provided a testbed that could support distributed fusion nodes residing on platforms, and which can integrate algorithms developed for naval and airborne platforms in a transparent plug-and-play manner.

2 Problems Addressed

2.1 Development of surveillance scenarios

A cooperative Search and Rescue (SAR) scenario was first developed that exercised the basic functionalities of Distributed Information Fusion (DIF) as described in Section 2.2, and Dynamic Resource Management (DRM), as described in Section 2.3. The cooperative SAR scenario consisted in locating and identifying a fishing boat in distress close to Chrome Island over a 2:30 hour time span. Any instance of a scenario is called a vignette. The cooperative SAR vignette that was developed was further complicated by having 10 other ships in the area, 10 fixed objects that need to be checked, and 10 adrift objects that also need to be checked, all with known but adjustable positions depending on the vignette. For this scenario, only airborne platforms are involved in the search: a CP-140 Aurora and a CH-149 Cormorant.

The next step was to develop a much more complex non-cooperative scenario that would more fully test the DIF and DRM capabilities. It focussed on a threat situation that develops off the northwest tip of Vancouver Island, and lasted 6 hours. The following Figure 1 identifies the region and major features:

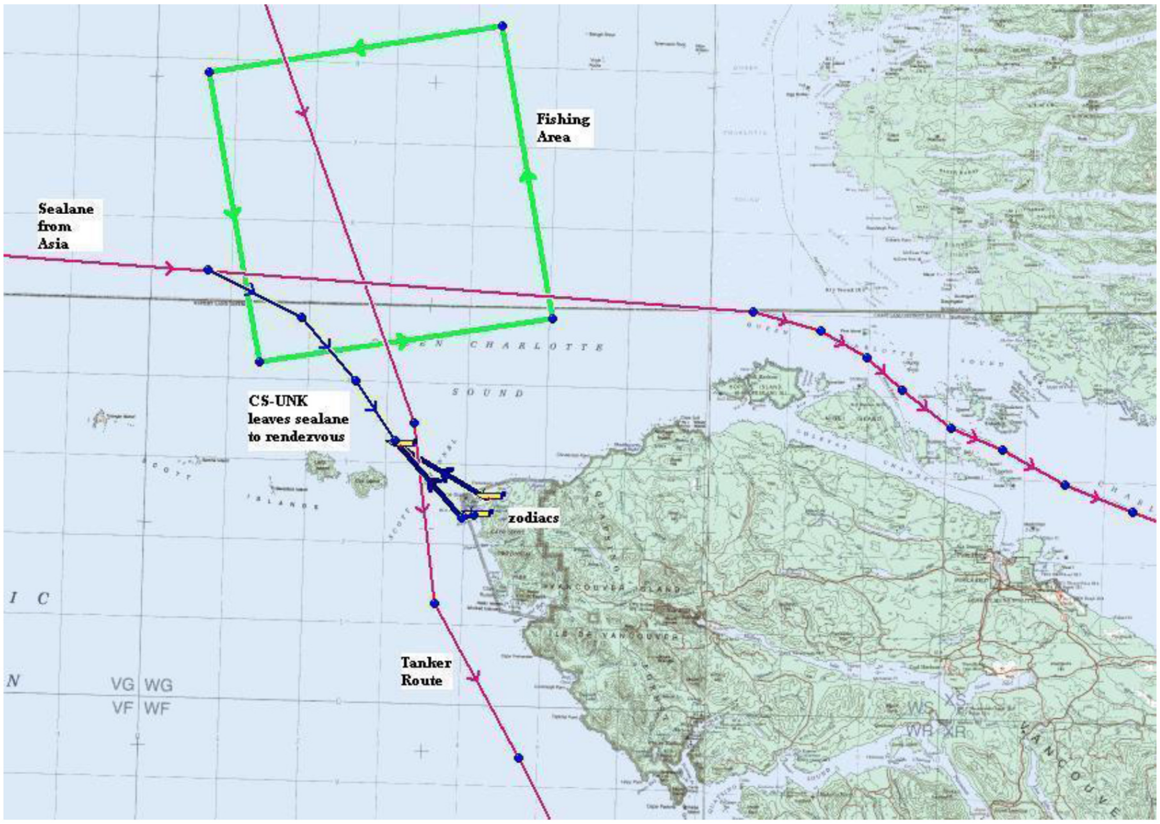


Figure 1: Non-cooperative scenario

A cargo ship, CS-UNK, will come to Cape Scott on northern Vancouver Island carrying illegal immigrants. CS-UNK will use two land-based zodiacs to offload the illegal immigrants by making multiple trips to/from the cargo ship to ferry persons to the coast. This cargo ship and the zodiacs will attempt various elusive manoeuvres depending on how the situation develops. For example, typical elusive manoeuvres for the cargo ship can be chosen amongst a pre-determined list, such as using a known commercial shipping route (sea lane) to mask its approach among other cargo ships, or failing to provide an AIS identification or providing a false AIS corresponding to a scheduled cargo ship known to be scheduled to be in the area around this time, etc.

The platforms involved in this scenario are now much more numerous:

- one Halifax-class frigate,
- one CH-148 Cyclone helicopter aboard the frigate,
- 4 CP-140 Aurora,
- 4 CH-149 Cormorant at various stages of readiness, and
- 8 UAVs at two different locations, also at different readiness levels.

Varying the readiness levels of the platforms from one vignette to another will create different DIF strategies, and different DRM solutions. Thus, all the platforms that were identified for DIF and DRM are present in this scenario, and many helicopters have also been added. As in the case of the cooperative vignette, the situation is complicated by the addition of 20 fishing boats and 30 other ships in the area.

2.2 Distributed Information Fusion

The starting hypothesis for DIF is that each platform has fusion capabilities and communication channels. Thus each platform can be thought of as a fusion node in a network, which first performs fusion using its own sensors, and then integrates situational knowledge acquired from other nodes through the communication channels (data links) in the network. Each fusion node follows John Boyd's Observe, Orient, Decide, Act (OODA) loop. OODA nodes represent entities such as physical resources or groups of physical resources that can have different levels of capabilities. A node’s behaviour is determined by its OODA components: Observe, Orient, Decide, and Act, as is shown in Figure 2 below, which described the architecture of an OODA node.

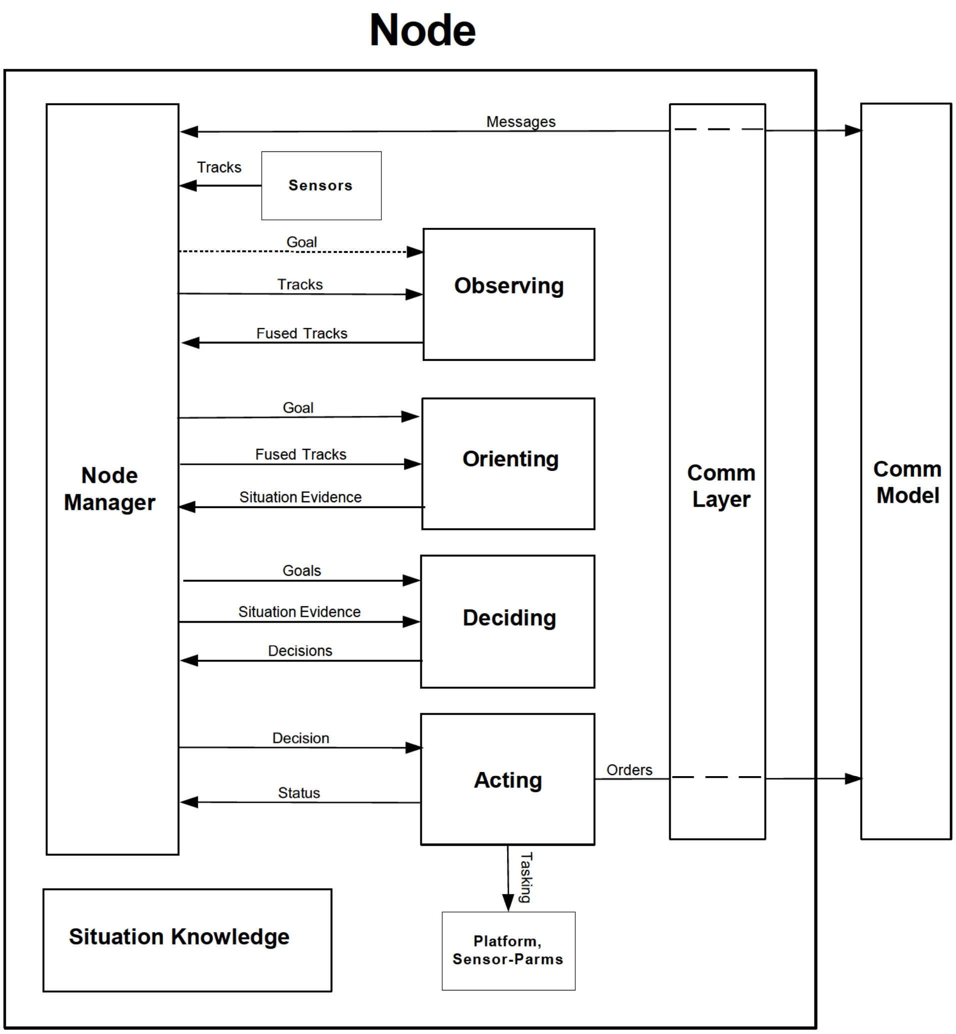


Figure 2: Internal Structure of a Node

Due to measurement noises and other uncertainties, different sensors report different tracks even for the same ships. Before fusing the multiple sensor tracks, we need to perform sensor-to-sensor track association. The main objective of sensor-to-sensor track association is to provide a one-to-one solution in which tracks from one sensor are matched in an optimal manner with tracks from the other sensor. The track association process is divided into two steps: assignment cost matrix calculation, and optimal solution finding. The assignment cost matrix calculation helps in obtaining all the costs of assigning one track of one sensor to one track of another sensor. Optimal solution finding helps in identifying the solution with a minimal total assignment cost.

Track fusion is performed in different ways for different track information (position/velocity, feature, track ID). A DST combination method is used to fuse the information about ship superstructure and ship type classification. Position/velocity estimates are combined using the Covariance Intersection method. The same method is also used to combine ship shape and head direction estimates. Since the local tracks that belong to the same target may be assigned different local track IDs by the surveillance sensors, we need to assign a common global track ID to each target. A fused track is obtained by combining the associated local tracks that belong to the same target. If the same global track ID is assigned to most of these associated local tracks at a previous time instant, that global track ID will be assigned to these associated local tracks again; or else, the global tracks at previous time instant are used to predict the fused track, and the "fused track" to the "predicted fused track" assignment is then performed by using the Munkres algorithm. Obtaining these fused global tracks completes the task of the Observing part of the OODA loop, which is essentially Level-1 data fusion, as outlined in Section 1.1.

Higher level fusion is then performed in the Orienting part of the OODA loop, which is Level-2 information fusion, as outlined in Section 1.1. The Orientation function works as a goal-driven rule-based expert system as illustrated in Figure 3 below.

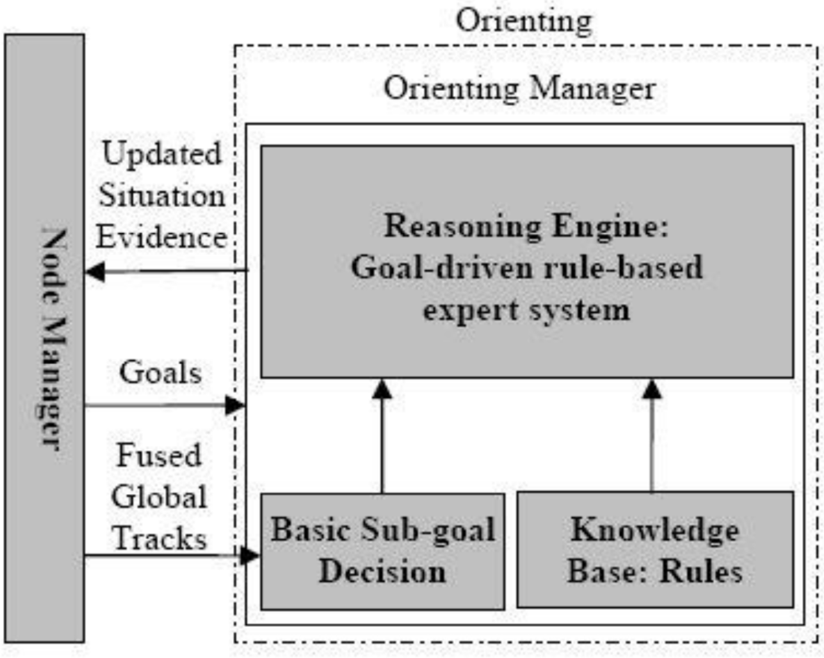


Figure 3: Orienting function

The knowledge base (which is part of the node's Situation Knowledge interface) contains rules that allow the Reasoning Engine to "prove" a goal proposition given a set of basic sub-goal propositions. The basic sub-goal decision, for example, compares the estimated velocity of a target with the estimated velocity of the ocean currents and the estimated heading direction with motion direction to assert isDrifting (which occurs in the first scenario described in Section 2.1. The Reasoning Engine can then, for example, infer from the propositions isDrifting and isFishingBoat that the goal isFishingBoatInDistress can be asserted. The asserted propositions (situation assessment results) are stored in a single output called Situation Evidence object.

Situation assessment makes decisions on goals, such as isShipInDistress, isMaritimeSuspiciousOperation, and isSmugglingOperation (the latter two belonging to the second scenario described in Section 2.1). In order to make decisions on goals, we define the basic sub-goals that can be identify directly as intermediate decisions, such as isShipSignalingDistress, isShipHeadingNotAlignedWithMotion, isReportedAsTankerByAIS, isShipRightName (again the latter two belonging to the second scenario). The goal-driven rule-based expert system based situation assessment works backwards from a hypothesized goal, attempting to prove it by linking the goal to the initial sub-goals. The inference engine works in the following way:

1. Select rules with conclusions matching the goal.
2. Replace the goal by the rule's premises. These become sub-goals.
3. Work backwards until all sub-goals are deduced.

2.3 Dynamic Resource Management

The dynamic management of surveillance platforms requires the optimization of resources allocation and improved adaptability as new information is gathered. In particular, the platform's area of operation can be dynamically allocated to a cluster of platforms/sensors to improve the quality, and accuracy of the fused information. Moreover, the resource management algorithms should be designed to maximize coverage, maximize probability of success, minimize risk, and minimize response time to unforeseen events. The coordination conflict arising from communication link failure between two platforms needs to be investigated in this light and based on the investigations, robust dynamic resource management algorithms for specific applications should be developed and tested.

An initial task allocation and scheduling system able to operate in different modes, commanding any to all of the platforms independently to deal with high priority task or to share load was implemented. Hence, each platform is semi-independent. With networked updates of distilled information from the fusion centre to all platforms, it is possible for each platform/sensor to make independent rescheduling decisions when communications fail. An initial surveillance plan is generated to start the mission, and then based on the evolution of the situation and the new information, decisions should be made according to the DRCMA model (see the next section) in order to act on the network, deploy new platforms or re-allocate the existing platforms.

In its actual implementation, resource management first reviews the feasibility of different configurations of the available resources for the task, then it generates a plan of action, and finally it schedules resources, such as UAVs, to fly search patterns over the area and switch sensors into modes appropriate for the task at hand. Dynamic management of surveillance platforms is investigated to optimize resources allocation and improve adaptability as new information is gathered. In particular, the platform's area of operation is dynamically allocated to an individual or a cluster of platforms/sensors to improve the quality, and accuracy of the fused information.

2.4 Auto-Configurable Information Fusion Architectures

Connectivity amongst fusion nodes allows sharing information among many fusion nodes. A multi-layer network architecture, called Dynamic Resource Configuration & Management Architecture (DRCMA), is adopted to represent a distributed fusion network. A key requirement is the need for efficient management of information fusion nodes under dynamically changing and essentially unpredictable conditions. To facilitate dynamic reorganization and to avoid the bottleneck of centralized fusion systems, a multi-agent based design approach is considered in order to explore robust and efficient fusion of heterogeneous data and information. The DRCMA model is formally described in terms of a distributed Abstract State Machine (ASM) with real-time constraints. The resulting machine model abstractly characterizes the dynamic properties of the distributed fusion architecture and serves as an abstract computational framework for requirements specification, design analysis and validation of the key system attributes prior to actually building the system.

The ASM formalism is well known for its versatility in semantic modeling of algorithms, architectures, languages, protocols and virtually all kinds of sequential, parallel and distributed systems. Concurrently executing tasks of a distributed fusion process change dynamically due to the dynamic nature of mission requirements. Resources allocated to tasks change dynamically as a result of unavoidable instabilities in the resource environment. This situation calls for reconfigurable applications that can adapt to internal changes in resource requirements and to external changes affecting the available resources. Sensor platforms are combined into clusters that can operate semi-autonomously. Dynamic reconfiguration of resource clusters is performed in an *ad hoc* manner using ‘plug and play’ mechanisms. At any time, additional resources can join clusters on demand based on their sensor capabilities and geographic position. Fault tolerant behaviour is crucial for avoiding catastrophic system failures as a result of communication failures (e.g., broken communication links, corrupted or lost messages) and partial or total resource failures (e.g., in disaster situations). In many respects, requirements and design principles of the distributed information fusion system resemble those of mobile *ad hoc* networks. Complex control structures and the need to deal with component and communication failures require investigating different organization structures (e.g., decentralized versus centralized). This will be realized by introducing a concept of generic control center, such that a uniquely identified control center is associated with each individual cluster in a hierarchy of logically linked resource clusters. At the bottom level, each physical sensor platform has its own control center. The proposed system will have the following functions:

Task Decomposition: principles for decomposing complex tasks (goals) into subtasks based on common patterns and schemes for mapping tasks onto resources. This also includes an abstract characterization of tasks according to their resource requirements and the orchestration of resources for processing tasks,

Resource Clustering: composition principles for a systematic clustering of resources based on abstract logical representations of their physical capabilities (e.g., sensor capabilities, mobility constraints, time restrictions). Primitive resources are joined to form composite resources with richer behaviours, as derived by an attribution scheme defined over a set of logical resource descriptors,

Resource Management: dynamic resource management policies to control resource migration between clusters based on prioritization schemes for resource selection and management of resource pools,

Fault Tolerance: robust mechanisms for dynamic resource linking (‘plug and play’) auto-reconfiguration and semi-autonomous operation of resource clusters,

Communication Framework: i) communication of information from control centers to resources and from resources to control centers; ii) intelligent exchange of information that prevents propagation of outdated information (information pollution); iii) management of meta-data required to identify the origin of information, the associated time line and life time.

Overall, the proposed design is characterized by its concurrent and reactive nature, making it difficult to predict the resulting system behaviour with sufficient detail and precision under all circumstances. Hence, there is a need for formalism. It allows us to not only reason about specification and design issues, but also uncover deficiencies that would otherwise go unnoticed. Finally, model-based systems engineering demands for abstract executable specifications as an instrument for design exploration and experimental validation through simulation and testing, as well as by means of symbolic execution. The ASM formalism, in combination with related tool environments, directly supports this modeling paradigm.

2.5 Development of a Test-Bed and Validation

A testbed was developed to evaluate DIF and DRM algorithms, and adaptive network configuration approaches in the context of large volume littoral surveillance. In addition the testbed allowed try-out of new software technology, (e.g., intelligent agents) and contained

a simulator to explore concepts to improve maritime domain awareness

a DIF and DRM architecture

a toolbox of DIF algorithms (particularly higher-level fusion)

a toolbox of DRM algorithms

an architecture to model distributed inter-platform communication networks

measures of success for the situation analysis application

The testbed provides the following novel aspects:

a) A realistic approach to the problem for a C2 perspective. Networks are represented by concepts from graph theory: sets of nodes and relationships. Nodes might represent any entity, unit, human, system or even virtual aggregation of swarm entities. Relationships might refer to social, C2 or communications relations between nodes.

b) A full integration of information fusion and resource management concepts. Networks are considered as a resource and managed accordingly to maximize the overall system performance. Efficient management of distributed resources under conditions of unpredictable and varying workload calls for reconfigurable applications adapting to internal (resource requirements) and external changes (resource availability). The intelligent implementation of dynamic multi-platform path planning and updating uses dynamic load balancing schemes.

The testbed uses open standards, modern architecture (e.g. SOA, agents), is plug-and-play, uses a toolbox for platforms and sensors, provides “net-centric” play vs. “command-central” play, and makes it easy to generate new demonstrations by providing documentation on how to add new components to the testbed. This testbed has four (4) components as shown in Figure 4 below.

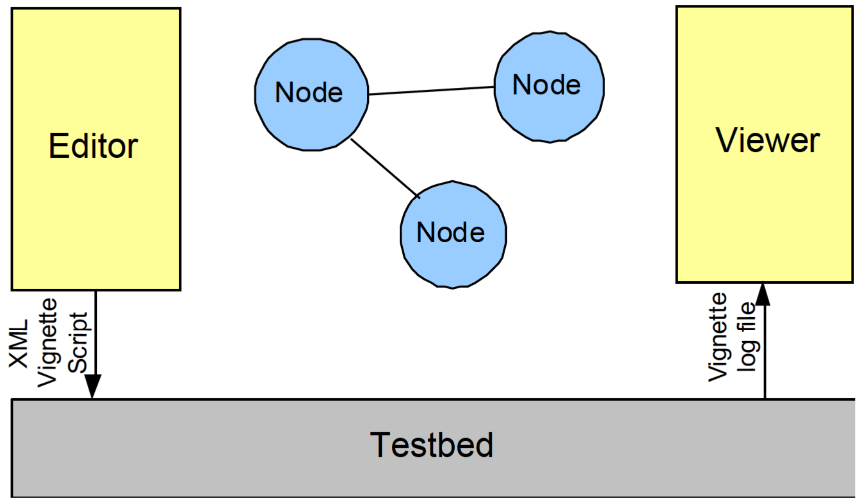


Figure 4: Testbed high-level architecture

1. The editor allows the user to configure the testbed and to experiment with different algorithms and different resource configurations. It allows creation of an experiment, vignettes, nodes and scripts and is supported by a Graphical User Interface (GUI).

2. The visualizer (or viewer in Figure 4 above) allows gathering data during the simulation for in-depth analyses and qualification of the tested concepts. Visualization greatly aids a user's understanding of how changes affect dynamic scenarios. Even small changes can have important impacts, especially over time. Without a means to see the effects, these impacts can easily be missed or misunderstood.

3. The application to be tested is represented by the network of nodes at the center of Figure 4. Each node has the structure depicted in Figure 2.

4. The testbed is the core to represent the environment, relationships, behaviour and interactions of all the simulated entities, and contains a testbed manager, a communication manager and the physical models.

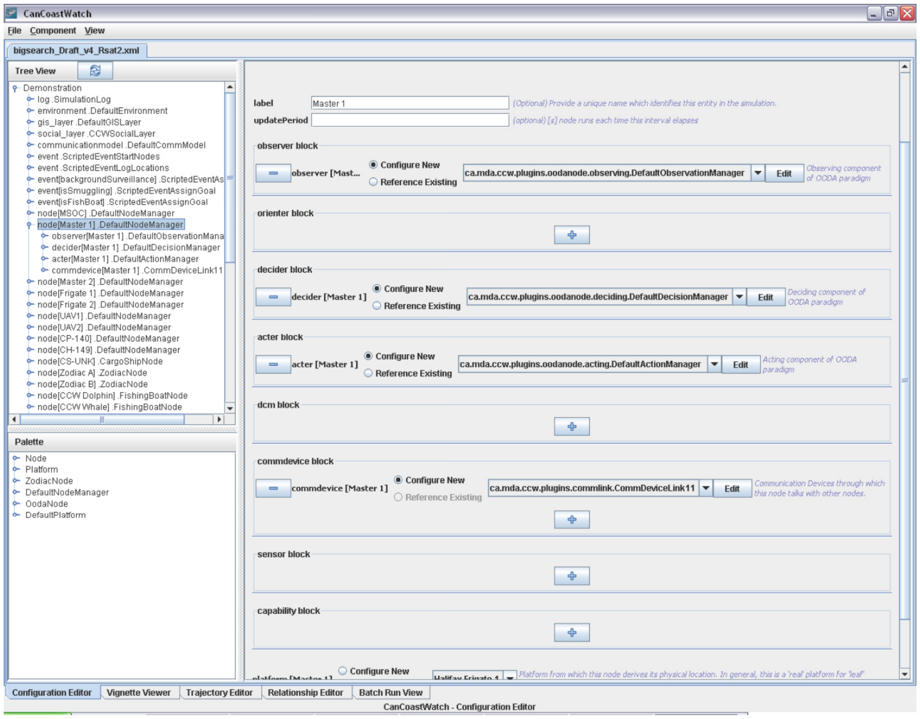
The testbed thus provides services to the developer of the applications before, during, and after a demonstration run.

Before the run, it allows the developer to set up the parameters of the experiment, and to initialize the run by using the editor.

During the run, it provides the applications with a physical model of the simulated world. This includes the behaviour of platforms, sensors, targets, communication links, and the physical environmental conditions such as weather, sea state etc.

After the conclusion of a run, the testbed provides services to visualize the results of the run, and to compute Measures of Performance (MOPs) and Measures of Effectiveness (MOEs).

The editor's GUI is shown in Figure 5.



label: Master 1 — (Optional) Provide a unique name which identifies this entity in the simulation.

updatePeriod: — (optional) [s] node runs each time this interval elapses

observer block: observer [Mast... ● Configure New ○ Reference Existing — ca.mda.ccw.plugins.oodanode.observing.DefaultObservationManager — Observing component of OODA paradigm

decider block: decider [Master 1] ● Configure New ○ Reference Existing — ca.mda.ccw.plugins.oodanode.deciding.DefaultDecisionManager — Deciding component of OODA paradigm

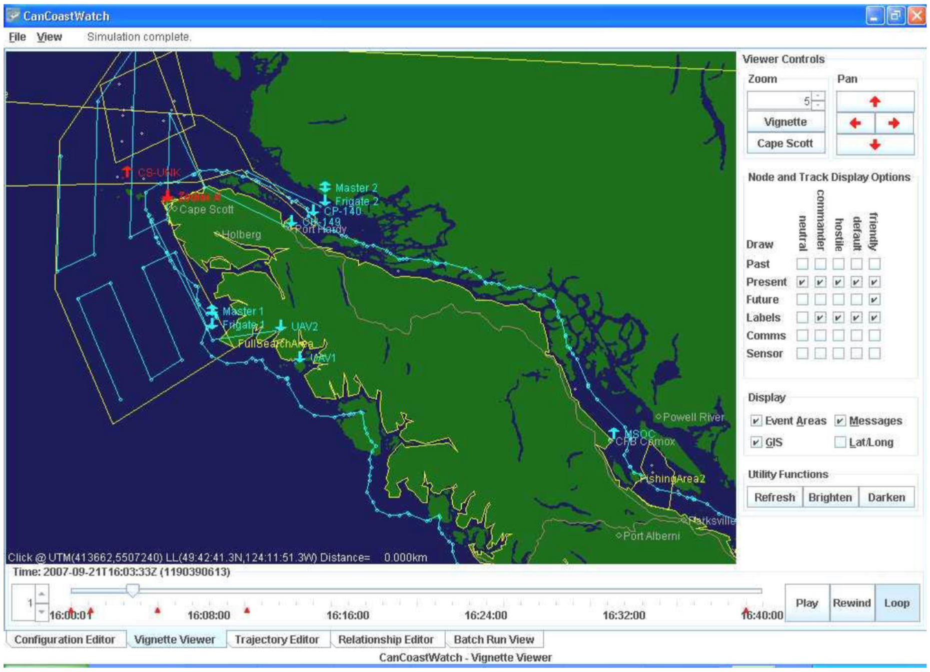
acter block: acter [Master 1] ● Configure New ○ Reference Existing — ca.mda.ccw.plugins.oodanode.acting.DefaultActionManager — Acting component of OODA paradigm

commdevice block: commdevice [Master 1] ● Configure New ○ Reference Existing — ca.mda.ccw.plugins.commlink.CommDeviceLink11 — Communication Devices through which this node talks with other nodes.

○ Configure New — Halifax Frigate 1 — Platform from which this node derives its physical location. In general, this is a 'real' platform for 'leaf'

Figure 5: Editor's GUI

Validation was performed using the two scenarios described in Section 1.1. Some screen captures relevant to the second scenario are shown below in Figures 6 through 8.



Click @ UTM(413662,5507240) LL(49:42:41.3N,124:11:51.3W) Distance= 0.000km

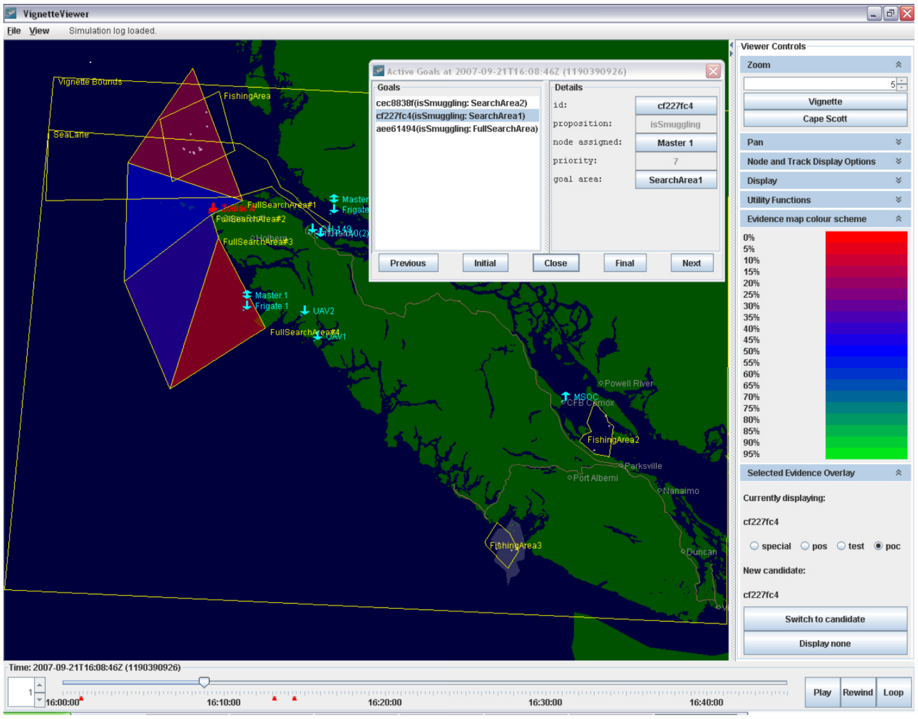
Time: 2007-09-21T16:03:33Z (1190390613)

Zoom: 5

Draw	neutral	commander	hostile	default	friendly
Past	☐	☐	☐	☐	☐
Present	☑	☑	☑	☑	☑
Future	☐	☐	☐	☐	☑
Labels	☐	☑	☑	☑	☑
Comms	☐	☐	☐	☐	☐
Sensor	☐	☐	☐	☐	☐

☑ Event Areas ☑ Messages
☑ GIS ☐ Lat/Long

Figure 6: Viewer Showing Node Positions and Planned Search Paths



Goals

cec8838f(isSmuggling: SearchArea2)
cf227fc4(isSmuggling: SearchArea1)
aee61494(isSmuggling: FullSearchArea)

Details

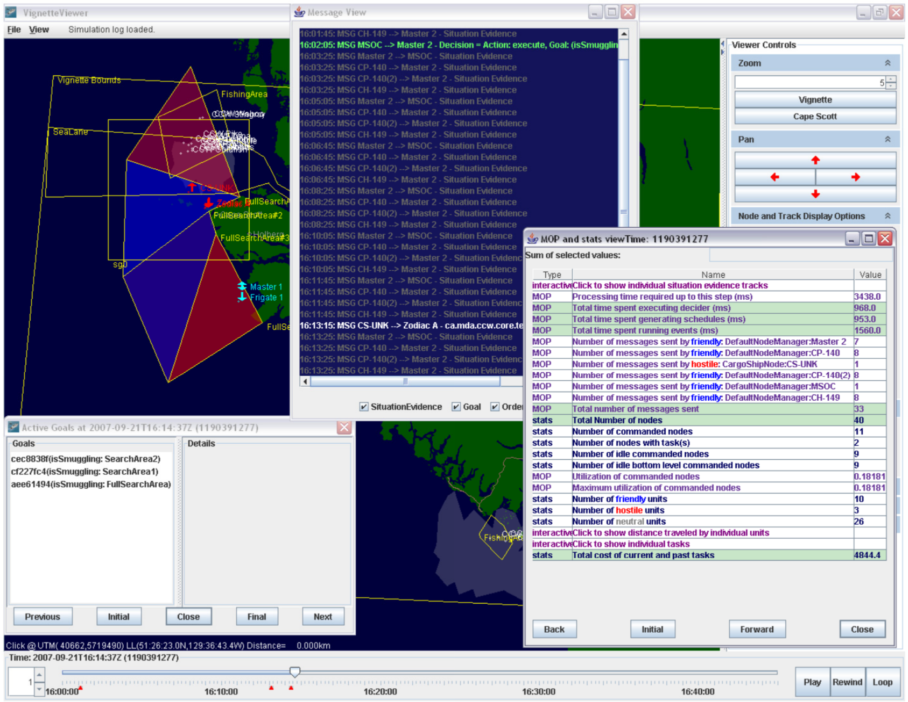
id: cf227fc4
proposition: isSmuggling
node assigned: Master 1
priority: 7
goal area: SearchArea1

Currently displaying:
cf227fc4

New candidate:
cf227fc4

Time: 2007-09-21T16:08:46Z (1190390926)

Figure 7: Viewer Showing Situation Evidence Probability for Search Area



```
16:01:45: MSG CH-149 --> Master 2 - Situation Evidence
16:02:05: MSG MSOC --> Master 2 - Decision = Action: execute, Goal: (isSmugglin
16:03:25: MSG Master 2 --> MSOC - Situation Evidence
16:03:25: MSG CP-140 --> Master 2 - Situation Evidence
16:03:25: MSG CP-140(2) --> Master 2 - Situation Evidence
16:03:25: MSG CH-149 --> Master 2 - Situation Evidence
16:05:05: MSG Master 2 --> MSOC - Situation Evidence
16:05:05: MSG CP-140 --> Master 2 - Situation Evidence
16:05:05: MSG CP-140(2) --> Master 2 - Situation Evidence
16:05:05: MSG CH-149 --> Master 2 - Situation Evidence
16:06:45: MSG Master 2 --> MSOC - Situation Evidence
16:06:45: MSG CP-140 --> Master 2 - Situation Evidence
16:06:45: MSG CP-140(2) --> Master 2 - Situation Evidence
16:06:45: MSG CH-149 --> Master 2 - Situation Evidence
16:08:25: MSG Master 2 --> MSOC - Situation Evidence
16:08:25: MSG CP-140 --> Master 2 - Situation Evidence
16:08:25: MSG CP-140(2) --> Master 2 - Situation Evidence
16:08:25: MSG CH-149 --> Master 2 - Situation Evidence
16:10:05: MSG Master 2 --> MSOC - Situation Evidence
16:10:05: MSG CP-140 --> Master 2 - Situation Evidence
16:10:05: MSG CP-140(2) --> Master 2 - Situation Evidenc
16:10:05: MSG CH-149 --> Master 2 - Situation Evidence
16:11:45: MSG Master 2 --> MSOC - Situation Evidence
16:11:45: MSG CP-140 --> Master 2 - Situation Evidence
16:11:45: MSG CP-140(2) --> Master 2 - Situation Evidenc
16:11:45: MSG CH-149 --> Master 2 - Situation Evidence
16:13:15: MSG CS-UNK --> Zodiac A - ca.mda.ccw.core.te
16:13:25: MSG Master 2 --> MSOC - Situation Evidence
16:13:25: MSG CP-140 --> Master 2 - Situation Evidence
16:13:25: MSG CP-140(2) --> Master 2 - Situation Evidenc
16:13:25: MSG CH-149 --> Master 2 - Situation Evidence
```

☑ SituationEvidence ☑ Goal ☑ Orde

MOP and stats viewTime: 1190391277

Sum of selected values:

Type	Name	Value
interactive	Click to show individual situation evidence tracks	
MOP	Processing time required up to this step (ms)	3438.0
MOP	Total time spent executing decider (ms)	968.0
MOP	Total time spent generating schedules (ms)	953.0
MOP	Total time spent running events (ms)	1560.0
MOP	Number of messages sent by friendly: DefaultNodeManager:Master 2	7
MOP	Number of messages sent by friendly: DefaultNodeManager:CP-140	8
MOP	Number of messages sent by hostile: CargoShipNode:CS-UNK	1
MOP	Number of messages sent by friendly: DefaultNodeManager:CP-140(2)	8
MOP	Number of messages sent by friendly: DefaultNodeManager:MSOC	1
MOP	Number of messages sent by friendly: DefaultNodeManager:CH-149	8
MOP	Total number of messages sent	33
stats	Total Number of nodes	40
stats	Number of commanded nodes	11
stats	Number of nodes with task(s)	2
stats	Number of idle commanded nodes	9
stats	Number of idle bottom level commanded nodes	9
MOP	Utilization of commanded nodes	0.18181
MOP	Maximum utilization of commanded nodes	0.18181
stats	Number of friendly units	10
stats	Number of hostile units	3
stats	Number of neutral units	26
interactive	Click to show distance traveled by individual units	
interactive	Click to show individual tasks	
stats	Total cost of current and past tasks	4844.4

Goals

cec8838f(isSmuggling: SearchArea2)
cf227fc4(isSmuggling: SearchArea1)
aee61494(isSmuggling: FullSearchArea)

Details

Click @ UTM(40662,5719490) LL(51:26:23.0N,129:36:43.4W) Distance= 0.000km

Time: 2007-09-21T16:14:37Z (1190391277)

Figure 8: Viewer Showing Various Output Options

3 Summary of Achievements

3.1 Investigated Technologies

3.1.1 Multi-agent Technology

A Multi-Agent System (MAS) is a system composed of multiple interacting intelligent agents. Multi-agent systems can be used to solve problems which are difficult or impossible for an individual agent or monolithic system to solve. Multi-agent systems are particularly suited to the DIF and DRM problem, since they have several important characteristics:

Autonomy: the agents are at least partially autonomous, i.e. each node/platform is responsible for fusion of its own sensors (no raw data is exchanged through the network, only track data)

Local views: no agent has a full global view of the system, or the system is too complex for an agent to make practical use of such knowledge (imposed in our case by bandwidth limitations of the network)

Decentralization/distribution: there is no designated controlling agent

Typically multi-agent systems research refers to software agents. However, the agents in a multi-agent system could equally well be robots, humans or human teams. A multi-agent system may contain combined human-agent teams, which is referred to as “human-in-the-loop” for DSS.

Multi-agent systems can manifest self-organization and complex behaviors even when the individual strategies of all their agents are simple. Even a small change in initial conditions or boundary conditions, such as modifying slightly one vignette to create another can lead to substantially different, often unpredictable results.

3.1.2 Planning and Scheduling

Automated planning and scheduling is a branch of artificial intelligence that concerns the realisation of strategies or action sequences, typically for execution by intelligent agents. Unlike classical control and classification problems, the solutions are complex, unknown and have to be discovered and optimised in multidimensional space.

In known environments with available models, planning can be done offline. Solutions can be found and evaluated prior to execution. This is the case of the initial starting plan for assigning the resources (platforms and their initial trajectories). In dynamically unknown environments the strategy often needs to be revised online. This occurs as soon as accumulated situation evidence changes the assumptions that led to the initial plan.

A typical planner takes three inputs: a description of the initial state of the world, a description of the desired goal, and a set of possible actions. The planner produces a sequence of actions that lead from the initial state to a state meeting the goal. An alternative language for describing planning problems is that of hierarchical task networks, in which a set of tasks is given, and each task can be either realized by a primitive action or decomposed in a set of other tasks.

3.1.3 Service Oriented Architecture

Generally speaking, SOA is a flexible set of design principles used during the phases of systems development and integration. Upon deployment, an SOA-based architecture will provide a loosely-integrated suite of services that can be used within multiple business domains. SOA also generally provides a way for consumers of services, such as Web-based applications, to be aware of available SOA-based services. XML is commonly used for interfacing with SOA services, and was used in FUSEWARE

SOA defines how to integrate widely disparate applications for a world that is Web based and uses multiple implementation platforms. Rather than defining an API, SOA defines the interface in terms of protocols and functionality. An endpoint is the entry point for such an SOA implementation.

Service-orientation requires loose coupling of services with operating systems, and other technologies that underlie applications. SOA separates functions into distinct units, or services, which developers make accessible over a network in order to allow users to combine and reuse them in the production of applications. These services communicate with each other by passing data in a well-defined, shared format, or by coordinating an activity between two or more services.

Web services implement a SOA. A major focus of Web services is to make functional building blocks accessible over standard Internet protocols that are independent from platforms and programming languages. These services can be new applications or just wrapped around existing legacy systems (such as CASE ATTI for FUSEWARE) to make them network-enabled.

For example, the tracking service of CASE ATTI can be decomposed into the following Web services described below and shown in Figure 9:

1. the client connects to the tracking web-server and obtains a client ID number;

2. the client provides to the tracking web-server the tracking and connection CONFIG files, the input socket port, address and key for the reports reception;

3. the tracking web service extracts the CONFIG files in a separate directory and spawns the tracking module specifying the client's socket port, address and key;

4. the tracking web service asks for the contact buffers which are provided by the client using the "stimulation output" file;

5. the client receives all the buffers and can process them at will;

6. the client asks the tracking web-server to close the tracking simulation;

7. the tracking web-server closes all processes and removes the CONFIG files associated with the completed simulation.

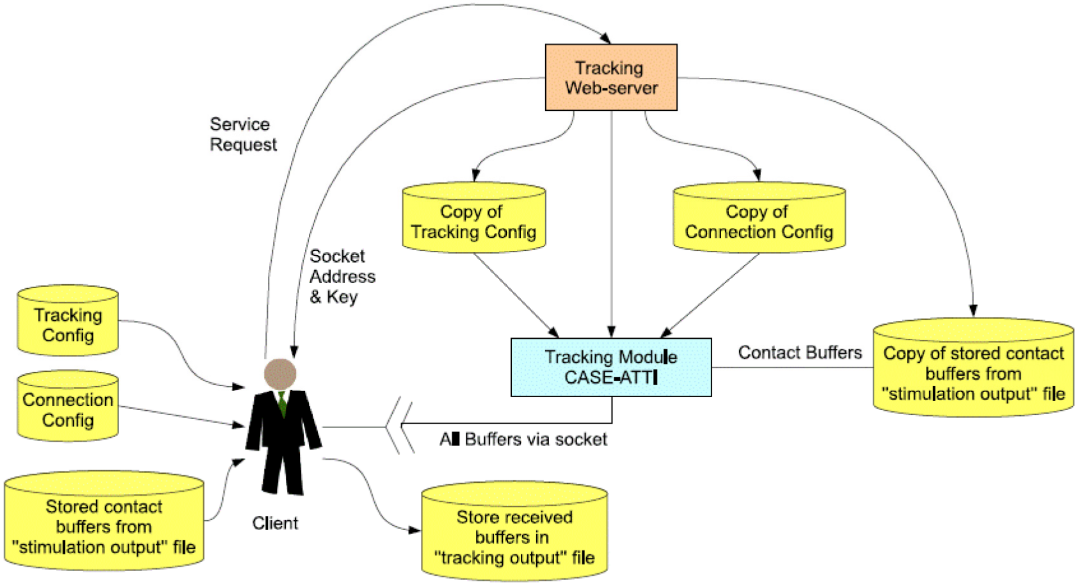


Figure 9: Tracking Web service

3.1.4 Abstract State Machine

The ASM method is a practical and scientifically well-founded systems engineering method which bridges the gap between the two ends of system development:

the human understanding and formulation of real-world problems (requirements captured by accurate high-level modeling at the level of abstraction determined by the given application domain)

the deployment of their algorithmic solutions by code-executing machines on changing platforms (definition of design decisions, system and implementation details).

In the original conception of ASMs, a single agent executes a program in a sequence of steps, possibly interacting with its environment. This notion was extended to capture distributed computations, in which multiple agents execute their programs concurrently. It is this distributed version of ASM which was used for CCW.

Since ASMs model algorithms at arbitrary levels of abstraction, they can provide high-level, low-level and mid-level views of a hardware or software design. ASM specifications often consist of a series of ASM models, starting with an abstract ground model and proceeding to greater levels of detail in successive refinements or coarsenings.

Due to the algorithmic and mathematical nature of these three concepts, ASM models and their properties of interest can be analyzed using any rigorous form of verification (by reasoning) or validation (by experimentation, testing model executions). ASMs were used for DRCMA.

3.2 Capabilities

3.2.1 Algorithms

Algorithms are constantly in a state of flux. To list them all chronologically would not be fruitful, as newer versions replace older versions on a regular basis. For the ARP 13qa, numerous Universities independently developed algorithms which were integrated into the testbed by MDA. The University of Calgary concentrated on higher-level fusion (see for example sections 3.3.5.7, and 3.3.5.15), and Simon Fraser on dynamic resource management (see for example sections 3.3.5.13, and 3.3.5.16), and auto-configurable information fusion architecture (see section 3.3.5.20). These algorithms are now being refined under the ARP 13qi by the same organizations, with the addition of the University of Victoria.

Existing algorithms developed at DRDC, such as SARPlan [8] were integrated into the testbed (see section 3.3.5.16), in order to generate the initial search-and-rescue plan. SARPlan provides help in the optimal use of available effort by identifying appropriate search areas and in assigning search patterns and altitudes to specific aircraft types, all with due regard to examining the ground both speedily and efficiently. Its database includes the bases, flight characteristics and logistic requirements of the search vehicles, so its suggested search plans are both realizable and cost-effective. By applying sophisticated search algorithms, SARPlan suggests strategies that concentrate search assets where they are most likely to be effective. Technologies employed include search theory, non-linear optimization and constraint satisfaction programming for optimal effort allocation. Bayesian statistics are used to estimate the location of the search object. These technologies are incorporated into statistical models and optimization algorithms that use both artificial intelligence and operational research principles specifically tailored to search and rescue functions.

3.2.2 Plug-and-Play Testbed

Plug-and-play facilities for the testbed have been designed to satisfy the following goals:

Maximize the mutability of a simulation through a strictly compartmentalized architecture allowing different algorithms or physical simulation entities to be swapped for the purposes of experimentation.

Allow for a flexible configuration file format, which can be dynamically constructed by the visual editor tool and built up from pre-configured components.

Minimize the impact of plug-and-play conformance on individual development efforts of experimenters wishing to plug in custom components.

Plug-and-play is fundamentally very straightforward involving only a few updates to an existing class implementation. Plug-and-play was required because of the many developers in different Universities writing independently their code.

Another use of the testbed as a whole is as a simulation tool. An example application is as an intelligent advisor in support of purchasing decisions: by experimenting with different numbers and types of resources or capabilities users can explore the pros and cons of using different resources.

3.3 Publications

The work conducted under the 13qa ARP generated many publications from 2006 to 2009, such as DRDC internal publications (4), contractor reports, book chapters (2), publications in the scientific literature, conference contributions, and a Master's thesis. The following sub-sections give an exhaustive list of these publications, as well as a short abstract for each of these publications.

3.3.1 DRDC publications

One Technical Memorandum (TM), two Technical Reports (TR), and one Technical Note (TN) were produced under the ARP 13qa. The TM sets the stage of the research by providing a state-of-the-art review of DIF and DRM, the TRs evaluate existing joint software under consideration by the Canadian Forces (CF), and explore a new theory applied to highly conflicting reports for identification and recognition, and finally the TN situates data/information fusion in the context of the C4ISR plan.

3.3.1.1 Distributed information fusion and dynamic resource management – State-of-the-art status in 2007 [9]

This DRDC memorandum provides a survey of recent research developments in DIF and DRM, as exemplified by articles, guest speaker presentations and panel discussions presented at two renowned conferences: the International Society of Information Fusion conference FUSION 2007 (Quebec City, 9-12 July 2007, hosted by DRDC Valcartier), and the SPIE Defense & Security Symposium (Orlando, 9-13 April 2007). This memorandum reviews current trends, expert position papers, scientific articles, posters and presentations at these conferences and places them in the context of scientific progress over the last decade. Whenever appropriate, relevant research articles are situated within ARPs, TDPs, and acquisition programs of the CF.

The memorandum first discusses design considerations for modern DIF and DRM systems in the Canadian context, focusing on Service Oriented Architectures (SOA) and multi-agent implementations. It then identifies target identification (ID) fusion as a key enabler in DIF and reviews work on ontologies, as well as recent progress in two popular theories allowing cumulative reasoning over target IDs. The main application of surveillance and situation analysis is then covered with an emphasis on large volume surveillance, particularly in the maritime domain. Finally, the interaction of DRM with higher levels of fusion is presented through the opinions of experts and selected examples.

3.3.1.2 Evaluation of the Joint Automated Deep Operations Coordination System (JADOCS) [10]

The Joint Automated Deep Operations Coordination System (JADOCS) is already fielded to over 5,000 users throughout the world, including many Coalition partners of the US. The Joint Fires Support (JFS) TDP of DRDC has requested an evaluation of JADOCS for the CF. This technical report contains the results obtained through a questionnaire that was given to members of the CF (and some civilians) who attended extensive JADOCS training courses. A thorough qualitative analysis recapitulates the major successes/drawbacks of using JADOCS for the CF, and highlights what would be needed to field a Canadianized version of JADOCS.

3.3.1.3 Dezert-Smarandache theory applied to highly conflicting reports for identification and recognition – Illustrative example of ESM associations in dense environments [11]

Electronic Support Measures (ESM) consist of passive receivers which can identify emitters coming from a small bearing angle, which, in turn, can be related to platforms that belong to 3 classes: either Friend, Neutral, or Hostile. Decision makers prefer results presented in STANAG 1241 allegiance form, which adds 2 new classes: Assumed Friend, and Suspect. Dezert-Smarandache Theory (DSmT) is particularly suited to this problem, since it allows for intersections between the original 3 classes. In this way, an intersection of Friend and Neutral can lead to an Assumed Friend, and an intersection of Hostile and Neutral can lead to a Suspect. Results are presented showing that the theory can be successfully applied to the problem of associating ESM reports to established tracks, and its results identify when miss-associations have occurred and to what extent. Results are also compared to Dempster-Shafer Theory (DST), which can only reason on the original 3 classes. Thus decision makers are offered STANAG 1241 allegiance results in a timely manner, with quick allegiance change when appropriate and stability in allegiance declaration otherwise.

3.3.1.4 Definition of Data/Information Fusion in the Context of the C4ISR plan [12]

This short technical note highlights the role of data/information fusion for the C4ISR campaign plan. It does so by providing a more precise and detailed definition of data and information fusion, and provides more insights on what the fusion process means, by briefly discussing its sub-processes, by describing some related relevant concepts, and by putting fusion in the context of C2, situation analysis and awareness, and computer-based decision support systems. The data fusion model continuously maintained by the JDL's Data and Information Fusion Group that is the most widely-used method for categorizing data fusion-related functions has been found appropriate to fulfill our purpose.

3.3.2 Contractor Reports

There were three major contractual initiatives related to 13qa:

1. A Precarn Technology Research and Development Program in Intelligent Systems project called CanCoastWatch (CCW), whose main goal was to provide DIF and DRM for Decision Support. Precarn Inc. helps Canadian companies to bridge the "innovation gap", between university and government research and commercial application. Precarn thus requires a company to head the project, which in this case was MacDonald Dettwiler and Associates Ltd. (MDA) with contributions from Actenum. These Universities were Simon Fraser University (Intelligent Systems Lab and Software Technology Lab), and University of Calgary (Electrical and Computer Engineering Dept.).

2. “Development of Data/Information Fusion Services to be used in a Service Oriented Architecture (SOA)”, a.k.a. FUSEWARE contract, which produced 10 reports. The main objective was to make CASE ATTI, an existing DRDC testbed for Level 1 data fusion, into SOA services. CASE ATTI uses an Object-Oriented (OO) software design allows for the easy development and incorporation of new tracking and fusion algorithms, sensor models, and analysis tools. CASE ATTI runs on both UNIX and Windows platforms and the design also has the capabilities of utilizing multiple computers across a Local Area Network (LAN). Portability requirements have also driven the selection of the various software technologies used (e.g., C++, Oracle, OpenGL, Java, etc.).

3. “Analysis of CF C2 Requirements and Science & Technology (S&T) Trends” performed as Task Authorization 24 of the Joint Command Decision Support (JCDS) for the 21st Century Technology Demonstration Project, which produced one final report, and organized a workshop with all stakeholders included a 3-day Workshop with 10 leading industry technical scientists, 8 DRDC scientists, and 19 CF representatives from all environments. This was followed by 19 interviews with many Director Generals, Directors of S&T, and Program Managers of TDPs, and integrated into the final deliverable.

The first two are directly related to 13qa, while the third ensures that the current research initiatives (such as those undertaken in 13qa) line up with C2 requirements of the CF and make use of the most recent S&T trends.

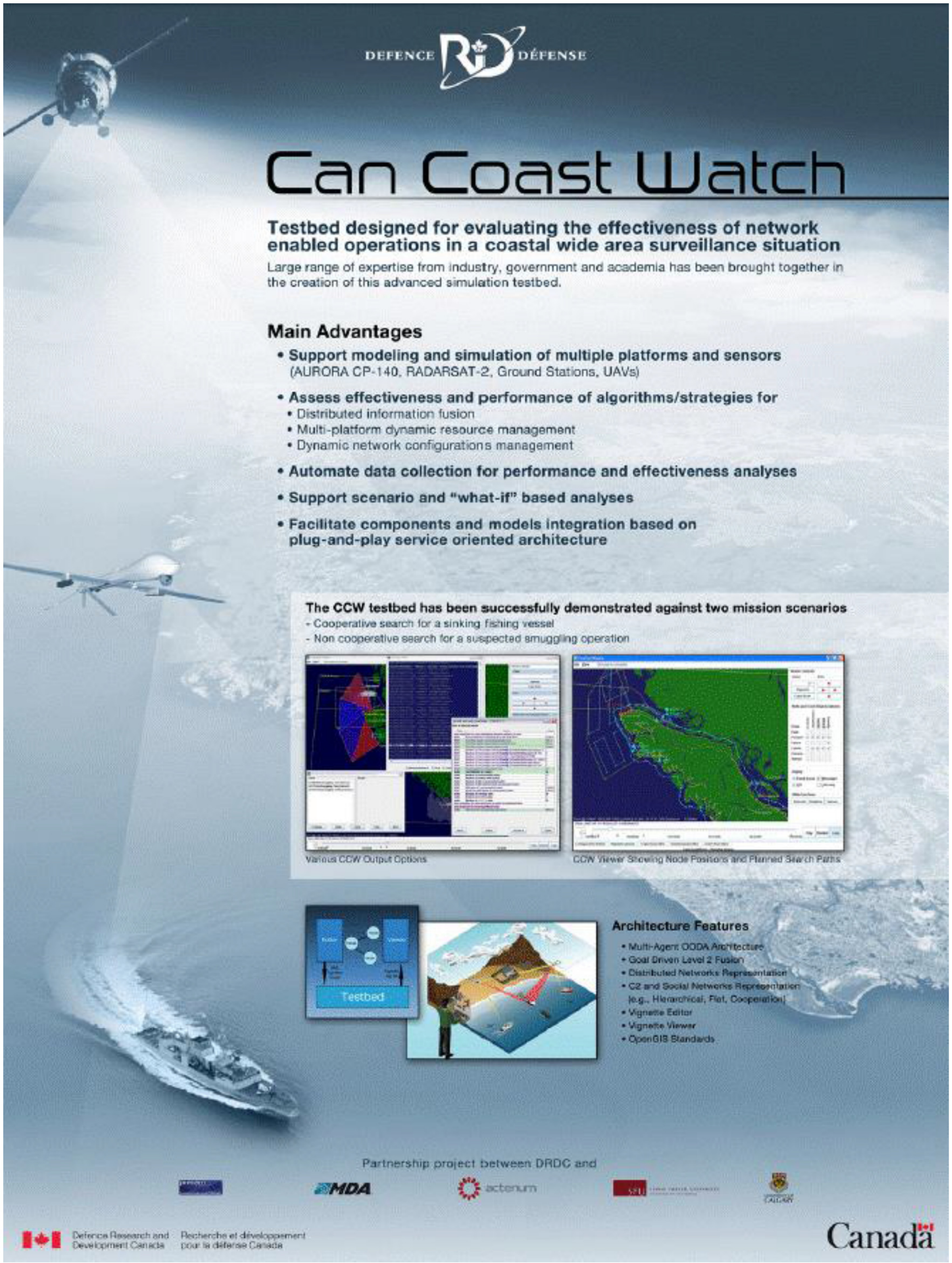
These are further described in the next subsections.

3.3.2.1 CanCoastWatch

CCW is a situation assessment system to support large-area surveillance missions, which require efficient deployment of multiple search resources and rapid extraction and distribution of key information. Two major design builds were done, and refined through several versions after revisions by DRDC researchers, the first document on Build-1 specification going up to revision v.4.21 [13] and the second document on Build-2 specification leading to v3.6 [14].

Following these specifications, four software builds were done as contributions from the different Universities were integrated. These Universities were Simon Fraser University (Intelligent Systems Lab and Software Technology Lab), and University of Calgary (Electrical and Computer Engineering Dept.). The vast majority of the open literature publications listed in the following sections originated within CCW.

The main features and advantages of CCW are shown in the poster below (Figure 1).



DEFENCE DÉFENSE

Can Coast Watch

Testbed designed for evaluating the effectiveness of network enabled operations in a coastal wide area surveillance situation

Large range of expertise from industry, government and academia has been brought together in the creation of this advanced simulation testbed.

Main Advantages

- **Support modeling and simulation of multiple platforms and sensors**
  (AURORA CP-140, RADARSAT-2, Ground Stations, UAVs)
- **Assess effectiveness and performance of algorithms/strategies for**
  - Distributed information fusion
  - Multi-platform dynamic resource management
  - Dynamic network configurations management
- **Automate data collection for performance and effectiveness analyses**
- **Support scenario and "what-if" based analyses**
- **Facilitate components and models integration based on plug-and-play service oriented architecture**

The CCW testbed has been successfully demonstrated against two mission scenarios
- Cooperative search for a sinking fishing vessel
- Non cooperative search for a suspected smuggling operation

Various CCW Output Options

CCW Viewer Showing Node Positions and Planned Search Paths

Architecture Features

- Multi-Agent OODA Architecture
- Goal Driven Level 2 Fusion
- Distributed Networks Representation
- C2 and Social Networks Representation
  (e.g., Hierarchical, Flat, Cooperation)
- Vignette Editor
- Vignette Viewer
- OpenGIS Standards

Partnership project between DRDC and

Defence Research and Development Canada Recherche et développement pour la défense Canada

Canada

Figure 10: Poster of CanCoastWatch.

3.3.2.2 FUSEWARE

FUSEWARE consisted of 4 tasks to which 10 deliverables were related.

The first task concerned the Definition of Level-0-1 data fusion services according to the engineering guidelines of the JDL data fusion model. Three reports were related to this task:

1. Analysis of the Department of Defence Architecture Framework (DoDAF) [15].
2. Analysis of SOA web-based approaches [16].
3. Definition of Level-0-1 data fusion services [17].
4. The second task was the translation of the Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification (CASE ATTI) system into data fusion services. Three reports were related to this task:
5. Translation of the stimulation module of CASE ATTI into services [18].
6. Translation of the level-1 data fusion module of CASE ATTI into data fusion services [19].
7. Translation of the performance evaluation module of CASE ATTI into services [20].

The third task was the validation of the fusion services into a service-oriented architecture. Three reports were related to this task:

8. Validation of the stimulation services [21].
9. Validation of the level-1 data fusion services [22].
10. Validation of the performance evaluation services [23].

The final task was the exploration of the potential fusion services for levels 2-3 of the JDL data fusion model, to which one final report “Definition of levels 2-3 data fusion services” [24] was related.

3.3.2.3 Analysis of CF C2 Requirements and S&T Trends [25]

Sponsored by DRDC, the aim of this study is to identify the Science & Technology (S&T) challenges inherent in emerging CF C2 requirements. This knowledge will provide a framework for the timely identification and prioritization of future Research & Development (R&D) efforts in support of the C2 function. The study started with a review of published documentation emanating from the various Department of National Defence (DND)/CF offices engaged in force development work, and specifically C2 capability development. From there, the study moved on to examine the DRDC role in C2 development. From both these endeavours, a number of questions and theories were generated, and these were subsequently pursued through the facilitation of a workshop and the conduct of numerous stakeholder interviews. The workshop was particularly useful in gathering the inputs, views and perspectives of many senior officials who are intimately involved in the day-to-day development of C2 capability, while the interviews served to fill information gaps and solicit views on the “way ahead” from key stakeholders.

Aggregated categories of C2 Objectives from this workshop are outlined in Table 1 below.

Table 1: Aggregated categories of C2 Objectives.

C2 Objectives – Aggregated Categories
1) Collaboration/Tools
2) Connectivity/Networks
3) Data
4) Infrastructure
5) Process
6) Simulation and Training
7) Technology Assisted Decision Making
8) Visualization

The ARP 13qa addresses the aggregates categories of C2 objectives #1, #6, #7, and #8, clearly showing its relevance concerning C2 objectives.

Aggregated categories of S&T enablers from this workshop are outlined in Table 2 below.

Table 2: Aggregated categories of S&T enablers.

S&T Enablers – Aggregated Categories
A) Artificial Intelligence
B) Biometrics
C) Cognitive Sciences
D) Decision Support
E) Genetic Engineering/Cybernetics
F) Human Machine Interfaces (HMI)
G) Networks
H) Improved Operating Systems
I) Physics
J) Security

The ARP 13qa makes use of S&T enablers A, C, D, F, and G, clearly showing its relevance concerning the S&T enablers used.

In concluding the study, the fact that C2 does not exist or function in isolation is reiterated for the sake of completeness. Having a coordinated plan for C2 capability development will not fully succeed unless combined with a related set of efforts in developing the Sense domain, the Intelligence function, and the Sustain domain. The knowledge gained through this study provides a framework for the timely identification and prioritization of future Research & Development (R&D) efforts in support of the C2 function. The recommendations stemming from this study provide the key elements of an “engagement strategy” for C2 capability development that can be further refined by the DRDC sponsors.

3.3.3 Book chapters

3.3.3.1 Reducing DSmT hybrid rule complexity through optimization of the calculation algorithm [26]

This book chapter in Vol.2 of “Advances and Applications of DSmT for Information Fusion – Collected Works” had for its objective writing a Matlab program able to execute efficiently the DSmT hybrid rule of combination. As is commonly known, the DSmT hybrid rule of combination is highly complex to execute and requires high amounts of resources. We have introduced a novel way of understanding and treating the rule of combination and thus were able to develop a Matlab program that would avoid the high level of complexity and resources needs.

This work was a preamble needed for the application described in the technical report on DSmT mentioned in Section 3.3.1.3, and for the following book chapter.

3.3.3.2 Fusion of ESM allegiance reports using DSmT [27]

This book chapter of Vol. 3 of “Advances and Applications of DSmT for Information Fusion – Collected Works” is mostly the TR mentioned in Section 3.3.1.3, but made available to a larger audience than just DRDC scientists.

3.3.4 Journal articles

Two scientific articles were published in 2006 in the journal *Information Fusion* published by Elsevier. The first concerns an airborne platform (the CP-140) and the second a naval platform (the CPF), providing 2 key elements in the distributed information fusion problem involving both naval and airborne platforms collaborating in NEOps.

3.3.4.1 Comparative Implementation of 2 Fusion Schemes for Multiple Complementary FLIR Imagery Classifiers [28]

Several classifiers for FLIR imagery are designed and implemented, and their relative performance is benchmarked on 2545 images belonging to 8 different ship classes, from which 11 attributes are extracted. These are a Bayes classifier, a DS classifier ensemble in which specialized classifiers are optimized to return a single ship class, a k-nearest neighbour classifier, and an optimized neural net classifier. Two different methods are then studied to fuse the results of selected subsets of these classifiers. The first method consists of using the outputs of various classifiers as inputs to a second neural net fuser. The second method consists of converting the outputs of these classifiers into masses for use in a DS fuser. In both approaches, the fused classifier achieves better results than the best classifier for any given class.

3.3.4.2 Exploitation of A Priori Knowledge for Information Fusion [29]

The Information Fusion (IF) process is becoming increasingly more sophisticated, particularly through the incorporation of methods for high-level reasoning when applied to the situation analysis domain. A fundamental component of the IF process is a database (or databases) containing *a priori* knowledge that lists expected objects, behaviors of objects, and relationships between objects as well as all the possible attributes that can be inferred from measurements coming from a given sensor suite. We first present the basic concept of an existing support database (consisting of more than 2200 platforms) for Identity information fusion, and discuss its extension for higher-level fusion (e.g. situation and threat assessment). The database contains all the salient features needed for refining the identity of any target by the fusion of sensor information, and for addressing the situation and threat posed by groups of objects. The database is especially well suited for use in a DS evidential reasoning scheme although it can also be used with Bayesian reasoning, if *a priori* probability distributions are known. Convincing results on several realistic scenarios of Maritime Air Area Operations and Direct Fleet Support are presented. This paper then develops the advanced concept of a Knowledge Management and Exploitation Server (KNOWMES) to support the IF process, through the use of ontologies and heterogeneous knowledge sources, which are necessary for higher level fusion.

3.3.5 Conference Proceedings

The work performed under 13qa was presented in different scientific events, including conferences, symposia, and workshops. The list presented below is in chronological order.

3.3.5.1 Adaptative Combination Rule and Proportional Conflict Redistribution Rule for Information Fusion [30]

This paper presents two new promising combination rules for the fusion of uncertain and potentially highly conflicting sources of evidences in the theory of belief functions established first in DST and then recently extended in DSmT. This work provides new issues to palliate the well-known limitations of Dempster’s rule and to work beyond its limits of applicability. Since the famous Zadeh criticism of Dempster’s rule in 1979, many researchers have proposed new interesting alternative rules of combination to palliate the weakness of Dempster’s rule in order to provide acceptable results especially in highly conflicting situations. In this work, we present two new combination rules: the class of Adaptive Combination Rules (ACR) and a new efficient Proportional Conflict Redistribution (PCR) rule. Both rules allow to deal with highly conflicting sources for static and dynamic fusion applications. We present some interesting properties for ACR and PCR rules and discuss some simulation results obtained with both rules for Zadeh’s problem and for a target identification problem

3.3.5.2 An Essay to Characterize Information Fusion Systems [31]

Characterisation of an Information Fusion System (IFS) is a very difficult challenge. There are many levels of information fusion and there are many decision fusion models. One can argue that each problem is very specific and thus developing a generalized framework is an ideal only. This paper presents a simplified, and sometimes naïve representation of IFS. This representation is based on characterising the inputs and outputs of IFS. An IFS is thus seen as a function that transforms the input into an output given some conditions. These conditions might include controls, background knowledge, and goals queries. We present a set of properties that might be considered to characterise a fusion function. This paper also discusses some challenges of distributed information fusion as a pre-requisite of Net-enabled operations.

3.3.5.3 A Testbed Simulator to Evaluate the Efficiency of Net-Enabled Surveillance [32]

A team of participants is creating an advanced simulation testbed for the purpose of evaluating the effectiveness of NEOps in a Coastal Wide Area Surveillance situation. The testbed allows experimentation with distributed information fusion, dynamic resources management and configuration management given multiple constraints on the resources and their communications networks. The situation being simulated is that of either a cooperative surface target or an elusive target wishing to avoid detection. The simulation consists of a networked set of surveillance assets including aircraft (UAV and manned), ships, and satellites.

Due to bandwidth limitations, full data sharing over most real world links is not feasible. Therefore on-platform data fusion must be simulated to evaluate implementation and performance of distributed information fusion. Surveillance platform behaviour is also simulated in order to evaluate different dynamic resource management algorithms. Additionally, communication networks are modeled to simulate different information exchange concepts. The testbed allows evaluation of a range of control strategies from independent platform search control through various levels of platform collaboration up to a centralized control of search platforms.

3.3.5.4 Dempster-Shafer theory made tractable and stable [33]

This presentation, during a panel discussion on “Issues and Challenges in Uncertainty Representation and Management with applications to Real-World Problems,” focussed on explaining that DST is used in both identity gating and in the fusion process itself. It listed the advantages of DST process: 1) it can deal with incomplete information because it supports the notion of ignorance, 2) it can handle conflicts between associated contact/track because it supports the notion of conflict, 3) it can resist countermeasures, and false associations, 4) it does not require *a priori* information, 5) it can become real-time if approximation (truncation) schemes are utilized. Platform DataBases (PDBs) needed to use DST in a military context were reviewed (STANAG 4420 and MIL-STD 2525b). Finally existing approximation schemes were reviewed.

3.3.5.5 Testbed for large volume surveillance through distributed fusion and resource management [34]

DRDC Valcartier has initiated, through a PRECARN partnership project, the development of an advanced simulation testbed for the evaluation of the effectiveness of Network Enabled Operations in a coastal large volume surveillance situation. The main focus of this testbed is to study concepts like distributed information fusion, dynamic resources and networks configuration management, and self-synchronising units and agents. This article presents the requirements, design and first implementation builds, and reports on some preliminary results. The testbed allows modelling of distributed nodes performing information fusion, dynamic resource management planning and scheduling, as well as configuration management, given multiple constraints on the resources and their communications networks. Two situations are simulated: cooperative and non-cooperative target search. A cooperative surface target behaves in ways to be detected (and rescued), while an elusive target attempts to avoid detection. The current simulation consists of a networked set of surveillance assets including aircraft (UAVs, helicopters, maritime patrol aircraft), and ships. These assets have electro-optical and infrared sensors, scanning and imaging radar capabilities. Since full data sharing over datalinks is not feasible, own-platform data fusion must be simulated to evaluate implementation and performance of distributed information fusion. A special emphasis is put on higher-level fusion concepts using knowledge-based rules, with level 1 fusion already providing tracks. Surveillance platform behavior is also simulated in order to evaluate different dynamic resource management algorithms. Additionally, communication networks are modeled to simulate different information exchange concepts. The testbed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of search platforms.

3.3.5.6 A Distributed Information Fusion Testbed for Coastal Surveillance [35]

MDA led a PRECARN partnership project to develop an advanced simulation testbed for the evaluation of the effectiveness of NEOps in a coastal large volume surveillance situation. The main focus of this testbed is to study concepts like distributed information fusion, dynamic resources and networks configuration management, and self-synchronising units and agents. This article presents the system architecture with an emphasis on our approach for distributed information fusion.

3.3.5.7 High Level Data Fusion System for CanCoastWatch [36]

In this paper, a goal-driven net-enabled distributed data fusion system is developed for the CCW project. Multiple sensors are deployed and managed to achieve the goals of situation assessment using a net-enabled architecture. The local tracks reported by multiple sensors are first integrated into global tracks. Decision making is then performed on basic sub-goals that can be directly derived from the fused global tracks. Finally, a goal-driven rule-based expert system uses the basic sub-goal decisions for goal reasoning.

3.3.5.8 Analysis of information fusion combining rules under the DSm theory using ESM inputs [37]

This poster presentation showed the first results of using DSmT instead of DST for fusing ESM reports. More complete and more significant results occur in later conferences (see below) and in a TR (section 3.3.13) and a book chapter (section 3.3.3.2).

3.3.5.9 A generalized framework for concordance/discordance based multi-criteria classification methods [38]

This paper reviews multiple criteria classification methods (or multi-criteria classifiers), particularly those based on Concordance/ Discordance concepts. The concordance refers to an aggregated metric indicating the truthfulness of a proposition according to a coalition of criteria.

The discordance is an aggregated metric representing the strength of the opposition coalition to the truthfulness of the proposition. A generalized framework is proposed to synthesise the underlying computation algorithms for each classifier. In this paper, we argue the benefits of cross-fertilization of multiple criteria classification methods and information fusion algorithms.

3.3.5.10 Automated Learning Multi-Criteria Classifiers for FLIR Ship Imagery Classification [39]

This paper proposes an automated learning approach based on real-coded Genetic Algorithm to infer the Multi-Criteria Classifier (MCC) parameters. The Multi-Criteria Classifiers (or Multi-Criteria Classification Methods) considered are based on concordance and discordance concepts. A military database of 2545 FLIR images representing eight different classes of ships is therefore used to test the performance of these classifiers. The empirical results of MCC are compared with those obtained by other classifiers (e.g. Bayes and Dempster–Shafer classifiers). In this paper, we argue the benefits of cross-fertilization of multiple criteria classification methods and information fusion algorithms.

3.3.5.11 Canadian Coast Watch test bed for large volume surveillance through distributed fusion and resource management [40]

The Northern region is a very large area to be surveyed. DRDC Valcartier has initiated, through a PRECARN partnership project, the development of an advanced simulation testbed for the evaluation of the effectiveness of Network Enabled Operations in a coastal large volume surveillance situation. The main focus of this test bed is to study net-enabled concepts such as distributed information fusion algorithms and architectures, dynamic resources and networks configuration management, and self-synchronising units and agents. Surveillance assets have electro-optical and infrared sensors, scanning and imaging radar capabilities. Surveillance platform behaviour is simulated in order to evaluate different distributed information sharing and dynamic resource management algorithms. Communication networks between platforms are modeled. The testbed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of search platforms. In this paper, we present the main project findings.

3.3.5.12 A System for Testing Distributed Information Fusion Applications for Maritime Surveillance [41]

A PRECARN partnership project CCW, is bringing together a team of researchers from industry, government, and academia for creating an advanced simulation test bed for the purpose of evaluating the effectiveness of Network Enabled Operations in a Coastal Wide Area Surveillance situation. The test bed allows experimenting with higher-level distributed information fusion, dynamic resource management and configuration management given multiple constraints on the resources and their communications networks. The test bed provides general services that are useful for testing many fusion applications. This includes a multi-layer plug-and-play architecture, and a general multi-agent framework based on John Boyd's OODA loop.

3.3.5.13 Dynamic Resource Management for Adaptive Distributed Information Fusion in Large Volume Surveillance [42]

We propose here a highly adaptive and auto-configurable, multi-layer network architecture for distributed information fusion to address large volume surveillance challenges, assuming a multitude of different sensor types on multiple mobile platforms for intelligence, surveillance and reconnaissance. Our focus is on network enabled operations to efficiently manage and improve employment of a set of mobile resources, their information fusion engines and networking capabilities under dynamically changing and essentially unpredictable conditions. This situation calls for reconfigurable applications that can flexibly adapt to internal changes in resource requirements and to external changes affecting the availability of resources. A high-level model of the proposed network architecture is formally described in abstract functional and operational terms based on a multi-agent modeling paradigm using the Abstract State Machine formalism. This description of the underlying design concepts provides a concise and precise blueprint for reasoning about key system attributes at an intuitive level of understanding.

3.3.5.14 A Web Services Approach for the Design of a Multi-Sensor Data Fusion System [43]

In compliance with the Department of National Defence Architecture Framework (DNDAF) and SOA, we develop a new web services implementation of a MSDF System. The migration and the decomposition into web services of the CASE ATTI test bed, developed at DRDC Valcartier, is realized using a spiral approach. A validation process of the web services is proposed by comparison with the results generated by the CASE ATTI testbed. We also present some general guidelines that should be satisfied by a MSDF web services provider.

3.3.5.15 Fuzzy Cognitive Map based Situation Assessment for Coastal Surveillance [44]

This paper presents a Fuzzy Cognitive Map (FCM) approach to develop an inference engine to perform goal reasoning based on information gathered by a sensor network. Statistical estimates obtained from a preceding data fusion operation are converted into fuzzy memberships and then propagated through the causal structure of the FCM. Sensor information based decisions are fused into higher level goals and premises until the system level objective is achieved. The developed situation assessment framework has been evaluated for two search scenario simulations.

3.3.5.16 Application of Search Theory for Large Volume Surveillance Planning [45]

DRDC Valcartier has initiated, through a PRECARN partnership project, the development of an advanced simulation test bed called CCW. The main focus of this test bed is to study net-enabled concepts such as distributed information fusion algorithms and architectures, dynamic resources and networks configuration management, and self-synchronising units and agents. The test bed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of search platforms. In this paper, we present the integration of a planning tool based on search theory concept: SARPlan. In particular, we discuss the original idea of combining fusion results to build a containment probability distribution according to the search theory approach. This paper presents the results and discusses future development.

3.3.5.17 A Simulation Framework for Higher-Level Fusion [46]

Led by MDA and DRDC Valcartier, a partnership project, called CCW, has brought together a team of researchers from industry, government, and academia for creating an advanced simulation testbed that addresses higher-level fusion concepts for the purpose of evaluating the effectiveness of Network Enabled Operations focused on Coastal Wide Area Surveillance applications. The testbed allows experimentation with higher-level distributed hierarchical information fusion, dynamic resource management and configuration management given multiple constraints on the resources and their communications networks. The test bed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of search platforms.

3.3.5.18 Decision Support Systems Design for Joint Multi-national Multi-agency Defence and Security Environment [47]

In complex environments like harbour security, where human errors may have tragic consequences, decision support systems are essential to execute complex tasks. This paper discusses critical issues in the design of computer-based support systems that can support operators/decision-makers to better understand the situation, select a course of action, monitor the execution of operations, and evaluate the results. These aids will support the decision-makers to cope with uncertainty and disorder and to help people to exploit technology at critical times and places, to ensure success in operations. Because the human cannot be completely replaced or removed from the execution of these tasks, the interaction and coordination between the human and the automated support systems becomes crucial. In emergency situations, that would necessitate the ability to coordinate multi-agency and multi-national operations, advanced decision support, knowledge exploitation, information fusion and the management tools that can significantly improve the ability to respond to such emergencies. A technological perspective alone has led system designers to propose solutions by providing operators with Decision Support Systems (DSS). These DSSs should aid the operators to achieve the appropriate Situation Awareness (SA) state for their decision-making activities, and to support the execution of the resulting actions. The lack of knowledge in cognitive engineering has, in the past, jeopardized the design of helpful computer-based aids aimed at complementing and supporting human cognitive tasks. Moreover, this lack of knowledge has, most of the time, created new trust problems in the designed tools. Providing the appropriate level of support thus requires balancing the human factor perspective with that of the system designer and coordinating the efforts in designing a cognitively fitted system to support the decision-makers.

3.3.5.19 An Agent Framework for Maritime Situation Awareness [48]

Maritime Situation Awareness involves keeping track of and understanding hundreds of pieces of information. Automated higher-level data fusion (Level-2 fusion and resource management) can provide valuable assistance to commanders and analysts who need to achieve situation awareness. INFORM Lab was created to help with this task. It is an advanced simulation framework that addresses higher-level fusion concepts for the purpose of evaluating the effectiveness of Network

Enabled Operations focused on Coastal Wide Area Surveillance applications. The testbed allows experimentation with higher-level distributed hierarchical information fusion, dynamic resource management and configuration management given multiple constraints on the resources and their communications networks. The test bed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of search platforms.

3.3.5.20 A Multi-Layer Network Architecture for Dynamic Resource Configuration & Management of Multiple Mobile Resources in Maritime Surveillance [49]

Maritime surveillance of large volume traffic demands robust and scalable network architectures for distributed information fusion. Operating in an adverse and unpredictable environment, the ability to flexibly adapt to dynamic changes in the availability of mobile resources and the services they provide is critical for the success of the surveillance and rescue missions. We present here an extended and enhanced version of the DRCMA, with new features and improved algorithms to better address the adaptability requirements of such a resource network. The DRCMA system concept is described in abstract functional and operational terms based on the ASM paradigm and the CoreASM open source tool environment for modeling dynamic properties of distributed systems.

3.3.6 Thesis (in French)

A behavioral comparative analysis of various combining rules in a simple context is presented in a Master's thesis [50]. We can find the impact of identification through the information fusion with various combining rules applied on Electronic Support Measures (ESM) output within this thesis. Our main objectives will be to use the DSmT for ESM, and implement the DSmT for use on ESM reports. Then we will identify the impact of information fusion under the STANAG 4162 which uses the STANAG 1241 to derive an allegiance. Our working environment, the DSmT of plausible, paradoxical, and neutrosophic reasoning is quite new and has not been used much, or implemented before the work covered by this thesis. It has been implemented here for an ESM environment.

4 Recommendations for future work

The CCW testbed will continue to evolve as a renamed INFORM lab (see section 3.3.5.19) under ARP 13qi. Collaboration between the various Universities (Calgary, Simon Fraser and Victoria), industry, and DRDC is ensured by the creation of the Wiki Net-enabled Adaptive Distributed Information Fusion (NADIF) for large volume surveillance (hosted at SFU).

Each of the problems addressed under 13qa will be refined and expanded, as explained in the following sub-sections, which mirror the ones in Section 2.

4.1 Development of a littoral surveillance scenario

Many littoral surveillance vignettes are presently being developed to serve as a standard literature describing the white shipping and large volume surveillance problems, the conventional existing architecture and their drawbacks. Further, the vignettes will enumerate the different critical requirements and constraints in the surveillance problem. The main outcome will be to build the necessary background knowledge to understand the implications of different technologies to help solve the multi-platforms littoral large volume distributed surveillance problem.

4.2 Adaptive Distributed Information Fusion

A major problem for the dynamic side is a noticeable lack of fusion processes which identify the presence of a vessel and institute an identified track for the vessels of interest. Systems like the short and long range AIS systems offer considerable potential for maintaining tracks on vessels mandated to use the system. It is currently difficult to automatically form and maintain tracks on the reporting vessels, although it is clear that particular vessels of interest can be tracked by the efforts of human analysts reading and identifying the reports and logging them into tracks. But, as the system expands to its programmed potential with more and more vessels reporting more and more frequently, any manual system will be quickly overwhelmed. Without the automated (level 1 and above) fusion process this system will not be able to maintain a global or even a local White Shipping picture. It may be possible to track targets tipped or identified by other means, but traditional Level 1 fusion techniques such as time series analysis and long-term trend analysis used to identify abnormal behaviour will give poor performance without an enhancement. Other means used to identify ship “drop outs” or other changes in behaviour depends on the ability to maintain persistent surveillance and consistent tracks utilizing the continuous reporting. This is also true of other dynamic reporting systems such as the intercept of radar and communications signals by national or tactical sensors, acoustic signals by national means from a number of allied nations.

4.3 Dynamic Resource Management

Dynamic management of surveillance platforms will be investigated to optimize resource allocation and improve adaptability as new information is gathered. In particular, the resource management algorithms will be designed to maximize coverage, maximize probability of success, minimize risk, and minimize response time to unforeseen events. The coordination conflict arising from communication link failure between two platforms will also be investigated in this light and based on the investigations, robust dynamic resource management algorithms for specific applications will be developed and tested. This project will develop a task allocation and scheduling system that is able to operate in different modes, commanding any to all of the platforms independently to deal with a high priority task or to share a load. Hence, each platform is semi-independent. With networked updates of distilled information from the fusion centre to all platforms, it is possible for each platform/sensor to make independent rescheduling decisions when communications fail. Dynamic programming, evolutionary computation, constraint solving algorithms, stochastic local search techniques and control theory will be investigated to design near real time adaptive platform management solution.

4.4 Auto-Configurable Information Fusion Architectures

In the proposed distributed network, each fusion function might be represented as a node. Connectivity allows information sharing among many fusion nodes. In this project, a multi-layer network architecture, DRCMA, is adopted to represent a distributed fusion network. A key requirement is the need for efficient management of information fusion nodes under dynamically changing and essentially unpredictable conditions. To facilitate dynamic reorganization and to avoid the bottleneck of centralized fusion systems, this project aims at a multi-agent based design approach in order to explore robust and efficient fusion of heterogeneous data and information. In that respect, the proposed approach resembles the concept of distributed perception networks. The DRCMA model will be formally described in terms of a distributed ASM with real-time constraints. The resulting machine model abstractly characterizes the dynamic properties of the distributed fusion architecture and serves as an abstract computational framework for requirements specification, design analysis and the validation of the key system attributes prior to actually building the system.

4.5 Further Development of the Test-Bed and Validation

The research team will be using a test-bed based on industry contributions to investigate and incorporate algorithms for distributed and adaptive information fusion, adaptive fusion architectures and dynamic resource management techniques. Industry will provide the project with realistic data set as well as models previously developed to deal with information fusion and resources management. Several case studies and scenarios will be selected during the front-end analysis phase and developed as part of the experiment design phase. Since the scenario(s) must generate the stimuli necessary for the MOEs and MOPs, the development of MOEs and MOPs will progress in parallel with experiment design.

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List of acronyms

ACR	Adaptive Combination Rules
ARP	Applied Research Project
ASCACT	Advanced Shipborne Command and Control Technology
ASM	Abstract State Machine
C2	Command and Control
C3	Command, Control, Communications
CASE ATTI	Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification
CCW	CanCoastWatch
CF	Canadian Forces
COMDAT	Command Decision Aid Technology
CPF	Canadian Patrol Frigate
DIF	Distributed Information Fusion
DND	Department of National Defence
DNDAF	Department of National Defence Architecture Framework
DoDAF	Department of Defence Architecture Framework
DRCMA	Dynamic Resource Configuration & Management Architecture
DRDC	Defence Research & Development Canada
DRM	Dynamic Resource Management
DST	Dempster-Shafer Theory
DSmT	Dezert-Smarandache Theory
DSS	Decision Support Systems
ESM	Electronic Support Measures
FCM	Fuzzy Cognitive Map
FLIR	Forward Looking InfraRed
ID	Identification
IFS	Information Fusion System
ISM	Image Support Module
JADOCS	Joint Automated Deep Operations Coordination System
JCDS	Joint Command Decision Support

JDL	Joint Directors of Laboratories
JFS	Joint Fires Support
KNOWMES	Knowledge Management and Exploitation Server
LAN	Local Area Network
LAP	Local Area Picture
MCC	Multi-Criteria Classifier
MDA	MacDonald Dettwiler and Associates
MSDF	Multi-Sensor Data Fusion
MOE	Measures of Effectiveness
MOP	Measures of Performance
MTP	Maritime Tactical Picture
NCW	Network Centric Warfare
NEOps	Network Enabled Operations
OO	Object Oriented
OODA	Observe, Orient, Decide, Act
PCR	Proportional Conflict Redistribution
PDB	Platform DataBase
R&D	Research & Development
S&T	Science & Technology
SA	Situation Awareness
SAR	Search and Rescue
SSAR	Spotlight Synthetic Aperture Radar
STA	Situation and Threat Assessment
SOA	Service Oriented Architecture
TM	Technical Memorandum
TR	Technical Report
UAV	Unmanned Aerial Vehicle
WAP	Wide Area Picture

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DRDC Valcartier has long been in involved data/information fusion & resource management, mostly on platforms (e.g. in 13dv "Airborne Information Fusion & Management for Tactical Picture Compilation", 2004-2007). Continuing this investigation, the ARP 13qa generalizes the problem to involve multiple platforms, such as cooperating UAVs, CPFs, and CP-140s, the latter having been studied under 13dv.

The project has expanded the scope to address distributed information fusion and dynamic resource management in Network Enabled Operations (NEOps). It has designed and implemented an open standards testbed on which algorithms can be developed, tested and validated over a wide variety of scenarios relevant to the CF. In addition to the CP-140 results which were obtained under 13dv, it has leveraged lessons learned from previous naval TDPs, such as ASCACT and COMDAT.

The project has resulted in a list of achievements, which includes a Service Oriented Architecture (SOA) testbed, on which two complex scenarios have been developed (one cooperative and the other non-cooperative), distributed information fusion (concentrating on higher level fusion), and dynamic resource management algorithms (planning and scheduling) have been tested under various dynamic network constraints and environmental conditions. Numerous scientific publications have resulted from DRDC and its industrial and academic partners.

RDDC Valcartier participe depuis longtemps à la fusion de données et d'information, et de gestion des ressources, surtout sur des plates-formes (par exemple pour 13dv "Airborne Information Fusion & Management for Tactical Picture Compilation"). Pour faire suite à cette recherche, le PRA 13qa généralise le problème pour impliquer plusieurs plates-formes, telles des UAV, CPF et CP-140, cette dernière ayant été déjà étudiée dans le cadre de 13dv.

Ce projet a élargi l'envergure pour aborder la fusion d'information distribuée et la gestion dynamique des ressources dans les opérations réseaucentriques. Il a permis la conception et l'implémentation d'un banc d'essai basé sur des normes ouvertes, permettant le développement, l'essai et la validation sur une grande variété de scénarios importants pour les FC. En plus des résultats obtenus dans le cadre de 13dv pour le CP-140, le projet a profité des leçons apprises de PDT maritimes, tels que ASCACT et COMDAT.

Ce projet a produit une liste de réussites, incluant un banc d'essai en architecture orientée object, pour lequel deux scénarios complexes ont été élaborés (l'un coopératif et l'autre noncoopératif) et sur lequel les algorithmes portant sur la fusion d'information distribuée (surtout la fusion de haut niveau) et la gestion dynamique des ressources (élaboration des plans et des horaires) ont été testés sous diverses contraintes dynamiques de réseau et dans différentes conditions environnementales. De nombreuses publications scientifiques ont été produites par RDDC et ses partenaires industriels et universitaires.

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information fusion; resource management; distributed; NEOps

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