Representation of Dynamic Synthetic Environments in Distributed Simulation

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ABSTRACT

Current practices, standards and technologies are aimed at achieving correlated static synthetic representations of Defence operational environments across distributed simulation systems. However, real world operational environments are dynamic in nature. Weather varies with time and place, and the terrain is affected by both natural effects (e.g. heavy rainfall, snow, flooding) as well as the effects of force behavior, such as munitions damage to buildings and infrastructure. Where multiple simulation systems are federated, both the static and dynamic representation of the operational environment needs to be consistent.

This paper describes work being carried out by the MSG-156 Task Group (TG) to investigate simulation architectures, processes and standards aimed at achieving improved and consistent representations of dynamic environments across simulation systems. This includes the representation of weather data in simulation, processes to dynamically modify the terrain and protocols for simulation systems to retrieve the current state of the simulated operational environment. Modelling and Simulation as a Service (MSaaS) is assessed as being a key enabler required to achieve this.

This paper describes a set of Use Cases and the Conceptual Models that has been derived from these Use Cases. A proposed architecture for achieving a consistent dynamic synthetic environment is also included, together with a description of planned experiments to evaluate the proposed solution.

INTRODUCTION

Motivation

Defence operations are performed in a world where the environment is dynamic and where weather and warfare effects have an impact on operational capability, including platform and systems behaviour. Throughout history weather has been a fundamental element to the decisions made on the battlefield at the tactical through to strategic levels. The MSG-156 Task Group (TG) recognised a capability gap in current defence Simulation and Synthetic Environments (SEs). This has been identified as a lack of consistent representation of dynamic environments across simulation systems, specifically the representation of meteorological data and physical warfare effects and associated 2nd and 3rd order effects on the operational environment. Examples include the effects of rain on the terrain surface which can affect ground vehicle mobility, the effects of cloud formations and rain on airborne sensors, the effects of wind on air platforms, e.g. Unmanned Air Vehicles (UAVs), and the effects of munitions damage to the terrain surface (e.g. craters) and road infrastructures which impact route planning. Representation and effects of weather conditions (e.g. rainfall, wind, temperature), and climatic conditions (e.g. desert, arctic, etc.), within simulation systems has traditionally been poor, mainly due to lack of requirements and limitations in technology. This has resulted in disjointed approaches which have typically resulted in,

- two dimensional representations of clouds for ground training systems which cannot be re-used for airborne training systems;
- atmospheric modelling which does not match reality; for example cloud systems do not accurately affect the aerodynamic behaviour of air vehicles;
- no link between representation of weather visually (e.g. rain and fog), and its effect on the environment (e.g. 2nd order changes to the state of the ground), systems, equipment and human behaviour;
- disparities in weather representation within heterogeneous distributed simulation systems where some systems represent weather, some do not, and some simulate contradicting weather.

Current simulation standards based technologies and practices are aimed at achieving correlated static representations of the outside world environment based on sharing common environmental datasets and re-using environmental databases. While some simulation systems do support dynamic effects that reflect weather conditions and physical warfare damage, these are often pre-scripted and are not correlated across federated simulations. Subsequently, the extent to which dynamic aspects of operational environments are represented in current simulation systems is limited and often bespoke to a given simulation, resulting in different effects being represented across simulation systems. This limits the level of simulation interoperability that can be achieved when there is a need to configure a larger scale simulation based on networking a number of distributed simulation systems in order to meet a given requirement.

Where simulation is used for joint collective training, experimentation, support to defence equipment acquisition, mission planning or evaluation and test, these dynamic aspects need to be supported in a common and consistent way across dissimilar simulation systems. Current best practices, standards and technologies struggle to achieve correlated representations of the simulated operating environment. The inclusion of dynamic aspects of the environment will make this struggle even more challenging, thereby underlining the need for more extensive methodologies and technologies to achieve correlated environments in distributed simulation systems, including Computer Generated Forces (CGFs), Human-in-the-Loop (HITL) platform and sensor simulations. To ensure that simulations can be setup and used more effectively in the future by NATO and NATO Partner Nations it is important that correlation of dynamic operational environments in simulation can be achieved in a more responsive manner both in terms of cost and time.

Related work

Fully dynamic Synthetic Environments (SEs) have been on the 'wishlist' of the Modelling and Simulation (M&S) community for some time and work on this topic has already been performed in the 1990's [**e.g. Moshell1994**]. However, to date we are still not much closer to a commonly agreed approach to achieving dynamic SEs that provide correlated effects across distributed heterogenous federate simulations. Initiatives in the past have aimed to extend the existing Distributed Interative Simulation (DIS) and High Level Archiecture (HLA) simulation interoperability standards with messages to support changes in the state of the SE, but their acceptance and implementation in simulation systems has not been widespread.

On the level of a single simulation system (or a federation of systems developed by the same supplier), there are many interesting examples of dynamic changes to the SE. For instance, a Forward Air Controller simulation might feature destructible targets such as buildings and bridges, and a combat engineering simulator might contain a comprehensive and realistic model of soil and its deformation behaviour for e.g. digging trenches. However, each of these simulations implement only part of the wide range of possible dynamic SE interactions and in their own proprietary way, with no concern for communicating these changes in a standardized manner.

Another factor that might have hindered investments in dynamic SE capabilities in the past is the complexity and computational expense of simulating dynamic effects in a realistic way. A physics-based simulation of munitions damage to a building was simply not feasible in real-time. Therefore, methods employed included having a small set of pre-modelled damage states, which often did not match the actual point of impact and munition type employed, lessening the value of such dynamic interactions.

The increase in CPU/GPU computing power over recent years has now allowed for complex, physics-based deformation and destruction algorithms to run in real-time. In the entertainment gaming industry, this has led to numerous convincing examples of real-time destruction and deformation (for instance, physics-based building destruction in the Frostbite engine [**EADICE**], powering the BattleField series of games, or the complex terrain deformation and trafficability model of SpinTires [**Oovee2014**]). Furthermore, in the research fields of computer graphics and simulation there has been substantial progress on real-time, physics-based techniques for a large number of relevant dynamic effects. A full discussion of the current state of the art is out of scope for this paper, but can be found in a recent survey article on this topic [**Smelik2019]**.

The M&S community is currently investigating new approaches to delivering simulation for defence, transitioning from complete simulation systems hosted on dedicated hardware to access to more modular simulation components and services which are either readily deployable or remotely accessible on cloud-based servers **[MSG-136]**. This transition not only promises to reduce deployment and configuration costs and increase flexibility, but even more important in the context of synthetic environments it offers a more manageable way to enable correlation across federate simulations compared to current practices, and scalability in terms of data distribution and computation power by leveraging the cloud-based resources.

Taking into account the increase in processing power and network bandwidth, and the move from standalone, large simulation systems to modular cloud-based (micro-)services, there are now opportunities to work towards fully correlated dynamic synthetic environments.

MSG-156 Research Question

Given the importance of a realistic dynamic environment within simulation systems and given the challenges that are still faced to achieve this in a Mission Training through Distributed Simulation (MTDS) environment, in 2016 a NATO MSG Exploratory Team ET-045 was setup to investigate this topic. Based on the recommendations of ET-045 **[ET-045]** in 2017 a new NATO MSG task group, MSG-156, was setup with the objectives to:

- Define best practices, required methodologies, technologies and inform requirements for standards needed to achieve a correlated dynamic SE in future distributed simulation exercises.
- Evaluate methodologies and technologies through concept experimentation where needed.

MSG-156 is focused on the following aspects of a dynamic SE:

- Achieve a **dynamic terrain** that is shared between the participants of the distributed simulation, taking into account the natural, human geophysical and force engagement effects that influence the terrain. Methods and technologies are needed to deform the SE in a common and consistent manner.
- Achieve **variable weather** that is shared between the participants of the distributed simulation. Which aspects of the weather do need to be represented and which data sources are available to introduce the weather in the simulation? Which methodologies and technologies are needed to integrate the weather consistently in the simulation and to ensure that the weather affects the participants in a common and consistent way?

Representatives from France, Germany, Netherlands (chair), Norway, Slovenia, Turkey and the United Kingdom have joined MSG-156 and are working on these research questions.

Paper outline

This paper provides an overview of the MSG-156 TG progress to date, its plans for practical experimentation and future work.

Section 2 of this paper discusses the proposed approach to addressing the TG objectives. The section is divided in a number of subsections, describing example Use Cases of dynamic synthetic environments that were used as basis for group discussions, the development of conceptual models to understand how elements of a dynamics SE and simulation entities interact, and a technical architecture based on the MSaaS paradigm. Section 3 provides an overview of planned experiments which will be used to test and de-risk the concepts and the architecture. Finally, Section 4 provides a short summary of the paper, and discusses the expected results and future work beyond the scope of MSG-156.

APPROACH

Use Cases

The technical approach employed by MSG-156 is based around four Use Cases which will be used as a basis for experimentation on approaches and prototype methods relevant to the deployment, integration and execution of simulation scenarios which include the correlated representation and disturbances of weather (i.e. weather effects) on force behaviour.

- Close Air Support (CAS);
- Air engagement in realistic weather;
- Trafficability influenced by weather;
- Terrain modifications.

Use Case #1 "Close Air Support (CAS)": During a CAS mission the Forward Air Controller (FAC) on the ground and the Air Crew in the air need to visually identify the same target that should be attacked. This is done by describing the object using a standard report and by voice communications. Using the sensors of the aircraft, including a targeting pod, the air crew will aim to identify the correct object. Once the object has been identified the air crew will start the weapon delivery and afterwards the weapon damage will be assessed by both the FAC and the air crew to decide if the target has been destroyed or not. The trainees in the different simulation systems need to be able operate and communicate in such a way that they can identify the same target.

Figure 1: Close Air Support team (source Defensie.nl)

Use Case #2 "Air engagement in realistic weather": An Unmanned Air System (UAS) is deployed to conduct Intelligence, Surveillance and Reconnaissance (ISR) activities and identify a ground target. The UAS is configured with weapons, on-board radar and an Electro-Optic (EO) sensor. As the UAS carries out its reconnaissance of the operational area a weather front passes through bringing increasing cloud cover and some precipitation. An enemy manned aircraft is tasked with destroying the UAS. During the air-to-air engagement sensors on the airborne platforms are tracking each other. The clouds sometimes block the visual line of sight between the two airborne platforms and precipitation in the atmosphere introduces disturbances and degradation on the sensors. An air-to-air missile is subsequently fired at the UAS. The seeker of this missile will track the UAS and guide the missile to the target.

Use Case #3 "Trafficability influenced by weather": A convoy of armoured vehicles and supply trucks is traversing a difficult mountainous and densely vegetated terrain on a multi-day trip to resupply an isolated Forward Operating Base. Not all local roads are paved and in good condition, and heavy rainfall causes some of the dirt roads to become slippery, forcing the convoy to advance at reduced speed. The rain changes to snow, and with the decreased visibility and the trucks getting stuck in the high snow volumes, the convoy commander no longer considers it safe to continue and decides to take a long detour using only paved well-maintained roads.

Figure 2: Example of vehicle trafficiblity influenced by weather (source Defensie.nl)

Use Case #4 "Terrain modifications": A combat engineering unit prepares a defensive position for infantry in open terrain by digging a network of trenches. Later on, opposing forces applies a barrage of artillery fire on the reinforced positions, resulting in numerous large craters in the terrain and damage to the trenches. Opposing infantry units and vehicles now use these crates to advance on the defensive position under cover.

Figure 3: Example of craters in a terrain (source Defensie.nl)

Conceptual Models

To get a better understanding of the various concepts that are involved in a dynamic SE and to understand how these concepts are related to and influence each other, the MSG_156 TG created conceptual modelling diagrams for each of the four Use Cases described above. These four diagrams focus on the following aspects of a dynamic SE, i.e.

- The influence of terrain and weather on the trafficability of vehicles.
- Terrain and object deformation due to weapon effects.
- Flight dynamics of aerial vehicles influenced by weather.
- Sensor performance affected by weather.

Figure 4 shows the resulting diagram for the influence of terrain and weather on the trafficability of vehicles. The diagram shows that the traffiicabilty node at the center is influenced by the characteristics of the vehicle (e.g. weight, tracked or wheeled), the surface conditions and the surface characteristics (e.g. slope) of the terrain. The surface conditions on the other hand are affected by the terrain characteristics and by precipitation, e.g. an unpaved road can get muddy when it rains, while a paved road mainly gets wets with some puddles. In the end it is all about the driving behaviour of the driver of the vehicle who determines the speed and thereby the movement of the vehicle, and this driving behaviour is influenced by the surface conditions and by the visiblity (e.g. how well the driver can see the environment).

The other three conceptual modelling diagrams show the same kind of information for the topics that they address.

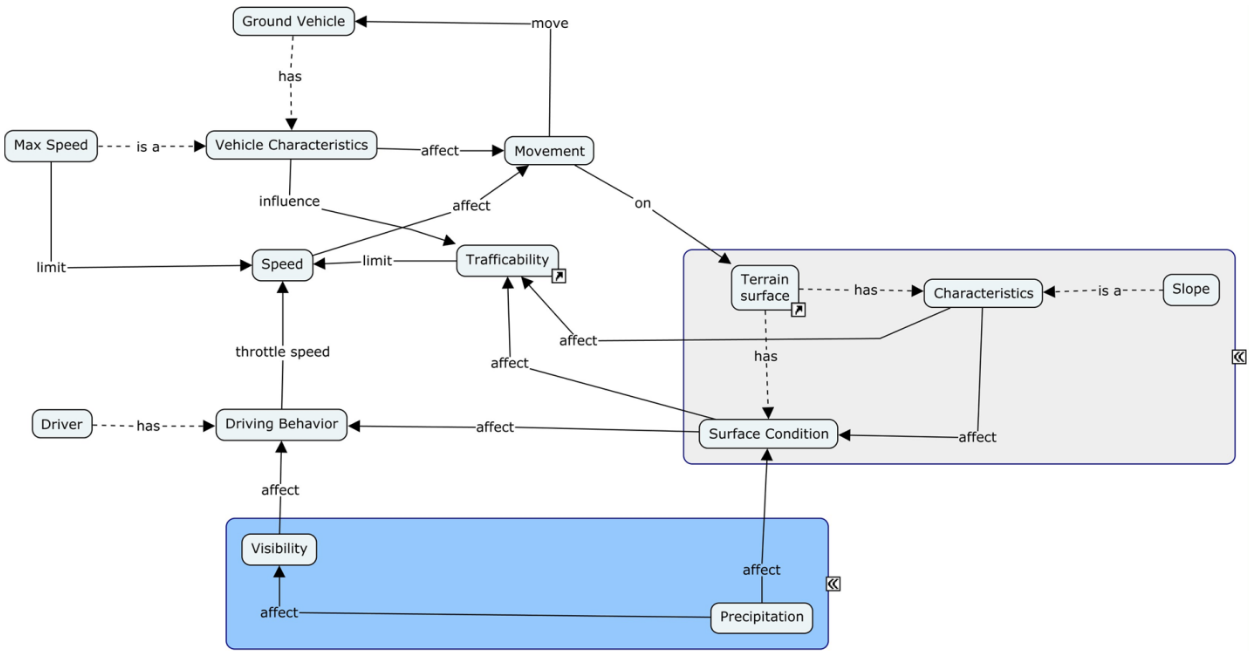

Figure 4:Conceptual modelling diagram for the influence of terrain and weather on the trafficability of vehicles

In the conceptual modelling diagram above the various concepts that play a role in trafficability are listed and it is also shown how they are related to each other. These concepts need to be implemented in the simulation environment to be able to simulate a dynamic SE in a realistic way. Therefore the information from these diagrams helped the TG in defining the proposed solution architecture that is discussed in the next section. The various aspects that have been identified in the conceptual modelling diagrams have to become the responsibility of a specific model or component within the simulation environment, e.g. a terrain weather interaction service might get the responsibility to calculate the influence of the weather on the terrain surface. By checking which concepts are related it also becomes possible to identify the interfaces that are needed to communicate the required inputs or outputs between the various simulation components, e.g. the model that calculates the trafficability needs to receive information about the terrain surface condition from the SE and the output of the trafficibilty limits the speed of the vehicle so that needs to be communicated to the ground vehicle dynamics model.

The conceptual modelling diagrams are therefore a tool that helps to define the responsibilities of the various simulation models in a logical way, since the diagrams help to understand the real world interactions that are being represented. Once these model responsibilities have been identified, the interfaces needed to exchange information can also be defined in a logical way.

Proposed Initial Architecture

A recent development within the NATO MSG community is to propose MSaaS as the forward-looking approach for distributed military simulation. A M&S service is a specific M&S-related capability delivered by a provider to one or more consumers according to well-defined contracts, including service level agreements (SLA) and interfaces. A distributed simulation is composed of either existing, reusable or newly implemented dedicated services.

Some of the advantages of the MSaaS approach have been covered in the Related Work section. The TG initially also considered following a more traditional approach, based on using existing infrastructure and protocols (i.e. DIS and HLA), to implement a correlated dynamic SE. However, there are a number of limitations when using more traditional approaches, notably the difficulty of maintaining a correlated SE across all federates while dynamic changes are being made when not working with a centralized SE model, but instead having each federate maintaining its own SE instance. This would require, among other things, standardized deformation algorithms to be employed and expected outcome of dynamic effects (e.g. munition detonation on soft soil). Experiments have been performed in the past based on sending complete delta's of SE data layers after dynamic interactions have occurred, packaged as DIS Protocol Data Units (PDU's) or HLA messages. However these approaches did not get much traction. Furthermore, DIS/HLA are not really designed for the distribution of large dynamic data layers to federate smulations, and it is typically more efficient to have federates only pull the data layers relevant to their simulation and area of interest.

Considering the above, and in order to come up with future proof concepts, and to maintain links with other ongoing MSG activities including MSG-131/MSG-136 ("Modelling and Simulation as a Service (MSaaS) – Rapid deployment of interoperable and credible simulation environments"), and MSG-164 ("Modelling And Simulation Aas a Service - Phase 2"), the group decided to follow the MSaaS approach. Ideally new service components, reusable for other experimentation will arise from this TG's work.

High Level Service architecture

Static terrain and weather

The high level service architecture looks simple, as long as the aspects of dynamic terrain and weather are not regarded. In the context of work being carried out by this TG terrain and weather data is transferred into a data repository which provides quality proofed and optimized data to the Terrain Service and the Weather Service. Both services deliver the data to the connected federates using service interfaces. Figure 5 shows this architecture.

Dynamic terrain and weather

For handling dynamic terrain the architecture has to be expanded. The static part remains and delivers the initial supply of the data. The aspect of dynamic terrain means that the terrain data may change either due to the effects of weather or federate simulations (e.g. air to surface missile). Examples include heavy rain, causing impassable ways, or weapon impacts generating craters or destroying buildings.

In order to support dynamic terrain effects Terrain Interaction and Modification Services (TIMS) are introduced. Such a service´s task is to receive events, calculate the impact on the terrain and finally update the terrain using the terrain service. To fulfil the task the TIMS pulls the terrain data of the area of interest, processes the modification and delivers the modified data back to the terrain service The terrain service requires additional capabilities, which includes being able to receive modified content and update the data repository in order to provide the modified terrain data. Furthermore the Terrain Service has to push change notifications to inform the other federates. Figure 6 shows the resulting architecture.

For reasons of clarification there are two classes of TIMS. The Federate-Terrain Interaction and Modification Service responsible for modifications induced by federates and the Weather-Terrain Interaction and Modification Service responsible for processing weather related impacts. Technically they should use the same interfaces.

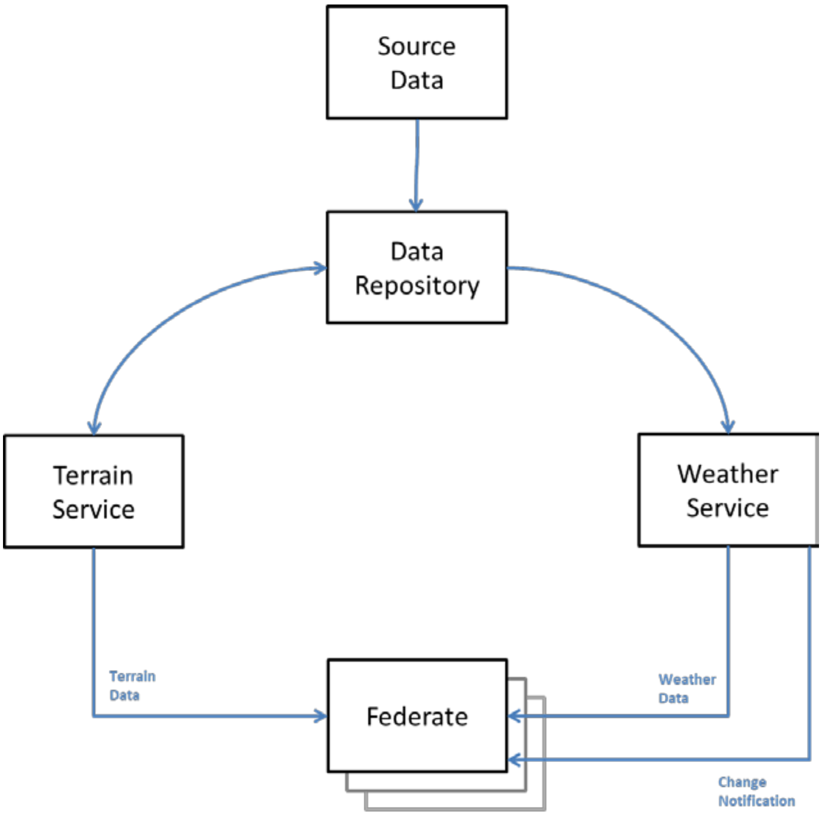

Figure 5: Solution architecture for static SE

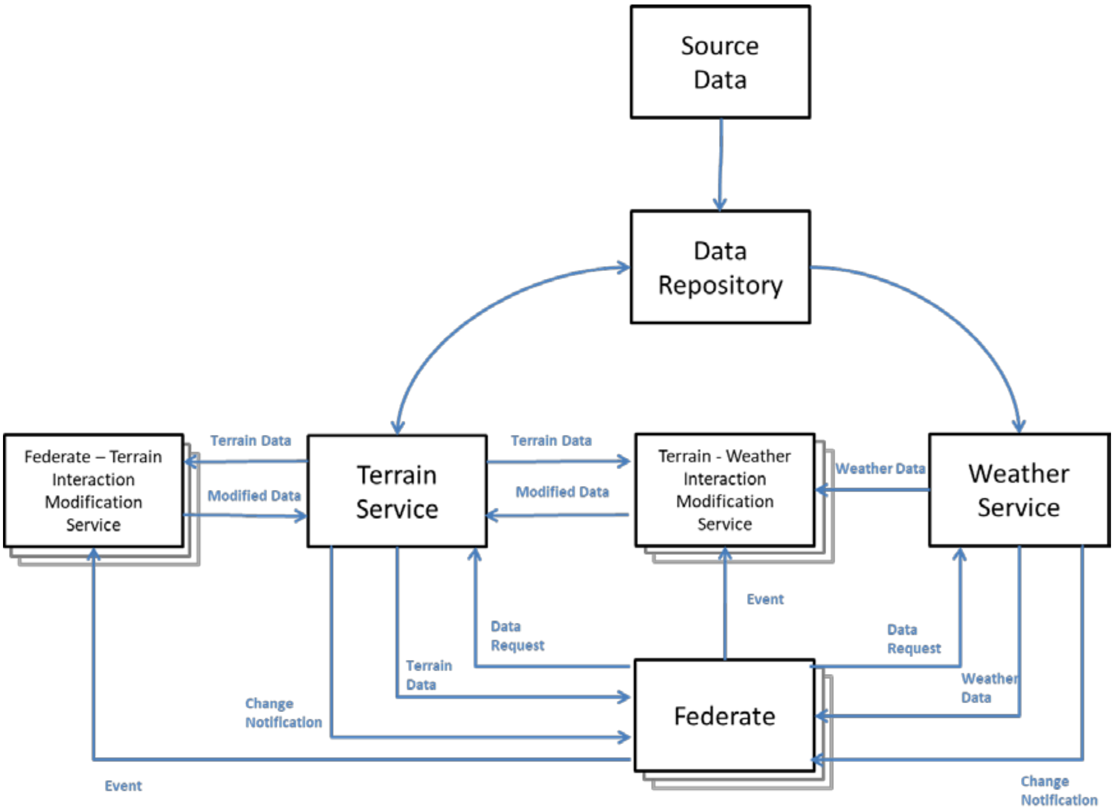

Figure 6: Solution architecture for dynamic SE updates

<u>Examples</u>

For comprehending the diagram above the two following examples may be helpful:

Impact of an explosive device:

- A federate launches an explosive device and sends that event qualified with necessary parameters to a Weapon Effect Service (WES), which is an implementation of a Federate-TIMS.
- The WES receives the event, pulls the affected terrain data, calculates the impact, regarding the weapon parameters and the terrain and transfers the update to the Terrain Service.
- The Terrain Service updates the data repository and sends a Change Notification.
- All federates, which require the changes 'subscribe' to the modified terrain.

Change of weather conditions:

- The weather service sends a Change Notification relaying that heavy rain has started in an area.
- The Weather-TIMS fetches the terrain and weather data of that area and recalculates the soil moisture layer for example, and pushes the update to the terrain service.
- The Terrain Service updates the data repository and sends a Change Notification.
- All federates, which require the changes pull the modified terrain.

Interfaces

The dynamic changes either can be calculated equally in every similar system or the dynamic changes can be shared using proprietary data flows. In the context of MSaaS a simulation environment is likely to consist of several heterogeneous systems. Thus an agreement for the interfaces has to be found. The MSaaS approach requires for services to exchange data, and because no simulation specific standard for these services exists new and well proven service standards have to be introduced. These services are the main interface for the access of the environment and the weather data. Remote information interchange is a great advantage of that approach. Any system on any platform running on any operation system can retrieve data without integrating any special programming library or any other proprietary software which may require a different runtime environment. For further consideration two general data types have to be looked into, i.e. Raster data and Vector data.

Raster data

The type of service to be used depends on the data types the federation has agreed on. In the context of MSG-156 raster data is predominantly used. This applies to elevation data, aerial photographs and weather data in general. Raster data usually is transported as image data, which can be delivered by two Open Geospatial Consortium (OGC) Services:

- The Web Map Service (WMS) delivers georeferenced imagery; this can be aerial imagery itself, which is part of the environmental dataset or cartographic information, which can be derived from the vector data contained in a SE service.
- A Web Coverage Service (WCS) provides coverage data like elevation, air pressure etc. as input for calculations, rather than displaying the raw data itself. The WCS provides the original data and has the capabilities to provide the description of the semantics as well. An important point for dealing with dynamic terrain is the WCS-T Extension. This extension (T standing for transactional) delivers the definition of mechanisms for uploading coverages to a server or modify existing coverages on it.

Raster/image data is very common and easy to handle, which makes it a good choice to be used in heterogeneous infrastructures. However, the raster structure itself can include coarse resolutions which do not deliver a precise representation of the situation; linear structures are especially problematic. To achieve a more precise spatial representation (e.g. of building footprints or roads), the resolution has to be increased which results in the amount of data to be transferred potentially being very large.

Vector data

To avoid storing and exchanging huge data amounts vector data is used. Vector data is not made up of a grid of pixels. Instead, vector graphics are comprised of vertices and paths, which define points, curves and polygons. This allows the exact representation of (geo-) data with very small datasets.

The OGC also provides a service for this kind of data, i.e. the Web Feature Service (WFS), which can have a transactional behaviour as well. But there is the issue that the vector data format has to be defined and agreed on. The starting point for that is XML/GML which the WFS concept requires and which can be enhanced to support specific semantics. This concept is very suitable for handling vector data like road networks or other positions of infrastructure in the training environment.

Although this way of interchanging data has a lot of advantages, it is very difficult to implement even in experimental environments. The reason is that it is often not possible for legacy systems to adapt any other data source, so there are ongoing discussions how to deal with that type of data.

<u>Weather FOM</u>

The requirements for a weather data FOM are being reviewed and assessed by the TG to identify which information should be included in such a FOM and which elements of weather are most suitable for use in simulation systems. This activity is based on an existing draft METOC data FOM (ref: MSG-163) and inputs from other related FOM activities being carried out by suppliers. The aim is to have an agreed draft FOM module for weather.

Links with other task groups

MSG-156 is cooperating with other MSG task groups while carry out this work. Most notabily this is with the following groups:

- MSG-163 ("Evolution Of Nato Standards For Federated Simulation"), which is working on expending the NETN FOM with additional modules; one such module is a weather or METOC FOM.
- MSG-164 ("MSaaS Part 2"), which is working on MSaaS technologies; since the solution architecture of MSG-156 is MSaaS based, the outputs and key findings of MSG-164 (and MSG-136) will be taken into account. The specific services MSG-156 is experimenting with are examples of implementations of the MSaaS concepts that MSG-164 is working on.

Experimentation

As part of the work of MSG-156 an experiment is planned to partially implement and evaluate the service-based architecture for dynamic SEs. It will also serve as a demonstration to highlight the potential of correlated dynamic synthetic environments realized using a service-based architecture. The experiment infrastructure and setup is planned to be implemented over 3 iterations and be finished in May 2020, after which the experiment and demonstrations are scheduled to run.

Taking the requirements and four Use Cases described above, as input, a military simulation scenario has been developed to drive the experiment. It aims to cover a variety of types of federates involved (CGF, human-in-the-loop, ground and air platforms) and to support a range of dynamic effects and events within a small scenario scope (scenario duration and geographic area). The focus is on the role of dynamic weather in simulation scenarios and how it affects the terrain state, trafficability, visibility and sensor performance, as correlated dynamic weather effects offer huge potential benefits for distributed military simulations, e.g. increased realism, higher training value, more interesting scenarios.

Below follows a brief description of the scenario script:

A convoy consisting of armoured vehicles and supply trucks leaves early in the morning on a long trip to resupply an isolated Forward Operating Base. A large part of the trip involves traversing a difficult mountainous and densely vegetated terrain, as this is the most direct route to the FOB and avoids the main roads in the valley, which the convoy commander considers to be unsafe due to recent IED incidents and other insurgent activities.

During the morning the fair weather quickly deteriorates into heavy rain showers. Since most of the mountain roads are unpaved and not well maintained, these dirt roads become slippery, forcing the convoy to advance at reduced speed. The rain then changes into snow and with the decreased visibility, tricky roads and the trucks getting stuck in snow, the convoy commander has no choice than to leave the mountains and take a long detour through the valley, where the paved and well-maintained roads are less affected by the weather.

A manned aircraft is now launched from the main base to provide air support and route clearance for the convoy. Due to the weather and thick cloud coverage, visibility is low and sensor performance is degraded. Therefore, it is unable to detect an ambush by local insurgents in time.

An IED is triggered remotely in front of the lead vehicle. The armoured vehicle and its crew are unharmed, however one of the supply truck suffers mechanical damage, halting the convoy. Immediately after this, the convoy receives incoming mortar fire from a compound situated on hills nearby. The convoy commander requests assistance and a Quick Reaction Force (QRF) is tasked to link up with the convoy and provide force protection for the duration of the trip.

Meanwhile, the manned aircraft uses it IR sensors to quickly determine the origin of the fire and engages the opposing forces, thereby damaging the compound. The convoy is mostly undamaged, but large craters have been struck in the road surface and terrain, forcing the convoy to back up, and reroute off-road, again delaying the convoy's progress. The QRF is able to link up with the delayed convoy and no further incidents occur during its course through the valley.

Late in the day, the convoy starts crossing a bridge over a wide river. Meanwhile, using its Night VIsion Goggles (NVG) and Infra Red (IR) sensors, the aircraft is able to spot a large group of improvised tactical vehicles in pursuit of the convoy. Since the group poses a significant threat to the convoy and the aircraft is already low on fuel, the convoy commander requests and receives permission to have the aircraft destroy the bridge after the convoy has safely passed it, thereby halting the pursuit.

Finally, at midnight, the convoy reaches the FOB intact and begins unloading the much needed supplies.

The scenario will run in a region of Norway, as both the local terrain and the typical weather map well to the script. Based on geo-specific source data provided by the Norwegian government, a 40x40km terrain dataset will be served to all participating federates and services. Although the intention is to keep the SE as geo-specific as possible, a number of minor changes will be performed to the source road network to provide alignment with the scenario, e.g. changing the surfaces of mountain roads to unpaved to increase the detrimental effects of the weather on the road state.

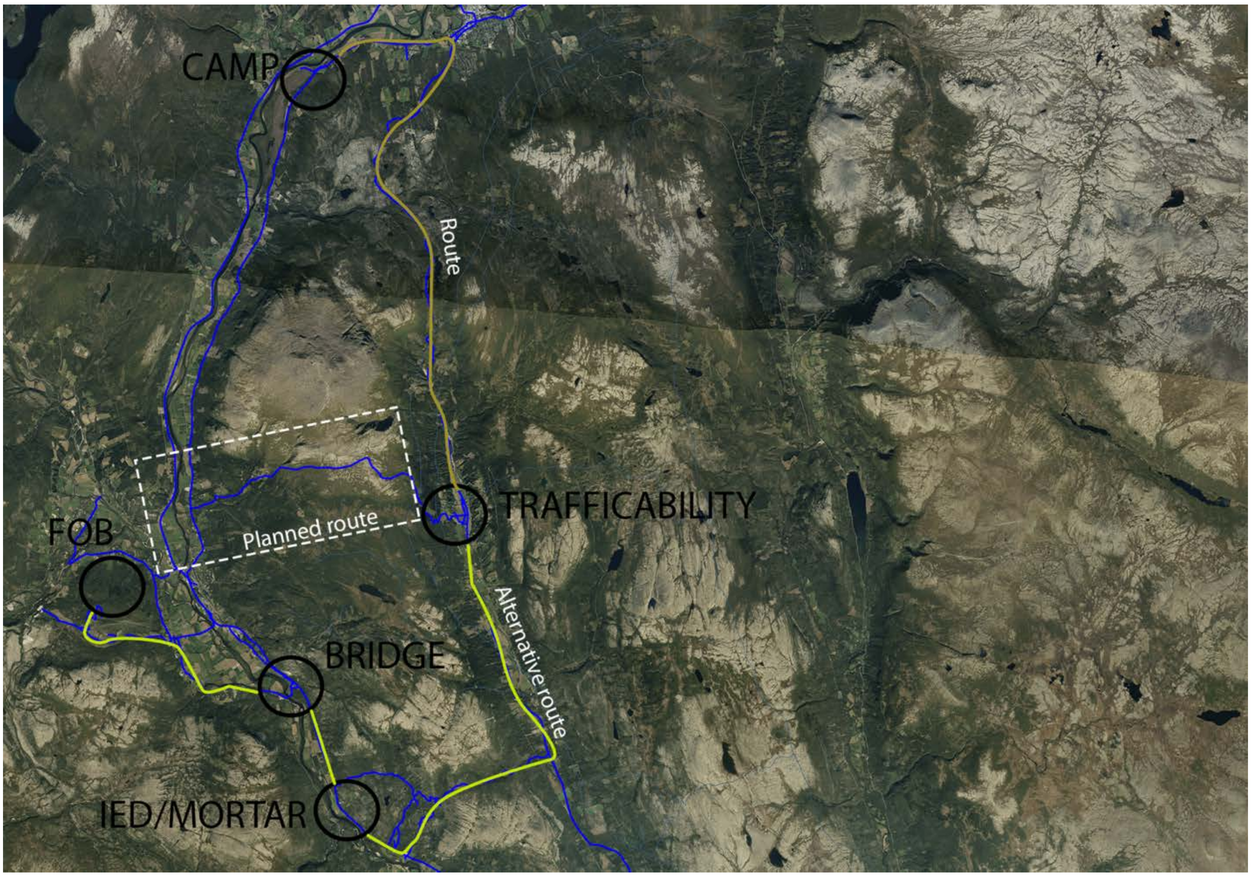

Figure 7: The route of the scenario projected on the geo specific area of Norway, including the convoy detour.

As part of the experiment, the architecture and interfaces described in Section 2 will be partially implemented. It will build upon a number of existing systems which will be provided by participating nations contribute and several newly developed assets. Specifically there hree types of assets have been identified:

- Data servers serve (dynamic) terrain and weather data layers using standard formats and protocols from the GIS community.
- Services respond to specific queries (e.g. routing) or events (e.g. weapon effects) and are accessible to all clients, thereby ensuring fair fight conditions and correlation.
- Simulations such as CGFs and human-in-the-loop systems act as clients that consume and interact with the dynamic SE data.

Within this distributed simulation, federate simulation entities will exchange data using HLA, while the state of terrain and feature data will be communicated using a combination of OGC web-standards and custom HLA FOMs (see Section 2.3).

Figure 8 shows the planned assets involved in the experiment. Note that each of the assets, even existing systems, will need to be modified to adhere to the interfaces of the proposed architecture and handle the messages and data regaring the dynamic state of the SE, i.e.

- Stealth: a 3D stealth viewer which will be used to get a visual overview of the events in the scenario and the dynamic effects that occur during its course;
- Lead vehicle: a human-in-the-loop desktop vehicle simulator that will be used to drive the convoy lead vehicle. The lead vehicle simulator will be used to have a human operator experience the effects of the dynamic changes to the road state and off-road trafficability due to the deteriorating weather conditions;
- CGF: a CGF tool will simulate the following vehicles in the convoy and all opposing forces. The CGF will be used to demonstrate how the dynamic changes in trafficability affect vehicle speeds;
- Fighter: a human-in-the-loop desktop fixed-wing simulator that will be used to provide air support for the convoy. The fighter simulator will be used to demonstrate the effects of dynamic weather on visual observations and sensor performance;
- Federate-terrain: a service that handles all dynamic effects on the SE originating from entities, for instance munition detonations impacting the terrain or an object such as a building or bridge. It is connected to the the HLA RTI to receive and process all relevant HLA interactions. For each received interaction, it requests the current local SE data and computes any changes in state (e.g. damage, deformation) and communicates any changes back to the terrain server;
- Trafficability: a service that computes upon request the local trafficability, given vehicle type(s) and a geographic location or route. For each request, it obtains the current local SE data (terrain surface state and road state), which might have changed by the Federate- and Weather-terrain services;
- Weather-terrain: a service that updates the SE state by simulating the effects of (dynamic) weather, in particular precipitation, on terrain and road surfaces (including infiltration and surface run-off). It receives changes in weather from the weather server, and updates the relevant SE data layers and communicates these back to the terrain server;
- Routing: a service that computes upon request the most efficient route to a given destination, taking into account the trafficability and road state;
- Atmosphere: a service that computes the additional attenuation that precipitation causes, based on the (dynamic) weather state. The resulting information can be used in a sensor model;

- Radar: a service that computes radar emissions and tracks based on HLA air and ground entities, and the information provided by the atmospheric effects service;
- Terrain service: stores the current state of all terrain layers of the SE (e.g. elevation, imagery, surface, vegetation, water bodies, infrastructure). Federates and interaction services can request layers, but also provide dynamic changes to layers. A notification mechanism informs all subscribers which data layers (and geographic bounds) have changed after each update;
- Weather service: stores the successive states of the dynamic weather during the scenario. Federates and interaction services can request weather data layers within a given geographic bound. A notification mechanism informs all subscribers when the weather state has changed.

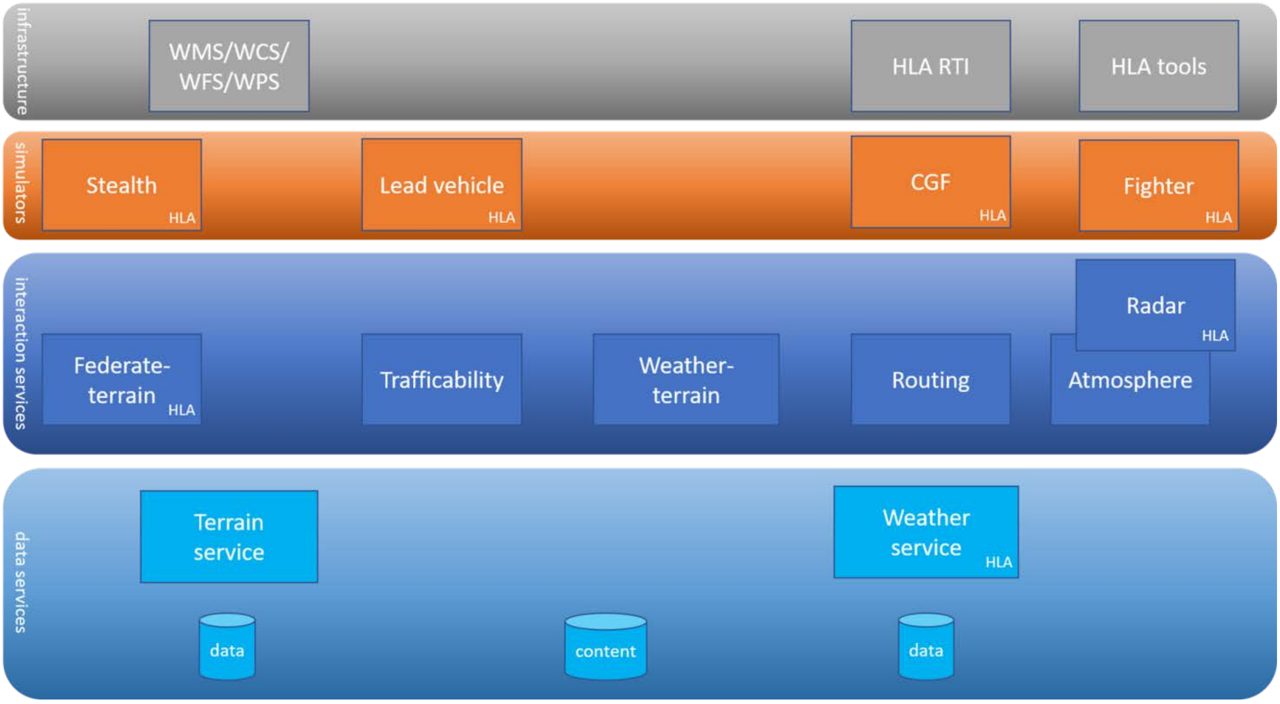

Figure 7: Overview of planned assets in the experiment

CONCLUSIONS

Discussion and Future work

The TG has just started preparing for the experimentation. The experiment will be performed in an incremental approach, where each increment will focus on specific services and interactions that are added. The aim of the experiment is to verify that the proposed solution approach works and to identify which areas of this approach need further work.

The lessons captured from the experimentation will be used by the TG to define recommendations on how future distributed simulation environments should be created so that a consistent, correlated and dynamic synthetic environment can be achieved among all participants. These recommendations will include:

- Advice on the M&S technologies and services that are needed to achieve a correlated representation of a dynamic SE.

- Advice on the best MTDS architecture that allows for the insertion of a dynamic SE.
- Identification of future standards and recommendations for the development of these.

The task group is planning to have this final report with recommendations ready by the end of 2020.

Summary

This paper first discussed the importance of have a realistic and correlated dynamic synthetic environment within future distributed simulation exercises, since a better representation of the dynamic conditions encountered in the real world will increase the value of such simulation environments. MSG-156 is studying how such a dynamic SE can be achieved. Using a number of concrete and compact Use Cases that require interactions within a dynamic SE, the TG will identify the requirements for such an environment and create conceptual modelling diagrams that illustrate how the various concepts that are involved are related to each other. Using this information an initial solution architecture has been created, which uses the MSaaS concept, to introduce terrain and weather information that can dynamically change during the running of the simulation.

Currently, MSG-156 is working on setting an experiment, where a number of assets from the participating countries are connected according to the solution architecture that has been created. With this experiment the taskgroup aims to check if the solution architecture is feasible and to derive more concrete requirements on the interfaces and standards used as well. In the MSG-156 final report these results will be used to inform recommendations on the architecture, methodologies, technologies and standards that are needed to achieve a dynamic correlated SE in the future.

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