An Architecture for Interoperability between the RNLA C2 WorkStation and Simulator tools.

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Abstract

The C2 WorkStation (C2WS), currently under development by the Royal Netherlands Army (RNLA), is a configurable, distributed information system that provides generic functionality to support the Command and Control process. One of the main tasks of the C2WS is to support the users in building and maintaining a Common Operational Picture (COP) that provides adequate situational awareness. The C2WS has conversion modules for ATCCIS and RNLA legacy systems e.g. the Integrated Staff Information System 'ISIS'. The C2WS is also prepared to integrate future developments (e.g. Battlefield Management Systems).

TNO-FEL has performed experimental studies on the C2WS to investigate the issues related to interoperability between C2 systems and simulators. The aim is twofold : support the C2WS assessment activities and investigate the options for operational C2 decision support tools based on simulators.
For assessment purposes (constructive) simulators are used to provide stimuli to the C2WS (e.g. unit detection or displacement) and thus objectively assess the behaviour of the C2-systems involved and assess the user's performance with these C2-systems. Interoperability with Decision Support Systems (DSS) concentrates on Course of Action (COA) analysis and mission planning. The COP defined in the C2WS is copied into a planning overlay on the C2WS and automatically transferred to the DSS. The DSS analyses this input through simulation and predicted results (e.g. rendez-vous times) are routed back into the C2WS as a new planning overlay available for evaluation by the C2 operator.
Our architectural approach is to provide a software gateway between the C2WS communication network (based on XML messaging) and the modern High Level Architecture (HLA) simulation interoperability standard. The link to HLA provides the possibility to connect many modern simulation components to the C2WS architecture. The HLA development process that was followed provides a generic approach to simulation interoperability for the C2WS. This process concentrates on defining a datamodel that matches the requirements and features of both the C2 system and the available simulation assets.

This paper presents an overview of the architecture, the development of the demonstrator and our results.

1. Introduction

This paper addresses the approach used by TNO-FEL to develop and demonstrate concepts for interoperability between C2 systems and Simulations. Simulation interoperability for C2 systems enables applications in training of army staff officers, operational support and procurement, assessment and evaluation of C2 systems. The presented project is aimed specifically at the C2 Workstation (C2WS), a new system for the Royal Netherlands Army (RNLA), which is in an early stage of its development.
The requirements for the design of the C2-Simulation interoperability architecture are : flexibility, scalability, robustness and compliance to international standards.
As a first demonstrator of interoperability between the C2WS and an HLA (High Level Architecture) based Simulation system, a Decision Support System (DSS) application was chosen, which concentrates on Course of Action (COA) analysis. The DSS analyses plans, prepared on the C2WS, using simulation and results from this analysis are routed back to the C2WS as a new planning overlay, for evaluation by the C2 operator.
The next section of the paper addresses the need for interoperability and the general concept of coupling C2 systems to Simulations. Section 3 explains the interoperability approach followed for the C2WS; section 4 discusses the High Level Architecture which has become the *interoperability standard* used in the Simulation domain. The remaining sections discuss the system architecture, implementation issues and some preliminary results and conclusions of this project.

2. Linking C2 systems to Simulation models

Linking C2 systems to Simulation systems has many potential applications :

- Simulation systems can stimulate the C2 system by providing data that simulates the 'real-world'. This information will now appear to have been received from peer C2 systems. In this way a simulated COP (Common Operational Picture) is created that is based on a simulation scenario. Applications of this technique are : assessment of C2 systems (performance, user interface etc.), assessment of C2 operator capabilities or training of C2 operators.
- The simulation can provide the C2 operator with operational decision support by executing 'what-if' scenarios. These scenario's can support the operator in his decision making process (e.g. mission planning or assessment of alternative COA's).
- New or experimental parts for an existing C2 system can be evaluated before purchase or even before full development of the component by replacing an existing component of the C2 system with an embedded or external simulation. Simulated systems can be 'initialised' from the existing COP in the C2 system and a simulation run can be started based on this information.

The advantage of using simulations as a tool for stimulation of C2 systems, as opposed to 'role players', is that the simulation has a consistent, controlled and reproducible behaviour, which allows objective assessment of system and/or operator performance. TNO-FEL has recognised an opportunity to support the C2WS assessment activities by ongoing experimental studies on coupling of our simulation tools with this innovative C2 architecture.
The aim of the research is to develop a flexible and future-proof approach to the C2-Simulation interoperability problem. First we need to clarify what we really mean by 'interoperability'.

Interoperability is the degree to which entities are able to co-operate in achieving a common goal. There are many interpretations of the concept of interoperability between computer systems. It varies from having a network connection and being able to transfer files (e.g. email) to using exactly the same applications at all systems and completely sharing the information they process. A commonly used form of interoperability is *'information interoperability'*, because it offers optimal connectivity between systems, while preserving maximum independence. Information interoperability is defined as the ability of systems to automatically exchange and interpret information that is common to those systems [Ref 1].

In this paper we focus on information interoperability that is achieved by the *automated exchange and interpretation of structured information* between systems. With minimum user intervention, C2 systems and Simulation systems must be able to *automatically* interchange certain information and utilise that for further processing. This means that the information must be *structured*, because this enables functionality such as distribution by subscription on certain topics, presentation of information and filtering by specific selection criteria. The emphasis here lies on the exchange of *information* (rather than 'free format' databits), preserving its meaning, integrity and context. Structured information is described formally by a *'Datamodel'*. The datamodel thus represents the foundation for information interoperability.

In the most common case where many systems have to exchange information, standardisation of a common ‘interface’ is a key factor to achieve information interoperability. Otherwise, dedicated interfaces are needed between every pair of interconnected systems, leading to an exponential grow of the number of interfaces required [Fig 1]. Preferably the exchange should not depend on proprietary products, such as database management systems and communication systems.

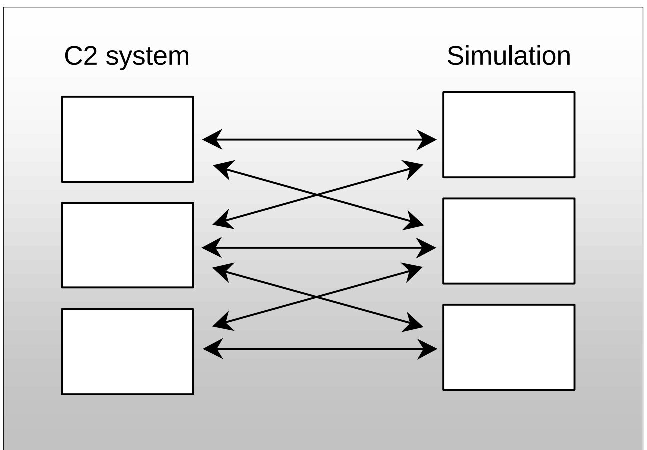

Figure 1 C2 and Simulation Interoperability (dedicated)

The key notion for information interoperability is *standardisation*. By having common agreements on which information is exchanged, in what format, and under what conditions, it becomes easier to allow systems of different types to interoperate [Fig 2].

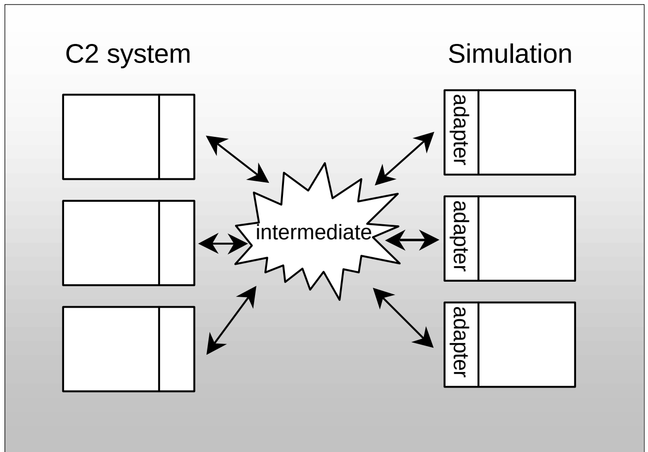

Figure 2 C2 and Simulation Interoperability (Standard Interface)

3. C2WS

The C2WS is a configurable *application platform* and information system that provides generic functionality to support the Command and Control process. The C2WS supports the users in building and maintaining a COP that provides adequate Situational Awareness.
The C2WS is being developed at the RNLA C2 Support Centre, with co-operation of TNO-FEL. The system architecture of the C2WS comprises of three layers: presentation services, business services, and data services [Ref. 2], [Fig 4].

The **presentation services layer** is responsible for gathering information from the user and presenting information to the user using the services of the business services layer.
The **business services layer** is responsible for end-to-end *business transactions* such as maintaining *roles*, *contexts* and *business objects* and the logic that applies within these concepts.
The **data services layer** is responsible for storage, retrieval, maintenance and integrity of data. The data services layer is also in charge of publishing as well as subscribing and listening to data on the C2 network.

The information exchange in the C2WS environment is based on commercial of the shelf publish/subscribe services and a tailored information exchange language [Ref. 3]. The information exchange language is based on the RNLA C3I Architecture (C3IA) Information Model (C3IA-IM) for C2 applications within the RNLA. C3IA is more generic than the fixed set of descriptive attributes of ATCCIS.

The C2WS has conversion modules for RNLA legacy systems such as the Integrated Staff Information System 'ISIS' and for the future Battlefield Management System 'BMS'. If required, a dedicated translator service shall be made available for translating C3I information to proprietary systems such as the German C2 system 'HEROS'.

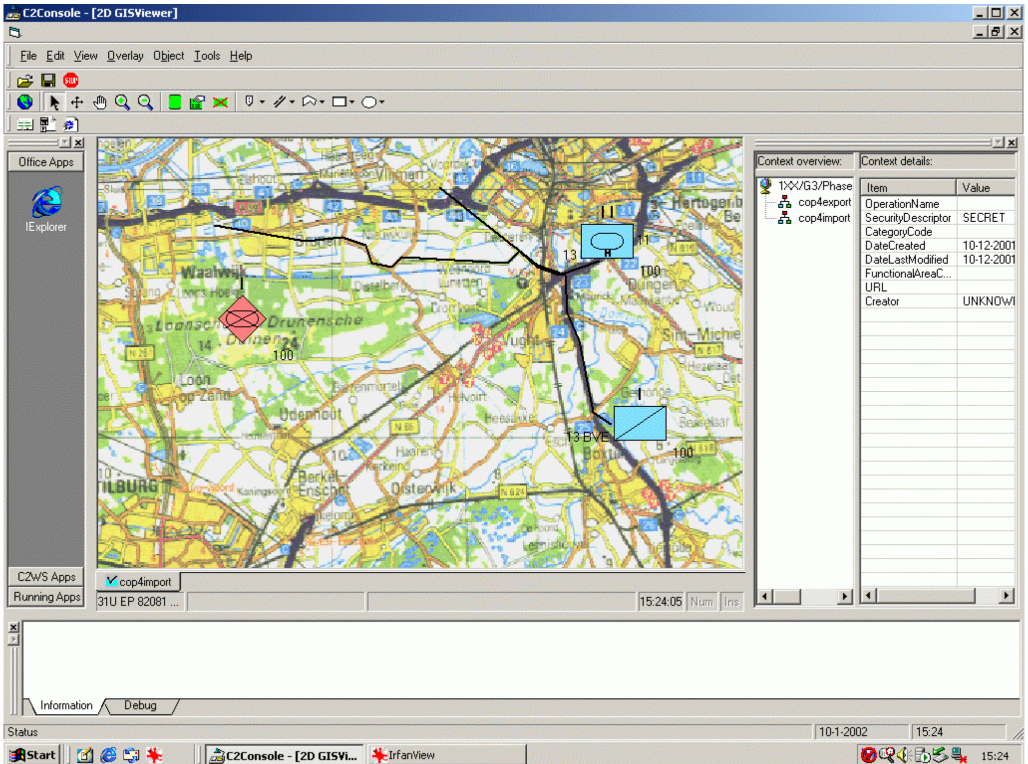

Figure 4 C2WS GUI (RNLA prototype)

At the time of writing, the C2WS supports GIS functionality for placing units and lines/areas on the map. The network functionality is partly implemented, for example updates of the COP for a certain 'context' can be exchanged between different C2WSs. However a means for a new C2WS to hook into the network and receive the full current COP has not yet been implemented.

4. HLA

The High Level Architecture (HLA) is an architecture for reuse and interoperation of simulations [Ref. 4, 5, 6], [Fig 6]. The HLA is based on the premise that no single simulation can satisfy the requirements of all uses and users. An individual simulation or set of simulations developed for one purpose can be applied to another application under the HLA concept of the Federation: a composable set of interacting simulations [See Fig. 6].

The intent of HLA is to provide a structure that will support reuse of capabilities available in different simulations, ultimately reducing the cost and time required to create a synthetic environment for a new purpose and providing developers the option of different implementations within the framework of the HLA. The HLA provides the specification of a common technical architecture for use across all classes of simulations: (a) *Virtual:* "Real people operating simulated equipment", (b) *Constructive:* "Simulated people operating simulated equipment" and (c) *Live:* "Real people operating real equipment on an instrumented training range". HLA provides the structural basis for simulation interoperability.

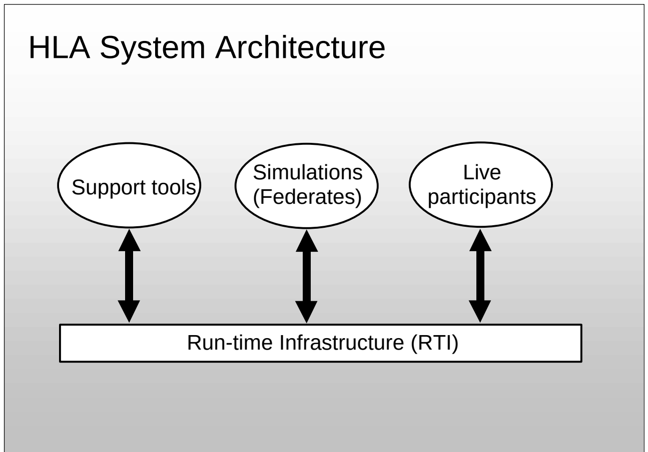

Figure 6 HLA Federation

The baseline definition of the HLA includes the HLA Rules, the HLA Interface Specification (IFSpec), and the HLA Object Model Template (OMT). The HLA interface specification defines the services that HLA provides to the application. These services include Object Management (publish/subscribe) and Time Management (i.e. synchronisation between distributed applications). The Federation Object Model (FOM) is the datamodel of the HLA Federation. The OMT is the standard datamodel format that is used in HLA documentation. The HLA does not prescribe a specific implementation, nor does it mandate the use of any particular software or programming language. Over time, as technology advances become available, new and different implementations will be possible within the framework of the HLA. In February 1998, version 1.3 of the HLA specification was adopted by the US Defense Modelling and Simulation Office (DMSO) and in september 2000 it has been accepted as IEEE Standard 1516 for simulation interoperability. The HLA is a standard for use in the US Department of Defense and within NATO (NATO M&S Masterplan, 1998). Development of a generic coupling between C2 systems and HLA thus provides the possibility to connect modern simulation components to the C2 environment.

One of the main components of HLA is the Run-Time Infrastructure (RTI). The RTI implements the HLA IFSpec and allows the user to invoke the RTI services to support run-time interactions among Federates and to respond to requests from the RTI. This interface is implementation independent and is independent of the specific object models and data exchange requirements of any Federation. At TNO-FEL we developed an HLA based middleware layer, called the Runtime Communication Infrastructure (RCI) [Ref. 7] which supports HLA. The RCI shields the developer from many intricate details concerning the usage of the HLA-RTI, including Data Distribution Management (DDM) [Ref. 4, 5, 6], when developing either a Component or a Federate. The RCI includes a C++ code-generator to translate the required HLA-OMT descriptions into easily accessible object-oriented classes. The C2-Sim coupling approach described here is based on our RCI concept.

5. C2WS-Bridge Federation

The first demonstration target of our project was to achieve interoperability between the C2WS and an HLA Simulation system. More specifically, the use of simulation as a Decision Support System (DSS), which concentrates on Course of Action (COA) analysis. The COP defined in the C2WS is copied to a planning overlay on the C2WS and transferred to the DSS. The DSS analyses this input through simulation and the results from the analysis are routed back to the C2WS to be presented as a new planning overlay available for evaluation by the C2 operator. The Federation that was developed for this demonstration is named the 'C2WS-Bridge Federation' and consists of the following Federates :

- FedMan, this (optional) Federate was developed by TNO and is used as Federation Manager. It has online capabilities to initialise, monitor, start, stop, pause and abort the whole system. The Federation Manager also has the ability to monitor the activities of all participants and systems and take appropriate (planned & unplanned) action, to ensure a successful completion of the exercise;
- Decision Support Federate. This Federate is based on the 'Bridge' constructive combat simulation model developed by TNO-FEL for the RNLA [Fig 7]. It is responsible for the simulation of ground and air brigade/division mobile operations. The Federate was modified to handle the input from the C2WS and deal with the required Objects and Interactions.
- Stealth Federate, a 3D viewer into the virtual environment. This (optional) Federate is based on the available TNO-FEL Stealth from TNO-FEL's Electronic Battlespace Facility (EBF). The Stealth is interoperable with the Federation through a 'DIS/HLA Gateway' and thus demonstrates our capability to deal with 'legacy' DIS Federates;
- C2WS Federate, one or more (unmodified) C2WS applications (C2 GIS) manned by their regular RNLA operators. See Fig 4.

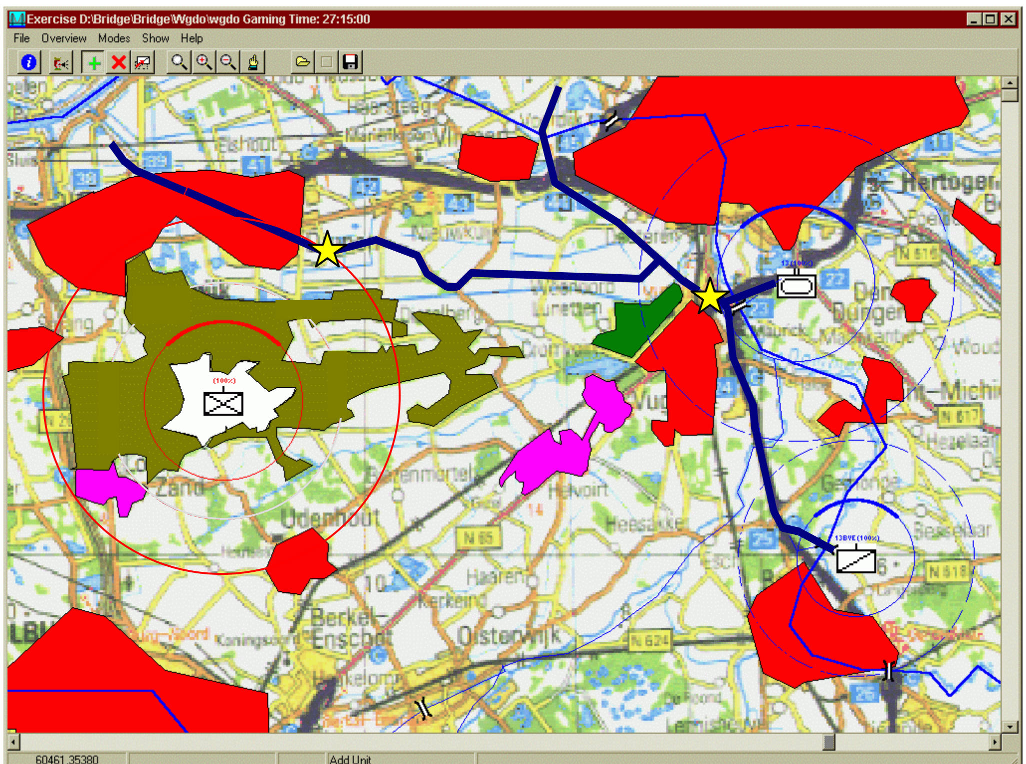

Figure 7 DSS tool Bridge (TNO-FEL prototype)

The C2WS-Bridge Federation was able to adopt the DiMuNDS 2000 FOM [Ref. 8] (see next section).

6. Bridging the gap

Previous attempts to couple C2 systems with simulations were often ad-hoc and resulted in tailor-made connections for every specific combination of C2 systems and simulation models. When one of the systems needs to be connected to another system or simulation, a new connection had to be developed. This approach means a lot of work for both the C2 system and the simulation models, [see Fig. 1]. A more flexible approach is the use of an intermediate layer as show in Fig 2.
Once a system or simulation has a (tailor made) adapter for the intermediate layer, the system can be connected to other systems or simulations without any additional work on the other players.

The approach that was followed to achieve C2WS-Simulation interoperability resembles the 'intermediate layer' solution, however with an important difference: both the C2WS systems and the Simulation systems already support interoperability within their own domain.
The C2WS system uses a commercial of the shelf product, TIB/Rendezvous (TIB/RV) from Tibco, to exchange information (i.e. data services layer). The simulation systems use the HLA interoperability standard. We developed a 'TIBCO-HLA gateway' to connect TIB/RV on one side to HLA on the other side (see Fig 8]).

In addition to interoperability at the technical level (protocols, networks etc), we also need to develop the information interoperability for the gateway: bring the Datamodels inline and provide a two-way mapping for all relevant attributes. HLA systems are connected to each other in a Federation and define their communication via a Federation Object Model (FOM). The FOM has to be agreed upon between the systems that need to be connected. For the C2-Simulation system a C2WS-Bridge Federation has been designed together with an initial FOM based upon the FOM used previously in the NATO DiMuNDS 2000 demonstration.

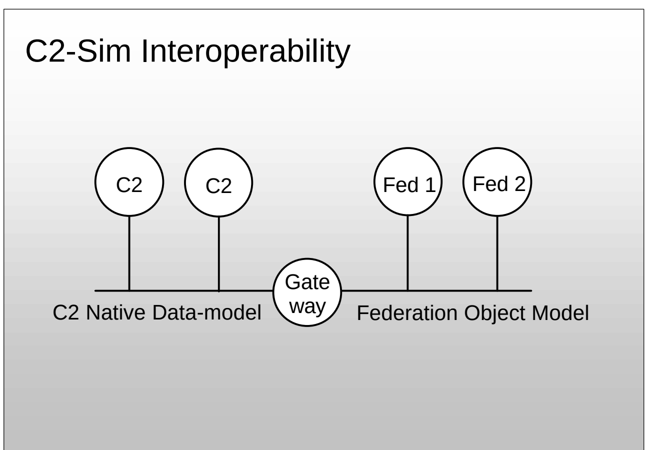

Figure 8 C2-Simulation Datamodel Interoperability

This FOM describes four generic objects, which are :

- Weather,
- Stationary,
- StationaryMultiLocation and
- Mobile

Table 1 below shows some more detail of the objects represented in this FOM.

Object	Specialisation	Specialisation	Specialisation
Weather			
Stationary	Seaport		
	Pumping station		
	C2-centre		
	Corridor		
	Airbase		
	Depot radarsite		
	Bridge	CivilBridge	
		Combatbridge	
StationaryMulti Location	Special area		
	Minefield		
	Non lethal obstacle		
Mobile	Sea	Surface	
		Sub-surface	
	Air	Cruise missile	
		Air mission	Fixed-wing
			Helikopter
	Ground	Non-combat	
		Combat service support	
		Engineer	
		Sensor	
		Fire-support	
		Manouvre	
		Airdefence	HiMad
			ShoRad

Table 1 Schematic DiMuNDS 2000 FOM datamodel

The information that is exchanged via the FOM consists amongst other things of the position of the object and depending on the object information, for example status and speed. Given the different development history of the C2WS and the DiMuNDS FOM it is often impossible to directly map the information exchanged between C2-systems onto the FOM.

In most cases it is necessary to combine information from the C2-system in order to get it mapped onto the FOM and vice versa. For example, the following fields were identified for a unit message that need adaptation before they can be mapped on either the FOM or on the C2 information.

FOM	C2WS
ObjName	Name
PartyNumber	Nationality
Velocity	SpeedQty
Position	Position
Front	BearingAngle

Table 2 Data mapping fields (not exhaustive)

A name in the FOM needed to be restricted to 10 characters, the FOM only knows of four different parties while the C2WS allows many more different nationalities, and the location of a unit in the UTM system of the C2WS needed to be translated into the relative map coordinates used by the FOM. Specific conversions and layout issues had to be resolved and implemented to realise any coupling between the two domains.

7. TIBCO-HLA Gateway

The TIBCO-HLA Gateway was developed for the purpose of incorporating a C2WS in the Federation. This Gateway (see Fig. 9) was implemented using two processes, one attached to the RCI (HLA middleware) and the other attached to TIB/RV (main component of the C2WS interoperability middleware from Tibco). Both sides use a publish/subscribe method to distribute data on their respective networks. TIB/RV listens to messages on the C2 network and places an image of the object/interaction data concerning the C2WS entities (to which a subscription was issued by the Gateway) in shared memory. The RCI process subsequently reads this data from shared memory and maps it onto the HLA-SOM via the RCI middleware. The same holds for communicating data from the HLA Federation to the C2WS world where TIB/RV publishes and updates the object/interaction data received from the Federates in the simulation Federation.

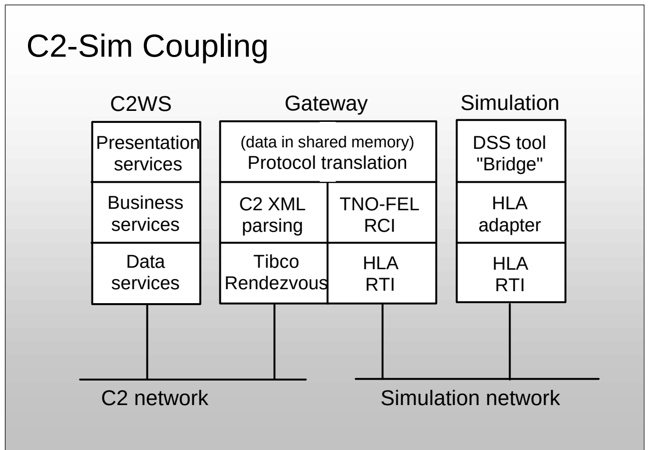

Figure 9 C2WS Federation with Tibco/HLA Gateway

The Federation was developed by (loosely) following the Federation Development and Execution Process (FEDEP) [Ref. 6].

The objective of the Federation was defined as :

- Demonstrate interoperability between constructive (wargame) simulations and C2 systems using HLA. The focus of the scenario and the simulation application is on features that are important for Decision Support.

The following documentation is typically produced in the FEDEP :

- *Federation Objectives, Requirements and Conceptual Model.* This provides details for FEDEP steps 1 (*Define federation objectives*) and 2 (*Perform conceptual analysis*). The document describes the statement of 'Federation Objectives', 'Scenario Requirements', 'Conceptual Model' and 'Federation Requirements'. Federation requirements described in the document serve as a vehicle for transforming objectives into functional and behavioural capabilities, and provide a crucial trace-ability link between the Federation objectives and the design implementation. The requirements are derived from the specification of the Federation Objectives and the high-level description of the Scenario.
- *Federation Scenario Document*; this document describes the scenario in full detail, the geographic location of interest, the nature and size of forces, in our total scenario represented by about 60 computer generated forces (CGF) units, the initial positions and the occurring events.
- *Federation Design and Development Document*; this document provides details for FEDEP steps 3 (*Design Federation*) and 4 (*Develop Federation*). This phase of the FEDEP is concerned with the detailed design of the Federation (including mapping of Federation Objectives and Requirements to Federates), the selection of and modification of existing Federates and the

development of new Federates. The document describes the results of the selection process, the definition and development of their interactions (laid down in the FOM) and mapping of Federation objects/functionality on Federates. The document also details Federation agreements (e.g. Operating Systems, Tool versions, and co-ordinate systems).

- Documentation supporting step 5 (*Plan, Integrate, and Test the Federation*).
- *Federation Execution and Evaluation Document*; this document provides details for FEDEP step 6 (*Execute Federation and Analyse results*). The document also details hardware and network requirements and organisational aspects (e.g. machines, network port numbers, script and required staff list for rehearsals and executions, list of invited guests).

Inconsistencies in co-ordinate conversion algorithms used by different Federates often pose an additional problem. But in our case, the terrain databases used by the constructive Federate (Bridge) on one hand and the C2WS Federate on the other hand, were identical and thus easily correlated. Only the usual conversion from map-co-ordinates to UTM, used in our FOM (and vice-versa), was called for.

8. Results

The prototype demonstrator for the C2WS with DSS tool is capable of transferring a COP to the DSS tool. The user can try out several courses of action and transfer the resulting situation back to the C2WS as a planning overlay. The gateway handles a limited set of units and other C2 items, which shall be extended in further versions of the demonstrator.

Due to the early stage of the development of the C2WS, some cumbersome precautions have to be taken when demonstrating the simulation functionality. The updates of the COP from the C2WS are incremental, so only changes are broadcast to other stations. A full COP transfer for when a new C2WS is added to the network, or in our case, for simulation purposes, has not yet been implemented in the current version.

Concentrating on coupling this RNLA C2 system with a simulation component in such an early stage of its development has resulted in encouraging insights in the possible additional functionality required of the C2WS and indeed other C2 systems.

9. Conclusions and further plans

The demonstration of coupling a C2 system to a simulation tool using HLA is expected to achieve its overall objectives and sofar received positive reactions from its audience. Some lessons learned to date from the project are:

- Use a single (authoritative) source for common data like terrain maps and data, co-ordinate conversion algorithms, equipment and weapon parameters, etc.;
- Pursue for a standardised C2-Simulation Datamodel, represented in FOM format.

In addition to full compliance with HLA, the innovative architectural concept that was developed supports the key capabilities required for future C2-Simulation interoperability applications :

- An abstraction layer (or TNO-RCI middleware) and a code generator hiding complexities of the underlying simulation interoperability standards and enabling simulation protocol migration with minimal changes to the functional implementation.
- A structured development process (the FEDEP), supported by appropriate tools, enabling migration of legacy simulations and COTS products to the new standard architecture;

- The Gateway approach is the optimal solution to allow interoperability between the different worlds that C2 and Simulation are today. It is unlikely that one single standard for all information exchange between systems is achieved in the near future, even if we restrict the ‘universe’ to NATO C4I systems.

The (completion of the) design and the development of the C2WS falls outside the scope of our project. However, we do believe that future C2 systems will include the design requirement for interoperability with Simulations and the results of our project will therefor influence the development direction of the C2WS. The C2WS is on its way to become a useful and exciting new C2 system, reaching out to the useful and exiting new simulation standard HLA.

Near future work on this project will focus on two aspects: the HLA gateway will be upgraded to the latest C2WS data services and business services layers (i.e. the C2WS 'framework') and the Bridge simulation tool will be replaced by the more capable Kibowi wargame simulation. This C2WS-Kibowi system is to be used first in staff training exercices.

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