INTEROPERABILITY AND PEROFRMANCE ANALYSIS OF A COMPLEX MARINE MULTIDOMAIN SIMULATION BASED ON HIGH LEVEL ARCHITECTURE

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ABSTRACT

In Modelling and Simulation the main standard for interoperability is HLA (High Level Architecture): this paper is focused on interoperability combining different simulators to create a modular and scalable approach for complex scenarios characterized by heavy computational workload. The case study addressed a within an extended maritime framework (EMF) including underwater operations, cyber warfare, autonomous systems and traditional vessels. The paper presents the architecture of the federation and also provides a performance analysis of the implementation when using different RTIs as well as a methodological approach to identify the most reliable and performing solution for the interoperability within this context.

Keywords: *HLA, Interoperability, Modelling and Simulation, Maritime Scenario.*

INTRODUCTION

Interoperability in Modelling and Simulation (M&S) addresses the goals of building large distributed simulations and facilitating model reuse. It is a key concept for organizations such as NATO where transformation efforts across multiple countries and research centers need to be integrated. For M&S applications the main standard for interoperability is HLA (High Level Architecture) (IEEE, 2010a), although other standards exist such as Distributed Interactive Simulation (DIS) (IEEE, 2015, 2012), CTIA, TENA, etc. Indeed HLA has been adopted as a international standard after being a solution promoted by US DoD; this architecture is evolving along last years and it has been subject of intense research for improving its potential and evaluating its capabilities .

This paper describes the work carried out in reference to a complex naval scenario involving multiple aspects requiring specific simulators. In the proposed case the authors address naval operations that involve multiple domains of the EMF including sea surface, underwater, air, cyberspace and space.

The paper presents an overview on interoperable simulation by addressing HLA and M&S related efficiency issues; these elements are used to address a specific simulation developed as HLA MCWS-MSTPA Federation by combining antisubmarine operations with cyberspace activities in a LVC (Live, Virtual Constructive) environment. The experiments conducted over this federation during integration tests are reported and used to address the performance analysis. In the tests, different analysis are conducted respect the influence of RTI (Run Time Infrastructure) respect federation involving multiple MCWS federates and execution federating MCWS simulators and MSTPA engine.

1. INTEROPERABILITY FOR MODELING THE CONTEXT

Indeed due to the complexity of this application area it is evident that it is an ideal context where interoperability represents an added value being able to integrate and substitute different models of the components (e.g. acoustic communications, electromagnetic communications, operational activities.. Indeed in the proposed case the use of a simulator developed by Cooperative Anti-Submarine Warfare based on multistatic sonar and autonomous systems is combined with the cyber warfare and its impact over the heterogeneous networks; the research is currently addressing aspects investigated by PARC and CASW programs within CMRE and carried out in collaboration with Simulation Team. Indeed the main focus of this paper is on interoperability of models operating within different domains and coupled by the operational environment: for instance in this case it is created an HLA federation where an acoustic physical model, a constructive tactical simulator and cyber warfare simulation interoperate dynamically real time and/or fast time. It is important to outline that this scenario is characterized by complex elements including physical components (e.g. environment, oceanic engineering, underwater acoustics), actor behaviors (e.g. ASW doctrine, submarine tactics, cyber defense) as well as influence of stochastic factors (e.g. sensor performance, system reliability, operational times and environmental conditions). Many boundary conditions strongly affect the overall performance of the ASW scenario and the entities are interacting dynamically within a context affected by uncertainty.

The introduction of AUVs (Autonomous Underwater Vehicles) and multistatic acoustic further emphasize the impact of cyber warfare being more sensitive to these aspects; the proposed case is based on not-classified releases of the models and by using variable that are not sensible (Bruzzone et al.2013b).

Traditionally Modeling & Simulation (M&S) has to be regarded as one of the most powerful methodologies for performance analysis of complex systems (Banks et al., 2010; Longo, 2011); indeed M&S has been largely used in this area (as suggested by the many research works already published, e.g. Longo et al., 2013; Longo et al. 2012) and, therefore, due to the reasons reported above, it represents the ideal a research tool to leverage on interoperability for producing scenarios within the interdependencies and constraints outlined above.

The authors developed these models and their interactions and studied how to federate together different systems, in particular the authors developed a Federation by integrating two federates adapted from previous models (Bruzzone et al. 2013c); one federate is the MCWS (Marine Cyber Warfare Simulator) tactical simulator (Bruzzone et al., 2013a). The other one is the acoustic engine MSTPA (MultiStatic Tactical Planning Aid) that has been adapted to operate as an HLA federate (Been et al., 2010, 2007; Wathelet et al., 2008).

MCWS is a simulator developed to explore operational scenarios involving the extended maritime framework over several different domains: underwater, surface, air, space and cyber with special attention to model the interoperability among actions carried out on the real world and that ones on the cyberspace. Indeed MCWS simulates a small scenario involving sonobuoys, multiple AUVs (Autonomous Underwater Vehicles) and surface vessels equipped by helicopters. In this case the geographic area is focused on a 400 square nautical miles where the role of the blue forces is to patrol the area and avoiding hostile submarine to cross it; indeed, concurrently, the simulator includes the model of an opposite submarine characterized by the goal to be able to move east to west under this area. It is possible to define different rules of engagement (ROE) to regulate the reactions of the submarine as well of the Surface ship. For instance with "*operational scenario mode*" whenever the submarine is detected the vessel proceed in engaging it and the submarine could react, while in "*not operational scenario mode*" the simulation goal is just to move the helicopter over the submarine without finalizing any engagement; in reality the model includes possibility to activate different ROEs (e.g. submarine could enabled/disabled to attack or just to react to an attack as well as the ship). This simulator allows estimating the probability of success of different players as well as detailed report on events, actions and Measure of Merits (MoM). In the model the heterogeneous network simulation is a critical component dealing with acoustic underwater modems, radio frequency, satellite communications (SATCOM) and LAN/WAN; indeed it is possible to consider the satellite constellation coverage as well as the influence of the weather conditions and general military traffic on their performance; as element of the networks it is also included a central HQs in charge of some decision along the operational processes.

The other model is an acoustic engine defined MSTPA that implements a set of advanced and reliable mathematical models and algorithms developed by CMRE for assessing the performance of a static and multistatic active sonar over a configurable mission environment (Strode et al., 2012). This model had to be adapted to be integrated within a federation with special attention to time management; indeed it was requested a set of architectural improvements to let it to become part of a dynamic interoperable simulation; indeed the federation developed requires to interact dynamically with events evolving based on stochastic simulation and with the humans in the loop in similar way to real system (e.g. sonar operator console in operations room) as in the reality; indeed this model has been subjected to refurbishments to become part of the proposed HLA Federation while further enhancements are planned.

2. HLA AND INTEROPERABILITY

The High Level Architecture (HLA) was originally developed by the US Department of Defence (DoD) and it has become a remarkable standard for distributed simulations for the whole M&S community. HLA uses range from military applications to civilian ones and have dealt with both simulation based learning (Massei and Tremori, 2010; Massei et al., 2013) and analytic purposes. Indeed HLA has been more successful in defense respect other sectors of application such as industry even if there are several case of successful use in logistics and aerospace manufacturing, (Boer et al., 2008; Bruzzone et al. 2008; Longo et al. 2013; Longo et al. 2014); currently HLA constitutes a key reference in the development of large distributed simulations and there are remarkable cases of application in different industrial sectors (Anagnostou et al., 2013; Bruzzone, 2002).

HLA is an architecture including a set of specific rules to be used for managing interoperability among simulators; in addition to these concepts the HLA provides a standard API to be used between a federate and the Run Time Infrastructure (RTI), which is the middleware that manages the federation execution and supports communications among federates. However, HLA does not specify the wire mechanism employed for communications among the different federates.

Originally the DMSO (former name of actual MSCO, Modeling and Simulation Coordination Office, US DOD) was distributing freely (through a controlled authorization process) the first releases of the RTI and the related libraries; the process was centrally controlled and supported updates and maintenance of the DMSO RTI promoting the HLA diffusion (McGlynn 1996); indeed since the beginning also private companies created a commercial releases of RTI and soon also open source software become available; therefore after first years US DoD stopped to support the DMSO RTI maintenance considering that commercial developments were mature in the sector. Currently there are different RTI implementations from different developers and vendors that use different wire mechanisms and algorithms and thus are not compatible among themselves in general (Ross, 2014, 2012). This issue may cause some problems when a federate designed for operating with one RTI is adapted to work with another RTI, but it also has the advantage that different implementations can be optimized for different purposes.

One important aspect studied in the literature about HLA is performance. Latency or throughput issues are a major concern when dealing with large federations that run in scaled time or in real time, in particular with hardware in the loop (De Grande et al., 2011; Knight et al., 2015; Malinga and Le Roux, 2009). Time management mechanisms in HLA ensure that the federation time is consistent among all federates. However, this requires that the advance of the federation for each federate is blocked until the time is granted by the RTI. If the delays due to latency and computational times are too long, the simulation time will not follow up the desired ratio to real time.

Some key factors that determine the efficiency of a federation are:

- The time management algorithms. HLA ensures time consistency among federates by a request/grant mechanism that blocks each federate until the RTI ensure that the whole federation has reached the next time step requested by the federate. HLA supports event driven, time stepped and parallel discrete event simulation paradigms (Fujimoto, 1998). In the case of parallel discrete simulation it allows for either conservative or optimistic synchronization.
- The wire protocol employed by the RTI to send and manage messages (Ross, 2014, 2012). Both TCP and UDP unicast and multicast protocols have been adopted by different RTIs as well as different size limits for the messages. Both reliability requirements and latency of the messages differ among RTIs and their differences might be significant depending on the case of use.
- The workload distribution among federates. Some federations may not allow to distribute the computational workload among federates because they perform tasks of different nature. Scheduling algorithms, whenever feasible, may help to balance the workload and thus avoid one federate to become the bottleneck that delays the whole federation. The works by De Grande are a good example of strategies that reduce this problem (De Grande and Boukerche, 2011; De Grande et al., 2012, 2011; Grande and Boukerche, 2010).

In this paper, three different RTI implementations have been tested to evaluate their influence on the efficiency of this specific simulation framework. Thus, this work contributes to the HLA literature by analyzing performance issues with a real complex federation as well as by demonstrating the synergies that can be achieved through the HLA integration of existing simulators from different fields. The interoperation of specialized simulators from different fields allows increasing the fidelity of a model in complex scenarios.

3. THE MCWS-MSTPA FEDERATION

3.1. Federation Design

The main goal set for the design of the MCWS-MSTPA federation was to test the technological capability to create an interoperable simulation to address EMF; in addition it was interesting to investigate the efforts to integrate MCWS with a legacy mathematical model such as MSTPA within an interoperable simulation. These results have been achieved by adopting the HLA interoperability standard and by defining modes, architecture, updates, and tests devoted to integrate, validate, and verify the federation. Obviously, in order to achieve these results it was necessary to address technological interoperability as well as conceptual model consistency.

Such a concept allows for separated models to be combined in an overall simulation architecture with each contributing its particular strengths. In this particular case, MSTPA is used primarily to conduct acoustic calculations with which to determine whether a given combination of sources and receivers existing within the MCWS framework are able to track a submarine target while MCWS handles platform motion and tactics.

In line with recommended practices in M&S, the steps followed in the development of the federation were:

1. M&S Requirement & Objective Definition
2. Scenario Definition
3. Revision of Conceptual Models and Architecture
4. Federation Design
5. Implementation and MSTPA Modification
6. Tests and Analysis of Results

After the definition objectives and the definition of the scenario to be simulated (Bruzzone et al., 2013a) the design of the federation begun and the main templates and object models were set up for the federation between MSTPA and MCWS.Figure 1 shows the scenario simulated by MCWS. MCWS is a stochastic discrete event simulator able to run in stand-alone and federated mode, enabling both real time and fast time simulation; its implementation allows it to run on multiple OS (Operating Systems) and it was tested in Windows, Mac OS and Linux; therefore in this experimentation MCWS is operating on Windows workstations. MCWS models include a destroyer that carries 2 helicopters, submarines, AUV, etc. The communication links are also simulated along with the headquarters and cyber networks. The destroyer may also use active sonar and/or work in passive sonar mode, on which it would be simply listening, while AUVs are controlled by Intelligent Agents sailing around to serve as receiver into a multistatic sonar architecture. AUV communication are simulated as they evolve along their dynamic network that is self reorganizing by connecting themselves in a chain, if possible, till the RF gateway (a buoy); these communications are operating while the autonomous systems are underwater by using acoustic communication while a mores simple approach based on RF (radio frequency) is used when they surface.

In the same area, an enemy submarine operates in the scenario and it is the target to be tracked by the blue force. The MCWS federate contains all the elements that correspond to a complex sonar architecture such as the vessels, sonobuoys and AUVs (from zero up to 4, concurrently, operating). MCWS includes meta-models of active mono-static sonar, active multi static sonar and passive sonar; these meta-models are simplified therefore consider all major parameters (target strength and target characteristics, relative direction, course, speed, mutual interference, etc); in general these have been developed based on public domain information to guarantee the not sensitive nature of MCWS allowing to move it around without heavy constraints introduced by any kind of security issue.

These metamodels could be substituted by MSTPA acoustic algorithms when requested; in the proposed federation for instance multistatic sonar are simulated by MSTPA engine; potentially this federate could address all the sonar issues, however, as of nowadays, only the active sonar operation is fully supported.

In the test simulation is directed by IA-CGF (Intelligent Agent Computer Generated Forces) by Simulation Team integrated within MCWS (Bruzzone, Tremori, Massei 2011).

MCWS includes tactical operations as well as cyber attacks and cyber defense actions (Bruzzone et al.2013b). these could be concurrently activated addressing each node and each link of the heterogeneous network; the attacks are addressing three different major cyber proprieties: availability, confidentiality and integrity; the element could be compromised and/or restored also partially and their status affects the operations: for instance, if the integrity of the buoy is depleted and this entity is serving as gateway between acoustic comms arriving from AUVs to Radiofrequency comms to the Destroyer, the sonar contacts of all the autonomous systems can't be more used for detection and tracking.

In addition to cyber defense issues, all the elements consider communication saturation due to simulated traffic plus other background data flow reproduced by statistical distributions; indeed all the nodes of the networks are also subjected to regular failures modeled as stochastic breakdowns regulated by MTBF (Mean Time between Failures) and MTTR (Mean Time to Repair). For simplicity in the current scenario all cyber attacks are carried out by red forces and all defensive actions are up to the blue forces even if the model allows to create more sophisticated issues.

In sense of tactical operations, the red submarine moves towards west reacting to its perception about foe activities and positions; when submarine detects suspects elements it deviates in order to reduce detection probability, concurrently time by time he tries to reach his destination crossing the area. So the submarine control course, speed and deep in order to avoid detection and cross the area by applying simple rules; even in this case it was decided to don't implement sophisticated cloaking tactics to avoid any classification issue, even if the simulator could easily implement most of them.

Indeed the agents could sail the submarine even outside of the area in case he feels in danger, but it should then come back; depending on submarine ROE it could react or attack the surface vessel. In addition to IA (intelligent Agent) driven simulation, MCWS allows also to control the submarine by an operator through da simple user interface; in this case it is possible to define course, speed, deep; the user could even to operate the weapon systems and activate attack procedures through its interface; in such case if the submarine by moving towards the ship detects it and the target is within weapon range, it launches a torpedo. Although MCWS could be used to simulate a broad range operating conditions, this scenario was selected as a significant one on which to perform the tests. The active sonar is simulated by MSTPA simulator; indeed the multi-static sonar system is composed by a source (the sonobuoy) plus different listeners; in our case the simulation was run including two AUVs as well as the destroyer, corresponding in MSTPA to three listeners controlled dynamically by MCWS. Water acoustics are simulated by MSTPS considering water conditions such as salinity, temperature, etc.

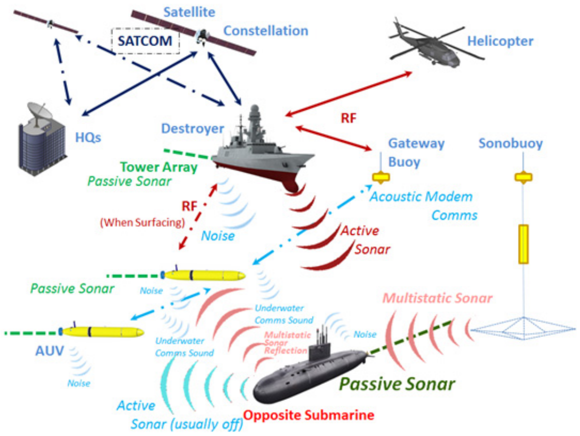

Figure 1. Simulated scenario

A general Federation structure is proposed on Figure 2 by using Pitch RTI; indeed the federation is enabled to to operate automatically with different RTI based on initial settings; currently the federation supports Pitch, Mäk and Portico RTIs. It shows the MSTPA and the MCWS federates. Actually, as the figure shows, the MSTPA is internally connected with other models that perform part of the calculations.

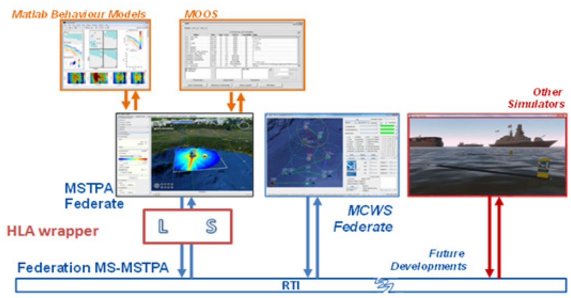

Figure 2. Federation structure.

This study has addressed the validation issues by applying logic structure analysis through flow charts and dynamic V&V as proposed in Figure 3. In terms of dynamic testing, the integration test has included: federation join test, publishing and subscribing attribute test (DoD, 2009). Further VV&A effort are planned for the future to improve realism of the simulation, but it was not conducted in this phase of the research as the main goal was the technological testing and demonstration.

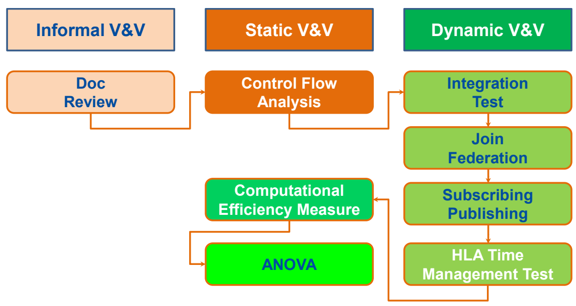

Figure 3. V&V flow diagram.

3.2. Federation Object Model (FOM)

The FOM (Federation Object Model) is a specification defining the information exchanged at runtime accordingly to the federation objectives. A first step to achieve interoperability is to set a common understanding of the semantics of data. The FOM lexicon provides the Federation with an available definition of all object classes, interaction classes, object class attributes, and interaction parameters (IEEE, 2010b).

We have chosen, at this stage, to have one Object class that represents each vehicle or system present in a defined scenario as well as each track by the acoustic analysis of each Fusion Set; a fusion set corresponds to a Command and Control (C2) solution able to combine single or multiple data to detect and classify potential targets. Thus, target detection and preliminary classification is carried out by MSTPA and decision making given the targets detected is performed by MCWS.

Table 1. Object class definition table

Class	Definition
Platform	Every asset on which sensors or weapons are mounted in the scenario (e.g. vessel, AUV, submarine, buoy)

The attributes defined for the platform class contain information about the name, type and characteristics of the platform, the geographical position, the speed, course and acceleration, the angles, the operational status the condition and the sensors. The condition attribute states whether the platform represents a real asset or a dummy track generated by MSTPA.

An interaction is an explicit action taken by a federate that may have some effect or impact on another federate within a federation execution. The federation considers pings generated by sonar and echoes generated from various objects in the scenario. During the simulation MCWS sends PING interactions and MSTPA subscribes to them (
Table 2).
The parameters of the PING interaction contain information about the emitter, its location and the physical characteristics of the sonar pulse.

Table 2. Interaction class definition table.

Interaction	Definition
PING	Ping Acoustic Sonar: pulse emitted by sonar

3.3. Federation Rules

Apart from the FOM, the federation rules are a necessary agreement among federates to ensure interoperability. They state the behavior of each federate and what information they expect to send and receive from the rest of the federates.

3.3.1. MCWS rules.

1. MCWS will run in its own simulation mode w/o any time synchronization with MSTPA.
2. MCWS will run in time constrained and time regulating mode. The look ahead time will be updated according to the time to next event.
3. MCWS will publish PING interactions and send them when the sonar is requested.
4. MCWS will publish and subscribe the PLATFORM class.
5. MCWS will register PLATFORM objects corresponding to the real assets in the scenario.
6. MCWS will start simulation execution upon pressing the Run button.
7. MCWS will update PLATFORM objects position attributes as they move through the map.
8. MCWS will discover the PLATFORM instances registered by MSTPA that correspond to the tracks.
9. MCWS will reflect the position attributes updated by MSTPA and display the tracks on the map.

3.3.2. MSTPA rules.

1. MSTPA will run in “simulation mode”, where events in its internal event queue are processed as soon as possible.
2. MSTPA will subscribe to PING interactions but will not use such information.
3. MSTPA will publish and subscribe to the PLATFORM class.
4. MSTPA will discover the PLATFORM objects registered by MCWS.
5. MSTPA will read from its xml configuration file the platforms configuration
6. MSTPA will link platforms specified in the configuration file to HLA platforms registered by MCWS thought the platform Name attribute
7. MSTPA will start simulation execution as soon as all the expected PLATFORM objects are discovered and their position attributes are updated.
8. MSTPA will reflect the position attributes for the PLATFORM objects.
9. MSTPA will ping accordingly to an internally scheduled time base using the last PLATFORM objects positions for ping calculation.
10. At the starting time of the simulation MSTPA will publish the PLATFORM class.
11. When MSTPA generates a track it will register it as a PLATFORM instance related to new targets tracks resulting from contacts detected with the sonar.
12. MSTPA will update the attributes of PLATFORM instance position and condition. The condition attribute will be set to 1 meanwhile the track is alive.
13. When a track dies in MSTPA, it will first change the Conditions attribute to 2 and then it will remove it from the RTI.

4. MCWS HLA EXPERIMENTATION

4.1. MCWS HLA Integration test

The goal of this integration test was to verify that the MCWS was fully interoperable through HLA and able to join the MCWS-MSTPA federation and running with time managed by the RTI; multiple instance of MCWS could be federated together to carry out more complex scenarios based on a scalable patrol solution. The proposed tests were conducted with three MCWS running on two different machines connected through a LAN.
Indeed the three MCWS federates were tested running together and synchronized being each one time constrained and time regulating. They publish and subscribe all submarines and frigates belonging to the different MCWS federates. They are also all able to see the different platforms in their sonar and select them as targets. They are able to launch torpedoes towards the objects owned by other federates, and it should be created a specific interaction to inform other federates by a message about the fact that the target has been terminated.

In this test, the submarines were published as if they were potential suspect tracks proposed by other federates in order to test also tracks visualization. Hence, the federates visualize each other's submarines as tracks and not as already confirmed enemy submarines. Figure 4 shows a screenshot of the integration test.

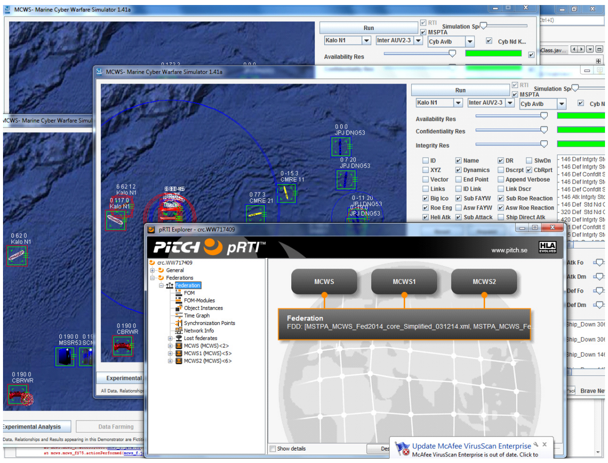

Figure 4. Screenshot displaying the Pitch CRC with three MCWS federates connected as well as the three windows that correspond to the three instances of MCWS running.

4.2. Analysis on the Federation Performance

The maximum time scale (simulation time / real time) that the federation is capable of achieving during a simulation run is used as a measure or performance.

As anticipated MCWS is able to run real time and paged and unpaged fast time depending on the settings; usually it could go at least 300 time faster than real time in stand alone paged mode also with the full scenario based on 4 AUV dynamically interacting with all other assets and elements.

The performance indicator carried is useful for analytic purposes since it is a measure of the computation time that is required to complete a simulation experiment in federated mode.

The maximum time scale (MTS) was measured under different conditions of experimentation. Two factors were considered:

- The RTI implementation. Three RTIs were used:
  - RTI 1: Mak 4.4.1.
  - RTI 2: Pitch 5.0.1.
  - RTI 3: Portico 2.0.1.
- The number of MCWS federates running in parallel

The RTI implementation may affect the maximum time scale since different RTIs may differ in the wire protocol used, the time management algorithms and the efficiency of the RTI implementation. In the experiment conducted Pitch and Mak use the TCP/IP protocol for communications. Portico uses the UDP multicast functions implemented in the library JGroups.

Table 3. Maximum time scale achieved by each federate (seconds of simulation time / seconds of real time).

RTI	Number of Federates	
	1	2
Pitch	3112.6 ± 77.19	1056.2 ± 59.02
Mak	3073.02 ± 77.19	978.93 ± 59.02
Portico	3242.92 ± 54.58	702.3 ± 41.73

* Error values correspond to the 95% confidence interval with 8 runs of each scenario.

Table 4. Rate of object updates received per second.

RTI	Number of Federates
	2
Pitch	125.88 ± 7.19
Mak	117.58 ± 7.19
Portico	82.74 ± 5.08

* Error values correspond to the 95% confidence interval with 8 runs of each scenario.

Table 3 and Table 4 show the results achieved when running the simulation using the different RTIs with 1 and 2 federates. The results show non-significant differences among the RTI implementations when running with only one federate, as it might be expected considering that no communications are necessary under this circumstances. Figure 5 displays the same results in a graph. The error bars correspond to the 95% confidence intervals.

When two federates join the federation, communications through the local area network are required. In this case, time synchronization mechanisms and latencies reduce the maximum time scale achieved by a factor of 3. In this case, Portico RTI showed a significantly lower performance. Pitch was achieved a 50% increase in time scale compared to Portico and Mak a 39.4% higher time scale. The difference between Pitch and Mak was significant at the 95% level of confidence The relative difference was a 7.3% in the proposed scenario. The number of object updates achieved per second is also an indicator of how fast the federation run with different RTIs and the conclusions are analogous to the previous ones. Figure 6 and Figure 7 graphs show the same results.

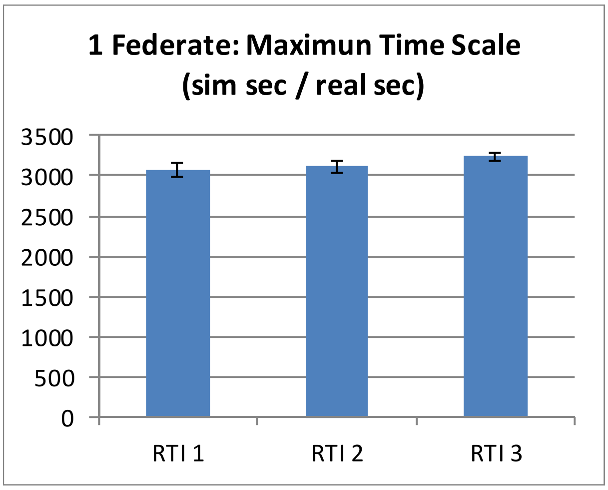

Figure 5. Maximum time scale for the federation running with 1 federate.

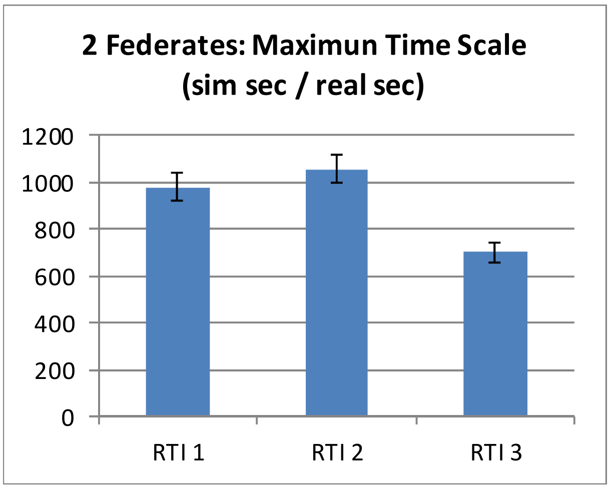

Figure 6. Maximum time scale for the federation running with 2 federates.

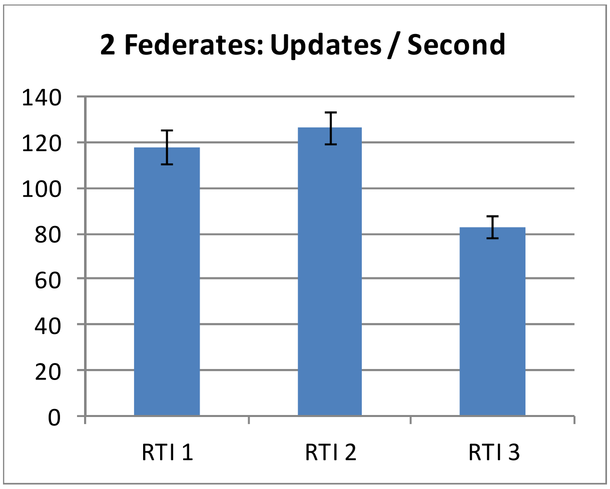

Figure 7. Object updates received per second running with 2 federates.

5. MCWS-MSTPA FEDERATION TEST

5.1. Integration tests

Once the MCWS- MSTPA federation was developed, three integration tests were conducted based on the simulation scenario implemented in MCWS. The goals of the integration tests were:

1. Check that both federates join the federation and publish and subscribe objects classes and interactions.
2. Check that both federates register and discovers object instances, that they add the discovered objects to their internal models and that they update and reflect object attributes.
3. Check that PING interactions are sent and received and that tracks are generated accordingly.

Figure 8 shows a screenshot of the 2[nd] integration test where the platforms in the MCWS federate is synchronized with the platforms in MSTPA after they have been discovered.

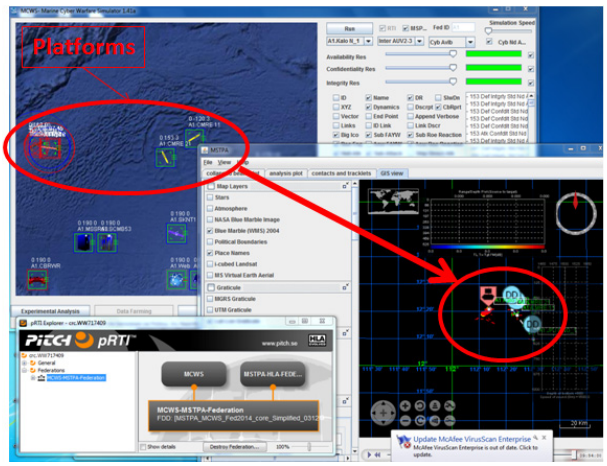

Figure 8. Integration Test 2: MCWS platforms synchronization in MSTPA's GIS.

Figure 9 displays a screenshot of the 3[rd] integration test where the track for the submarine generated by MSTPA is visualized in MCWS. MCWS is actually managing the movement and decisions of the submarine, but only the track generated by MSTPA through the acoustic calculations is displayed on MCWS as a red rhombus.
Figure 10 shows the platforms in MCWS along with the tracklets calculated by MSTPA based on the acoustic calculations.

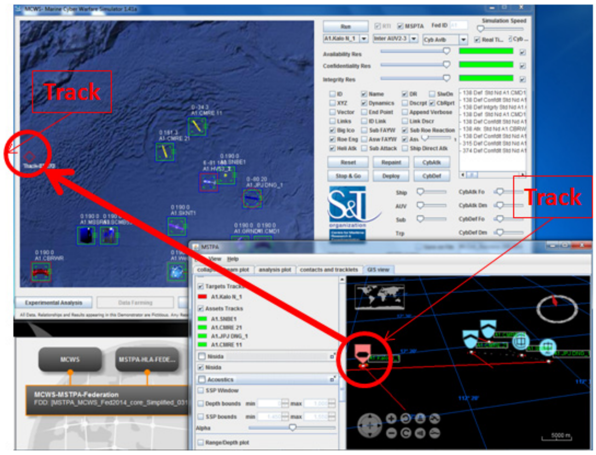

Figure 9. Integration Test 3: submarine's track calculated by MSTPA visualized in MCWS whilst the submarine is hidden.

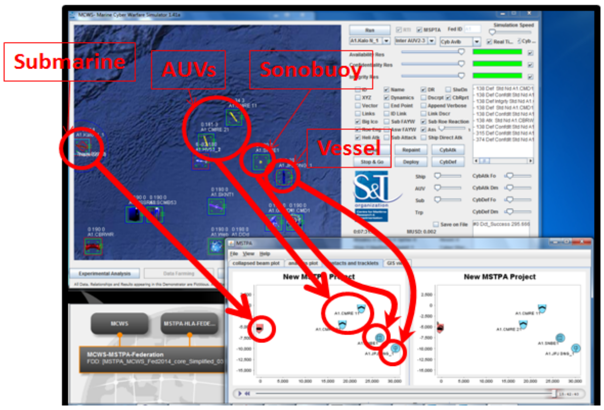

Figure 10. Integration Test 3: Contacts and Tracklets tab of MSTPA.

6. CONCLUSION

This paper describes an HLA federation that has been developed by combining different simulators used for marine operations. It demonstrates the potential of HLA for integrating models specialized in the evaluation of different elements in a complex scenario. In this case, the operations in this scenario are simulated by the MCWS federate and the sonar simulation is carried out by the MSTPA federate.
However, obviously federating a simulator through HLA comes at a cost in computing time and communications delays. In this specific federation it was observed a 66.6% reduction in the maximum time

scale achieved when using a federation with two federates connected through a local area network. Three RTI implementations were compared as well. The difference among them was not significant when using only one federate. When using more federates, it was possible to identify difference among different RTI performance; for instance in this specific scenario Pitch and Mak showed an higher performance respect Portico, the open source RTI solution. The difference observed between Pitch and Mak on the specific scenario used for the test was significant, although small; this suggest that even if the relative results it cannot be generalized to other federations or other setting it could make sense to conduct these tests to identify the most performing solution for the specific implementations in case extensive experimentation is expected for using an HLA simulator.

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