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Abstract

Experimentation can be considered an effective way to study command and control information system (C2IS) technology, and at the Norwegian Defence Research Establishment (FFI) a demonstrator to support C2IS technology experimentation has been established. The demonstrator is used for studying middleware, different communication media, legacy information system integration and user interface equipment employed in C2ISs.

A key property of the demonstrator is its flexibility provided mainly by its component-based structure. The component-based structure also makes the demonstrator easily extendible, allowing it to support studies of even more aspects of C2ISs in the future. The demonstrator also includes a high level architecture (HLA) based synthetic.

This paper contains a description of the demonstrator. Also, sample experiments utilizing the demonstrator are presented, and the demonstrator's role in a forthcoming Norwegian distributed battle lab for network-based defence is described.

1 Introduction

A demonstrator for experimentation with command and control information system (C2IS) technology has been established at the Norwegian Defence Research Establishment (FFI). Initially, it supported research within maritime command and control [Veum *et al.*, 2001], but it is currently being extended to support a broader research agenda. The demonstrator supports experimentation to exploit advances in distributed computing technology utilized in C2ISs as well as experimentation with user functionality provided by the C2ISs. The results should provide advances for C2ISs for joint network-based defence.

In the demonstrator, middleware and services/functionality for distributed situation picture production are of special concern. Another important aspect of modern C2ISs being studied is technology to facilitate and leverage the exploitation of functionality of legacy C2ISs.

This paper describes the architecture and the hardware and software components of the demonstrator. Also the high level architecture (HLA) [US DoD, 1997], [US DoD, 1998 a], [US DoD, 1998 b] based synthetic environment to stimulate the demonstrator is described. Some conducted technical experiments are also presented along with a description of the ongoing activities.

The paper is organized as follows: In section 2, experimentation and demonstrations is described in general. Section 3 gives a presentation of the demonstrator, while section 4 describes sample experiments. Finally, a conclusion is given in section 5.

2 Experimentation and Demonstrations

In the development of C2ISs a mixed approach is advocated, combining a top-down and a bottom-up approach. The top-down approach is founded on the use of architectures to integrate and co evolve command and control organization and processes with supporting information technology. Also, an architecture-based approach separates different perspectives and issues of concern of a C2IS. This allows e.g. a more rapid adoption of new technology with lesser impact of the services and functionality provided to the users, by separating issues that evolve by different time scales.

A complementary bottom-up approach in the development of C2ISs is needed for several reasons. Firstly, experimentation in an early stage in any development is an effective way to reduce risk, both technically and functionally. Also, in general experimentation supports an iterative and incremental development process. It is also well known that experimentation and demonstration are valid approaches to elicit user requirements given the problems users have to articulate their needs and requirements. Demonstrations are founded on “show rather than tell” and convey ideas and concepts time effectively to people in managerial and operational positions. C2ISs also need to leverage commercial off the shelf (COTS) products and experimentation is needed to evaluate their fitness in the command and control (C2) domain.

The need for experimentation and demonstration within C2IS is also apparent from an operational perspective. The Norwegian Defence has decided to move in the direction of a network-based defence. The diversity of types of operations is also increasing, where more emphasis is put on participation in allied and coalition operations outside Norway in operation on a varying scale of conflict in relation to invasion defence and full-scale war. Thus, forces must have a much greater flexibility for cooperation both within and between services and interoperability with allied and coalition partners.

3 The Demonstrator

The demonstrator consists of an infrastructure part and a synthetic environment.

3.1 Demonstrator Infrastructure

The demonstrator’s infrastructure can be divided into four parts, which will be described in the following:

- middleware,
- communication subsystem,
- legacy information systems, and
- user interface equipment.

Middleware

In [Veum *et. al*, 2001], a turn to component-based C2ISs is recommended. Using such a strategy, middleware becomes an important part of the C2IS, being responsible both for the integration of the components within a single C2 node and for the information exchange between geographically distributed nodes. Thus, it is important for a technology demonstrator as the one described in this paper to be equipped with relevant middleware. The middleware, then, is an important part of the demonstrator infrastructure for two reasons: it ties the different parts of the demonstrator together, and it enables studying the use of middleware in C2ISs as such.

The demonstrator currently includes the following middleware technologies:

- the Common Object Request Broker Architecture (CORBA),
- Jini networking technology,
- the Control of Agent Based Systems (CoABS) Grid, and
- JXTA.

CORBA [OMG, 2003] is an open industrial standard maintained by the Object Management Group (OMG). It specifies a system that provides interoperability between objects in a heterogeneous, distributed environment, i.e. an environment with heterogeneous programming languages, operating systems, computers and networking protocols.

Sun's Jini networking technology [Sun Microsystems, 2003 a] is a so-called service discovery middleware that allows reliable distributed applications to be built upon underlying unreliable networks. It achieves this by specifying protocols allowing components (services) to find each other and link in a dynamic, ad hoc manner.

The Control of Agent Based Systems (CoABS) Grid [Global Infotek, 2003] is a product from the CoABS program funded by the US Defense Advanced Research Projects Agency (DARPA) and the US Air Force Rome Laboratories. It is middleware integrating heterogeneous agent-based systems, object-based applications, and legacy systems using Jini. The CoABS Grid helper utility classes provide an abstraction on top of Jini, making it easier for programmers to exploit Jini. Other extensions to Jini provided by the CoABS Grid are messaging between agents, a logging service, and a security service.

JXTA [Sun Microsystems, 2003 b] is a set of open protocols that allows the building of peer-to-peer (P2P) networks. A P2P network is a network in which equal participants (peers) share resources (services) in a scalable, flexible and fault-tolerant manner.

Communication Subsystem

The use of the Internet protocol (IP) networks in military applications makes it possible to utilize state of the art COTS applications in a much larger degree than in military applications based upon proprietary military networks. This makes it easier and faster to develop distributed military applications such as C2ISs. In a transition towards such a network strategy, it is important to study different communication media's influence on C2ISs, and in particular geographically distributed C2ISs. To support this, the demonstrator is equipped with an HF radio link and a simulated satellite communication (satcom) link in addition to the usual 100 Mbit/s local area network (LAN).

The demonstrator can be configured to simulate a geographically distributed system by isolating parts of the demonstrator and making them communicate with each other via the HF radio or satcom link. This is shown in Figure 1, where the two LANs A and B only have two alternative routes between them:

1. Simulated HF radio wide area network (WAN) (simplex radio net)
2. Simulated satellite WAN (duplex satellite channel)

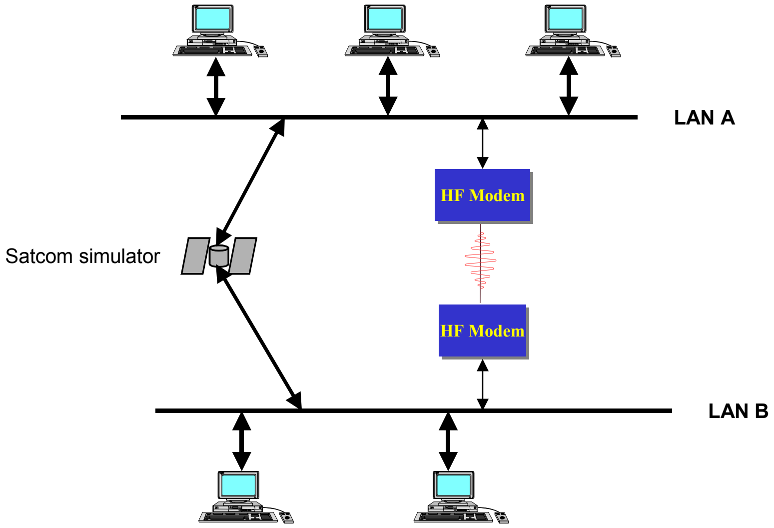

Figure 1 Two networks simulated to be geographically distributed

IP is used for data transfer, and the only differences observed by the applications residing on the two separated networks, are the speed of transmission and the delay introduced by the communication link.

The HF radio link is a simplex link implemented using two Harris RF-5710A HF modems connected back-to-back, giving a noise-free radio link. The modems are set compliant to the NATO standardization agreement (STANAG) 4285C waveform. Two NATO STANAG 5066 [NATO, 1999] servers run the data communication, and two IP clients provides the HF radio link with the ability to transfer IP packets.

NATO STANAG 5066, Profile for Maritime High Frequency (HF) Radio Data Communications, is a link and physical layer protocol designed for use on HF radio channels. The aim of this profile is to define the functions and interfaces required for networked, error-free communication over HF radio channels, nominally for beyond-line-of-sight communications. The STANAG is designed to transfer special packets, called S-primitives, and not IP packets. If it is desirable to send IP packets, an IP client utilizing STANAG 5066 for data transfer has to be used. Such an IP client has been developed by the NATO C3 Agency (NC3A) [Smaal, 2001], and has been installed in the demonstrator. Further information about STANAG 5066 and the IP client software can be found at [NC3A, 2003].

The simulated satcom link is a full duplex link, and it is implemented using a COTS satcom simulator.

Legacy Information Systems

A major requirement of future C2ISs is to be able to utilize relevant functionalities from legacy systems. In this way, one is ensured that the parts of the existing systems still usable are exploited. In order to study this issue, the demonstrator is presently equipped with the following legacy information systems:

- NATO Maritime Command and Control Information System (MCCIS),

- Norwegian Command and Control Information System (NORCCIS II),
- MARIA geographical information system (GIS), and
- the military message handling system (MMHS) XOmail.

MCCIS is a system presently used for recognized maritime picture (RMP) production throughout NATO, and in Norway it is currently being used in the naval operations center.

NORCCIS II is the Norwegian joint C2IS, and is being used to build the joint operational picture in the Norwegian joint headquarter. Additionally, NORCCIS II is presently being installed as the main picture compilation tool in the Norwegian armed forces.

MARIA [Teleplan, 2003] is a GIS that can be used both as a stand-alone map application and as a map component in a larger system. It is currently being used in NORCCIS II, among other C2ISs.

The purpose of a MMHS is to convey military messages between military organizations or individuals, and it guarantees that the message sent will be taken care of. The MMHS XOmail [Thales, 2003] is based on NATO's MMHS definition, STANAG 4406 [NATO, 1998], and is a multi-level secure system. It also includes a tactical profile (STANAG 4406 Annex E) that compresses the data and utilizes IP multicast, making the XOmail MMHS useful for transporting messages over links/networks with reduced throughput capacity (lower than 20 Kbps) such as HF radio networks.

User Interface Equipment

In Figure 2, some of the user interface equipment of the demonstrator is shown: a 3-screen display (right), various large screen displays (top), and a 3D passive stereo table (bottom). This equipment is used to study the effect different ways of visualizing the situation picture has on the users. The equipment can be configured to enable the studying of both shared situation awareness within a team in a command node, and shared situation awareness between teams in geographically distributed command nodes with varying communication capabilities.

Figure 2 User interface equipment.

3.2 Synthetic Environment

In order to support a range of different experiments, a flexible and extendable synthetic environment (SE) is needed. To achieve this goal, the demonstrator is equipped with tools and middleware for the development and execution of distributed simulations. The architecture for running distributed simulations is based on HLA.

The SE development tools may be divided into four areas:

- HLA based tools (both SE development and run-time tools),
- a Computer Generated Forces (CGF) toolkit,
- tools for visualizing simulations, and
- tools for generating databases and models representing the synthetic natural environment.

The HLA based tools include data loggers, execution management and control tools, federation design tools, etc. Two of the HLA based control tools included in the demonstrator are:

- a distributed time service, and
- a federation management tool.

The time service provides the demonstrator with a logical demonstrator time shared by all the demonstrator components, and it advances this time in a coordinated and consistent manner. It also provides the current logical time to the other demonstrator components. The time service is based on HLA time services.

The federation management tool is used to monitor and ensure a synchronized start-up of the SE. It also provides the users of the demonstrator with the ability to control the pace of the simulation, making it possible to quickly advance the logical time in order to e.g. populate the track database or to advance to an interesting point in time.

A CGF simulation toolkit, VR-Forces [MÄK Technologies, 2003], is serving as a general framework for rapid development of SEs. The CGF is used for describing the scenario and representing the behavior of most of the entities in the environment. The CGF participates as a federate in the HLA federation, allowing the CGF to exchange data with entities and systems represented in external simulation models.

In addition to the COTS CGF, the demonstrator includes an in house constructive simulation: SensorSim [Mevassvik *et al.*, 2001].

To generate databases and models representing the synthetic natural environment, the demonstrator includes COTS tools for generating visual databases. These databases are used for 3D visualization of the SE in an HLA stealth viewer. The stealth viewer acts as a passive HLA federate visualizing the information flowing in the HLA federation.

4 Sample Experiments

As examples of the kinds of experiments supported by the demonstrator, two finished experiments are presented:

- measurement of middleware performance over HF radio and satcom links, and
- an RMP production demonstrator

Additionally, the ongoing work in the demonstrator and a future distributed network-based defence battle lab, in which the demonstrator will be a part, are briefly described.

4.1 Measurement of Middleware Performance over HF Radio and Satcom Links

HF radio and satcom links represents two extremes of communication between geographically distributed C2 nodes. Being pointed out as an important part of the infrastructure of future network centric C2ISs [Veum *et al.*, 2001], it is important to examine how middleware performs over these relatively narrow communication links. In order to examine this, a technical experiment with a track reporting service reporting tracks to a track receiver service was carried out. The information exchange between the two services was handled by the CoABS Grid (see section 3.1). The reporter component was capable of using the LAN, the HF radio or the satcom link as communication medium, and the receiver component registered the number of tracks sent over the link used.

Clean separation between the service definition and the connector technology used for accessing this service, is an important property of the CoABS Grid. This property is inherited from Jini, and is due to the service representative (service rep) - a small program that is downloaded by the client upon connecting with the service. The service rep implements the public interface of the service, and is used by the client for accessing the service. The same service may implement several service reps tailored for specific communications media. This property makes the CoABS Grid well suited for implementing distributed services to be accessible through different communications media.

The reporting service, being responsible for forwarding the local picture of a platform or set of platforms, may use two different connector technologies. In the case of LAN/WAN, Java remote method invocation (RMI) is used for communicating with the client. In the case of HF or satellite communications, another service rep based on user datagram protocol (UDP) packets is used. This service rep uses bit-coded messages (similar to tactical data links) and thus is more optimal regarding the use of bandwidth than the RMI-based service rep. The connector technology used communicating with the service is transparent from the client's point of view. This knowledge is provided, however, in the service attributes registered with the CoABS Grid lookup service (application level quality of service information).

The conclusion of this experiment was that even while the Jini technology (here used via the CoABS Grid) is well suited for systems built upon networks with bandwidth down to 600 bit/s, a protocol tailor made for these low bandwidths is necessary for the system to function. A more thorough description of the experiment and the results can be found in [Rose *et al.*, 2002].

4.2 RMP Production Demonstrator

The main technical experiment using the demonstrator thus far, is a development of an RMP production demonstrator. The main objectives of this project were to demonstrate:

- advantages and flexibilities of modern object oriented/agent architectures for assuring interoperability, supporting the production and distribution of the situation picture (service based/component based systems),
- integration of present systems (legacy): how to integrate functionality from existing systems into a new system,
- the potential of data fusion techniques, with a focus on the RMP and fusion of tracks and non-sensor/non-real-time data, and
- situation picture presentation and user interface equipment to enhance the

understanding of the situation.

In short, the RMP production demonstrator constituted infrastructure technologies (middleware), two presently operational systems (legacy), new software components, and a simulation environment.

Information System Architecture

The following architectural requirements apply to a future system building an RMP (as to any other C2IS): it should

- support a component based system development that promotes reuse of components, facilitates vendor independence and has better properties for system evolution,
- have the ability to integrate legacy systems and thus reuse well-proven and mature functionalities of existing systems,
- support distribution of software components on heterogeneous platforms localized in one organisational element, and
- support message based information exchange between geographically distributed organisational elements. The latter for the possibility to exchange services in addition to traditional military messages [Mevassvik and Veum, 2001].

The technical architecture chosen for this RMP production demonstrator, shown in Figure 3, was a three-tier architecture based on the J2EE framework. The main reason for this approach was that it enabled modularisation and separation of concern as it provided a separation of business functions (components) from infrastructure technology and legacy systems.

As a middleware strategy, CORBA was chosen for integration of the legacy, and the CoABS Grid was chosen for network flexibility. The CoABS Grid was used both for implementing the component architecture on a single RMP production node, and for information exchange between geographically distributed units.

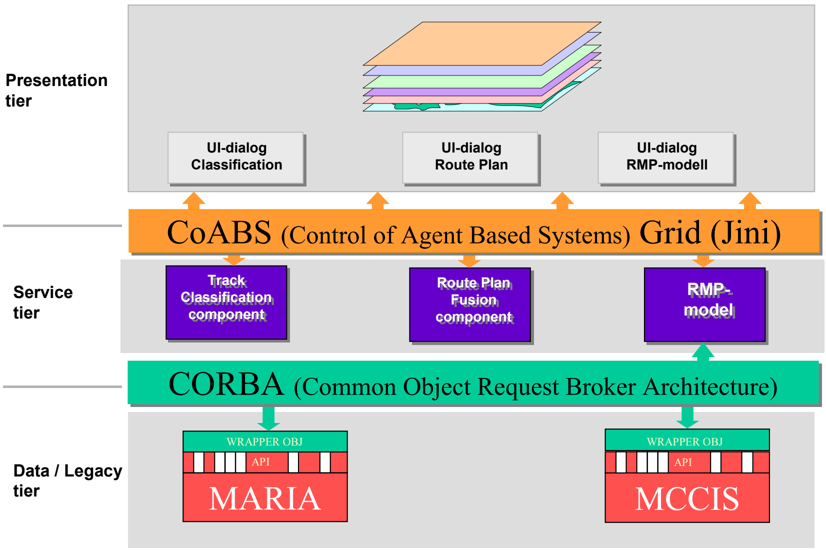

Figure 3 The three-tier technical architecture

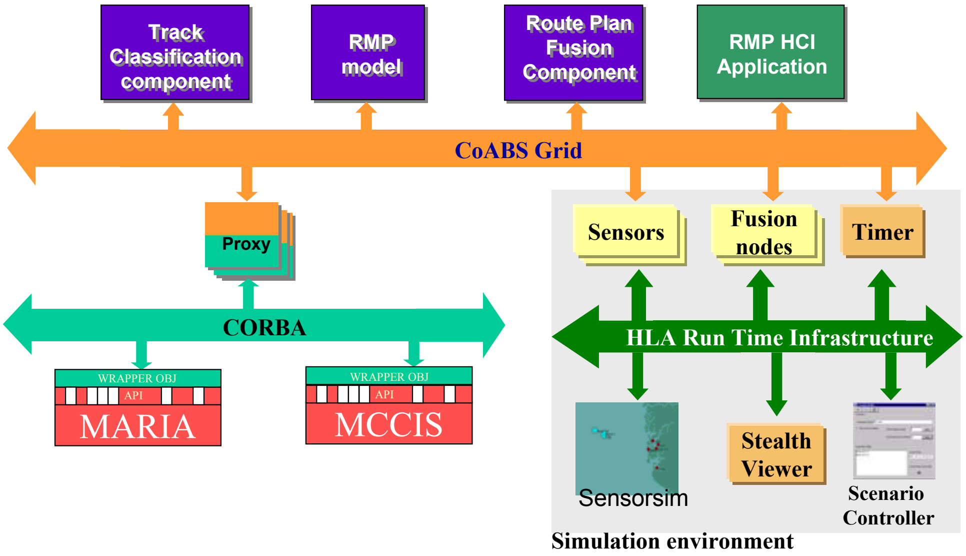

Figure 4 RMP technical architecture.

Legacy Systems

The two legacy systems used in the RMP production demonstrator were NATO's MCCIS and a MARIA map server. These legacy systems are presented in section 3.1. The functionalities provided by the legacy systems were track management (including track association) from MCCIS and a map service from the MARIA map application.

To make the desired functionalities from MCCIS and MARIA available to the other components in the CoABS Grid, proxy objects translating from CORBA to the CoABS Grid were used as shown in Figure 4. In the MCCIS case, parts of the track management application programmer interface (API) were made externally available with CORBA, while the MARIA proxy interacted with the MARIA map server using CORBA.

The Components Constituting the RMP Production

In Figure 4, the architecture of the RMP demonstrator is shown. The components constituting the main part of the RMP production were:

- a track classification component,
- an RMP model component serving as a track store,
- a route plan fusion component, and
- an RMP human-computer interface (HCI) component.

The track classification component fused classification decisions made by sensors. The component took all the available classification reports on one singular track and a model of the different sensors' classification abilities as input to a Bayesian net [Jensen, 1996] that produced a probability distribution over the track's possible classification. This distribution could then be used as a basis upon which a human operator/decision maker could make a classification decision.

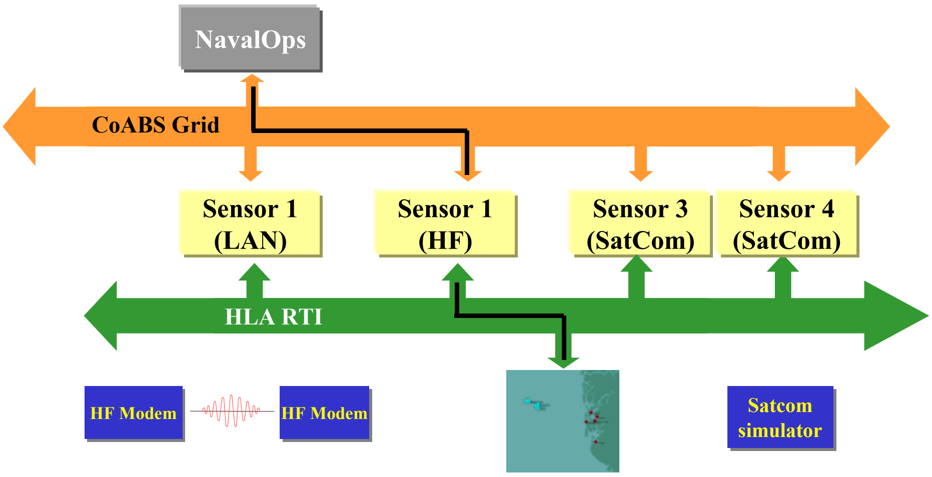

Figure 5 The simple sensor grid of the RMP production demonstrator

The route plan fusion component is an implementation of an algorithm for identifying vessels based on route plans combined with optional reports from the vessels [Mevassvik and Løkka, 2000]. The approach taken was threefold: using statistical models of fairways, using Kalman filter estimation, and using multiple hypothesis techniques formulated as a Constraint Satisfaction Problem (CSP). The output from the component was a set of tracks that were consistent with a given route plan.

The RMP HCI component was the user interface of the demonstrator, presenting the situation picture in an RMP production node.

Simulation Environment

SensorSim (see section 3.2) served as the engine of the simulation environment producing the sensor data and local pictures input to the RMP production demonstrator components. SensorSim is able to send Over-the-Horizon Targeting Gold (OTG) messages directly to MCCIS using a socket, or sending augmented OTG messages as HLA interactions. A number of reporting services were responsible for forwarding local pictures, representing the local pictures of specified platforms in SensorSim, and thus simulating a simple sensor grid (Figure 5).

4.3 Ongoing Work

At the moment, the main activity involving the demonstrator is to develop the RMP production demonstrator presented in section 4.2 in a joint and network-based direction. The focus of the new picture production demonstrator is picture compilation strategies for network-based defence. Within this context, the demonstrator is also used to gain more experience with the middleware technologies listed in section 3.1. More specifically, it is planned to at least partly replace the CoABS Grid with JXTA as the middleware tying the components together. In this way experience with P2P networking can be gained. Other aspects are service description and meta-data for e.g. sensors to provide the necessary flexibility of participants in the picture compilation process.

4.4 *Distributed Network-based Defence Battle Lab*

A distributed battle lab to support experimentation for transformation towards a network-based defence is under establishment in Norway. The battle lab will contribute to an environment where development, prototyping and testing of concepts and technology relevant for a network-based defence can be done in an efficient manner. The distributed battle lab will also enable experimentation with coalition partners through the Combined Federated Battle Lab Net (CFBLNet).

FFI will be a node in the battle lab, and the demonstrator will constitute an important part of the node at FFI.

5 Conclusion

In this paper a flexible demonstrator for experimentation with C2IS technologies has been presented. The demonstrator is established at a lab at FFI, and is used for studying middleware, different communication media, legacy information systems and user interface equipment employed in C2ISs. The demonstrator's flexible and extendable HLA based synthetic environment is also described.

Also, the Norwegian distributed battle lab initiative, and the demonstrator's role in this, was briefly outlined.

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