

Architecture for a Distributed Integrated Test Bed

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ABSTRACT

M&S is used in the German Armed Forces for supporting processes in the following application areas:

- analysis and planning,
- procurement,
- missions, and
- training and exercises.

These four areas of application are closely connected to each other, especially in the context of

- supporting the method of *Concept Development and Experimentation (CD&E)*,
- support of networking and linking national and international simulations and information systems,
- the entailing support for the realization of *Network Centric Warfare (NCW)*.

Therefore, the further development of M&S towards interconnected systems by applying a *Distributed and Integrated Test Bed*¹ is indispensable to achieve the required capabilities and objectives.

Such a test bed can be used as an armament test bed for a fast and effective evaluation of technical and technological solutions in a realistic and operational test environment to support all phases of the development and procurement cycle of material and equipment as well as the other application areas of M&S.

¹ in German: *Verteilte Integrierte Erprobungslandschaft*, abbreviation: *VIntEL*

And such a test bed has to satisfy the demands concerning the acceptance of interconnected simulations as well as to meet the requirements resulting from the NCW idea of joint and combined missions by adapting to national and international standards.

In this paper, we summarize the results of a large combined study of the German government, industry and research institutes that addresses the architectural aspects for such a distributed integrated test bed and encompasses issues like ensuring fair fight conditions as well as the reproducibility and reliability of simulation results.

1.0 INTRODUCTION

The provisions for modeling and simulation (M&S) in the German Bundeswehr are outlined in the *Bundeswehr Concept (KdB)* and are described in more detail in the *Bundeswehr Modeling and Simulation Subconcept (TK M&SBw)*.

According to TK M&SBw, M&S is responsible in the Bundeswehr for supporting processes in these areas of application:

- analysis and planning,
- procurement,
- missions, and
- training and exercises.

As a part of the armament organization, the *Federal Office of Defense Technology and Procurement (BWB)* and its subordinate agencies have the task to guarantee that the Bundeswehr demand is met by supplying state-of-the-art technology and modern equipment at economic conditions. Therefore, the main task of the *BWB* concerning the *TK M&SBw* consists of equipping the Bundeswehr with simulation systems in all the above mentioned areas of application and of supporting the process of determination and satisfaction of demand according to *CPM*² by means of special models and simulation systems.

The four areas of application are closely connected to each other in content, especially in the context of

- supporting the method of *Concept Development and Experimentation (CD&E)*,
- support of networking and linking national and international simulation and information systems,
- the entailing support for the realization of the *Network Centric Warfare (NCW - NetOpFü)*.

The report by the *Directorate General of Armaments* on realizing the transformation process concretizes the framework conditions established in the *TK M&SBw* by demanding the creation of a common defense modeling and simulation test bed. Such a test bed can be used as an armament test bed for a fast and effective evaluation of technical and technological solutions in a realistic and operational test environment to support all phases of the development and procurement cycle of material and equipment. Therefore, the main activities in the field of R&D for common modeling and simulation were pooled in the *System Demonstrator VIntEL (SD VIntEL)* in early 2008.

When approaching the SD VIntEL, BWB tried to link as many activities in the field of modeling and simulation as possible (see figure 1). Therefore, it does not only consist of a project with the central aspects process model and establishment of a stable, technical architecture, but also of a project called

² *CPM: Costumer Product Management* (the procurement process of the *BWB*)

Agent Based Sensor Shooter Modeling (German short form: ABSEM) as a data farmable technical model, and the project Knowledge Management which shall assist developers and users to perform experiments. This paper deals mainly with the basic architecture of the SD VIntEL.

Such a test bed has to satisfy the demands concerning the acceptance of interconnected simulations as well as to meet the requirements resulting from the NCW idea of joint and combined missions by adapting it to national and international standards.

Due to the fact that such a test bed requires a high flexibility and that there is an increasing demand for analysis, the implementation of new technologies is absolutely necessary. Such new technologies may be *data farming* to analyze probabilities and the so-called *outliers* in simulation runs, or an *agent based simulation* to represent simulation participants with a certain degree of artificial intelligence.

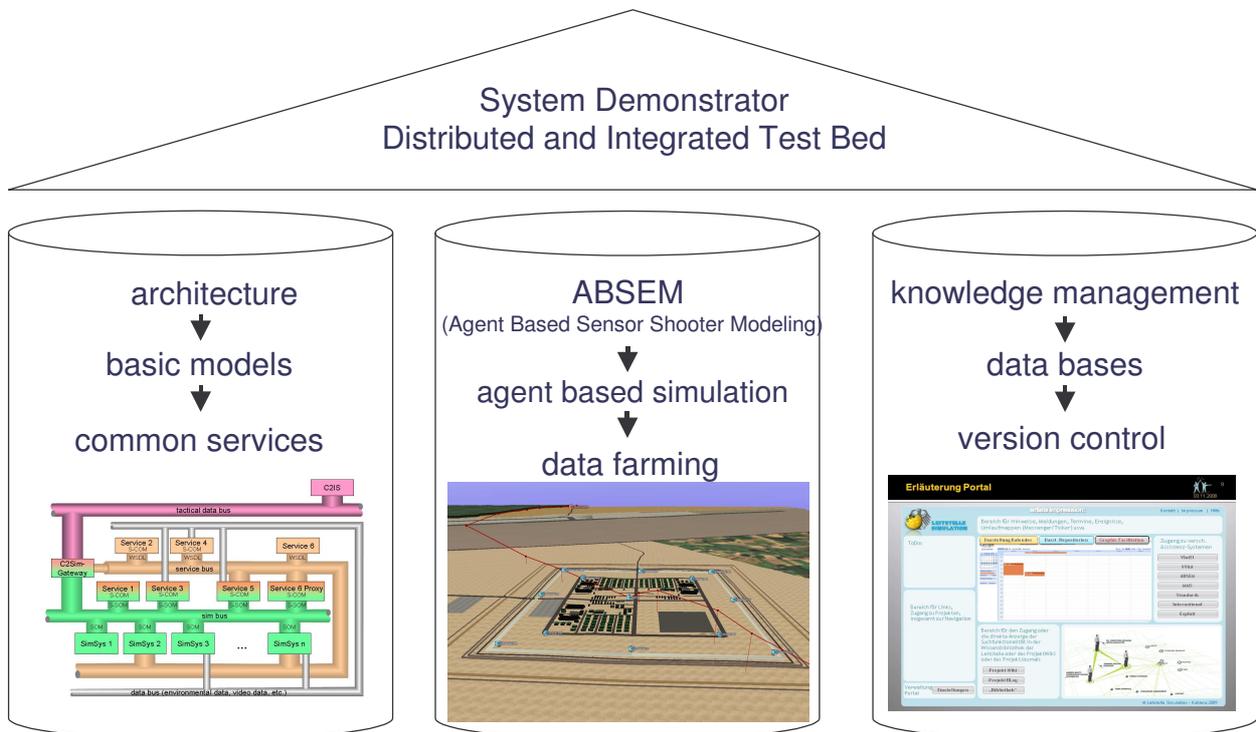


Figure 1: SD VIntEL

In this paper, we concentrate on the left pillar in figure 1: establishing an architecture for future projects where national and international simulation systems are linked together. The experience of the past shows quite clearly that the proper coupling of simulation systems beyond the technical level is not an easy task: reproducibility and reliability of the simulation results are still a severe challenge. Part of the problem is due to so-called unfair-fight effects, e.g. the different treatment of communication effects or weapon effects in different simulation systems. One solution can be the use of uniform procedures for these effects by all simulation systems. These procedures could be provided by specific services to all relevant systems.

2.0 REFERENCE ARCHITECTURE FOR THE TEST BED

2.1 General Requirements

The architecture for the test bed shall support any experiments coming from the above mentioned M&S areas of application. The following general requirements have been defined:

- reliability of the simulation results
- reusability of simulation systems, models and documentation

A reference architecture for a SD VIntEL test bed has to be deduced from these general requirements. This reference architecture describes only abstract component classes, service models, their interfaces and their relations, without any reference to a special experiment. Therefore, in the reference architecture, no specific simulation systems or services will be named, because simulation systems and services can vary from experiment to experiment.

For any specific experiment, an implementation architecture has to be deduced from the reference architecture. In this step, specific simulation systems, services and communication busses are selected, that are suited for the given task, and will be connected to each other, following the prescriptions of the reference architecture. Thereby, the abstract component classes of the reference architecture will be replaced by specific instances within the implementation architecture³. Component classes, which are not needed for a specific experiment, will be dropped completely.

Other general requirements for the reference architecture are:

1. performance
2. scalability
3. Components that are implemented in the programming languages C#, C++ or Java, can be joined to the architecture.
4. Components can be distributed spatially (using LAN and WAN connections).
5. There exists an error management:
 - a. errors will be categorized
 - b. errors will be logged
6. Operations can be conducted asynchronously.
7. Components shall have an interface for initialization data.

2.2 Special Requirements

The reference architecture shall foster a higher degree of reliability of simulation results by the use of dedicated special services. These services shall support fair-fight conditions between simulation systems. Therefore, parts of the internal logic of the simulation systems must be transferred to the commonly used services. In a first step, the following services will be implemented and tested:

1. *Geo-referenced Environment, Object and Infrastructure Service (GOIS)*
This service is responsible for the uniform delivery of environmental data of any kind.

³ For the current VIntEL experimentation, some services are already realized, e.g. a weapon effects service. These services will be reused and further developed in future test bed applications.

2. *Communication Effects Service (CES)*

This service is responsible for the uniform evaluation of communication effects. A client has to ask the CES, whether a radio connection exists between a given transmitter and receiver. Only if a connection exists, the receiver is allowed to interpret a radio signal.

3. *Weapons Effects Service (WES)*

This service is responsible for the uniform evaluation of effects of ammunition against targets. A target may be a platform or an element of the infrastructure, e.g. a building. Due to restricted availability of vulnerability data, only special combinations of firing weapon, ammunition used and target material can be considered by the high fidelity vulnerability model of the WES. Low fidelity models may be used, if detailed information is missing.

A service may not only be used by simulation systems, but may be called by other services as well (e.g. the GOIS might be called by WES or CES).

2.3 Proposed Architecture

In figure 2, the current proposal for the reference architecture is shown. The main elements of this architecture are simulation systems, services, interfaces to real systems, and busses. All components can be realized as independent processes, and can be freely distributed over LAN or WAN.

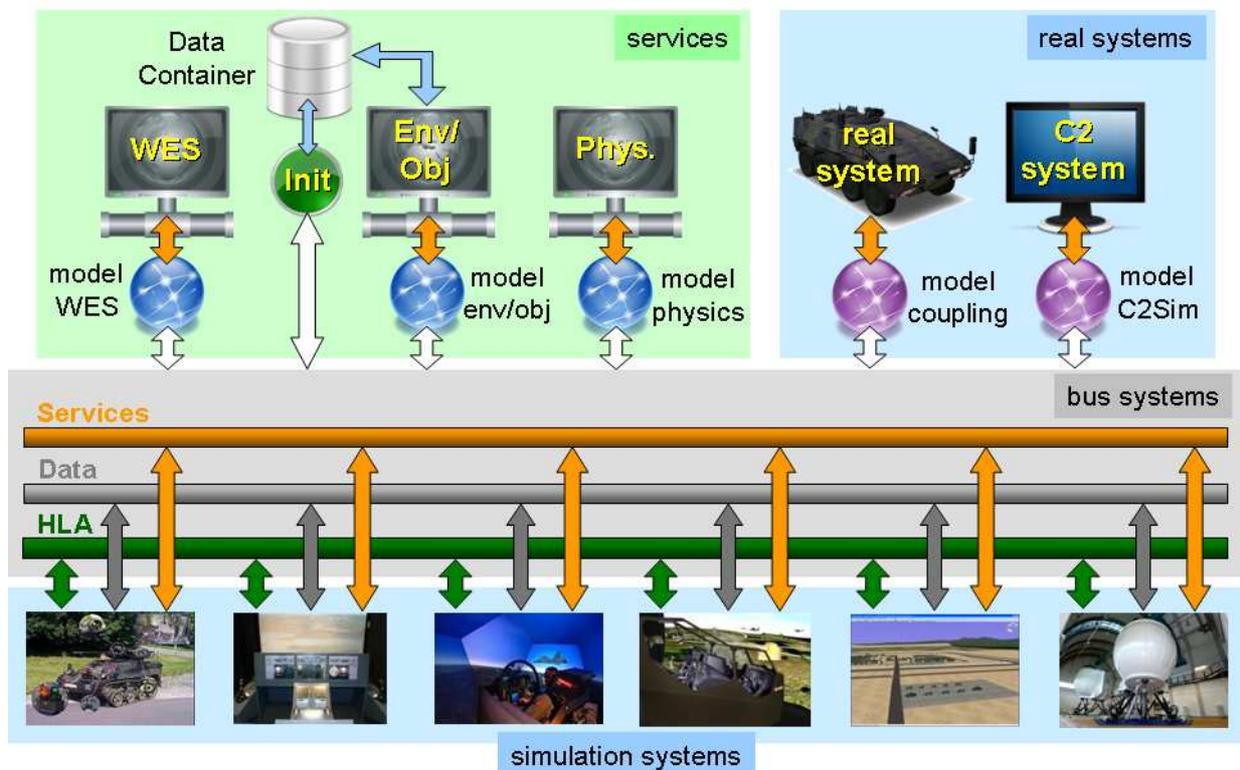


Figure 2: Proposed Reference Architecture

2.3.1 Simulation Systems

A simulation system maps a piece of reality onto a model. The details of the model depend heavily on the purpose and on the application area of the simulation system. Different simulation systems will therefore model the same part of reality differently. Consequently, this will usually lead to interoperability problems between the involved simulation systems, at least on the higher levels of interoperability (pragmatic, dynamic and conceptual). But experience shows that in general modifications or additions to the software of the simulation systems are necessary to accomplish the necessary interoperability.

2.3.2 Services

Here, a service is defined as a component that delivers a well-defined functionality to applications or other services, using a standard interface. The main purpose of services is to provide uniform solutions to all involved systems, e.g. a uniform treatment of weapon effects, and to reduce thereby unfair-fight effects as much as possible.

To get a clear understanding of the role of services in contrast to simulation systems, we categorize services under application aspects as well as under technical aspects:

2.3.2.1 *Application-dependent categorization of services*

We distinguish services according to the role they are fulfilling in the architecture. Up to now, we have identified the following three categories:

1. **Infrastructure services:**

These services do not influence the outcome of simulations. Examples are services for initialization purposes, for format conversion, or monitoring.

2. **Functional services:**

These services represent a specific piece of reality, and therefore do influence the outcome of simulations. Examples are services for the evaluation of weapon effects, or communication effects.

3. **Adapter services:**

These services link e.g. real systems to the simulation federation.

A clear separation between services and simulation systems is hardly possible, mainly, because some services are kind of simulations. This applies especially to the functional services.

2.3.2.2 *Technical categorization of services*

Another way to categorize services is according to the way how they are integrated into the test bed. Again, we find three categories:

1. **Federate:**

These services are connected directly to the simulation bus. This approach is most advantageous if the functionality of the service depends heavily on the object states or on interactions in the federation. It might be that the data exchange model⁴ of the federation has to be enlarged in order to use these services⁵. An example is a weapon effect service, which transmits a weapon effect via an interaction to the effected simulation objects.

⁴ A FOM in the case of HLA.

⁵ In the current VIntEL experimentation, we use a *VIntEL FOM*, which is an extension of the *RPR FOM 2.0 D17*.

Simulation systems can use the established interface to the simulation bus in order to use these services. But it might be that they have to be adapted to an extended data exchange model.

2. **Web-service:**

These services do not use the simulation bus but a dedicated service bus or data bus. This approach might be useful if legacy simulation systems shall use a service, but there is no way to modify their simulation interface (e.g. a training simulation using DIS). Adaptations to these systems can then be limited to the interface to the service bus.

3. **Use of service-proxy:**

It is possible to implement a service not as a simulation (with a direct connection to the simulation bus), but to use a service-proxy for the connection between simulation bus and service. The advantage of this approach is that the simulations can still use their well-established interface to the simulation bus. An example is the connection of a real system without a simulation interface like HLA or DIS to a simulation bus.

In any case, a *Service Canonical Object Model (S-COM)* has to be defined for each service. The S-COM is the data exchange model of the service and should be kept independently from the specific implementation of the service.

According to this definition of S-COM, the S-COM must be mapped onto the used exchange model. If the service is realized as a federate, the S-COM will be mapped onto a *Service Simulation Object Model (S-SOM)*, if the service is realized as a web-service, the S-COM will be mapped onto a WSDL-specification. Regardless of the technical category the service belongs to, the same semantics should be modeled in the same way, e.g. the semantic expressions describing geometrical abstractions like points should be modeled in the same way, regardless whether an HLA-SOM or a WSDL-interface is used.

2.2.3 **Busses**

Several busses are used for connecting the components of the reference architecture:

- a simulation bus for connecting the simulation systems,
- a service bus for connecting service providers and clients,
- a data bus for the transmittal of geo-referenced images or other voluminous data,
- one or more tactical busses for the coupling with C2-systems, e.g. via MIP or Link.

If needed, more busses would be possible (e.g. voice communication for controlling experiments).

As far as possible, international standards are used for all busses.

2.4 **Process Model**

To make sure that the reference architecture for test beds is applied properly in specific applications, the process model VEVA⁶ was set up. VEVA borrows heavily from the FEDEP (and its proposed successor, DSEEP) and from similar activities in other working groups, e.g. MSG-052.

⁶ VEVA = *Vorgehensmodell für den Einsatz der VIntEL-Architektur* = *Process Model for the Application of the VIntEL Architecture*

3.0 VERIFICATION OF THE ARCHITECTURE

To prove the applicability of the proposed reference architecture, a series of experiments was conducted. In these experiments, the following components were used (see figure 3 and 4 for examples):

1. simulation systems:
 - a. constructive simulations ABSEM (EADS) and PABST (IABG)
 - b. virtual vehicle simulations GeneSys and GenPlatSim (both IABG)
 - c. virtual target simulation dome at WTD 81 in Greeding
2. services:
 - a. geo-referenced environment service GOIS (IABG)
 - b. communication effects service KESS (Thales)
 - c. weapons effects service WES (IABG)
 - d. *GEPARD*-proxy (gateway between anti-air tank *GEPARD* and HLA)
 - e. Recce-proxy (gateway between reconnaissance systems and HLA)
 - f. C2SimProxy (gateway between MIP DEM and HLA)
3. busses:
 - a. simulation bus: HLA with MÄK RTI v3.x or PITCH pRTI v3.x and VIntEL FOM
 - b. service bus: HTTP / SOAP
 - c. data bus: XML over TCP/IP for synthetic environment data and STANAG 4609 for video data
 - d. tactical bus: MIP DEM
4. real systems:
 - a. anti-air tank: *GEPARD* (German anti-air tank)
 - b. reconnaissance system: AMFIS (evaluation of UAV data)
 - c. C2-system: FIS-H (C2-system of the German Army)

Three experiments were devoted to the use of services to reduce unfair-fight effects (use of a weapon effects service, a communication effects service, or a geo-referenced data service). In a further experiment, several real systems were linked with simulation systems and services.

The main findings of these experiments are described in the following sections.

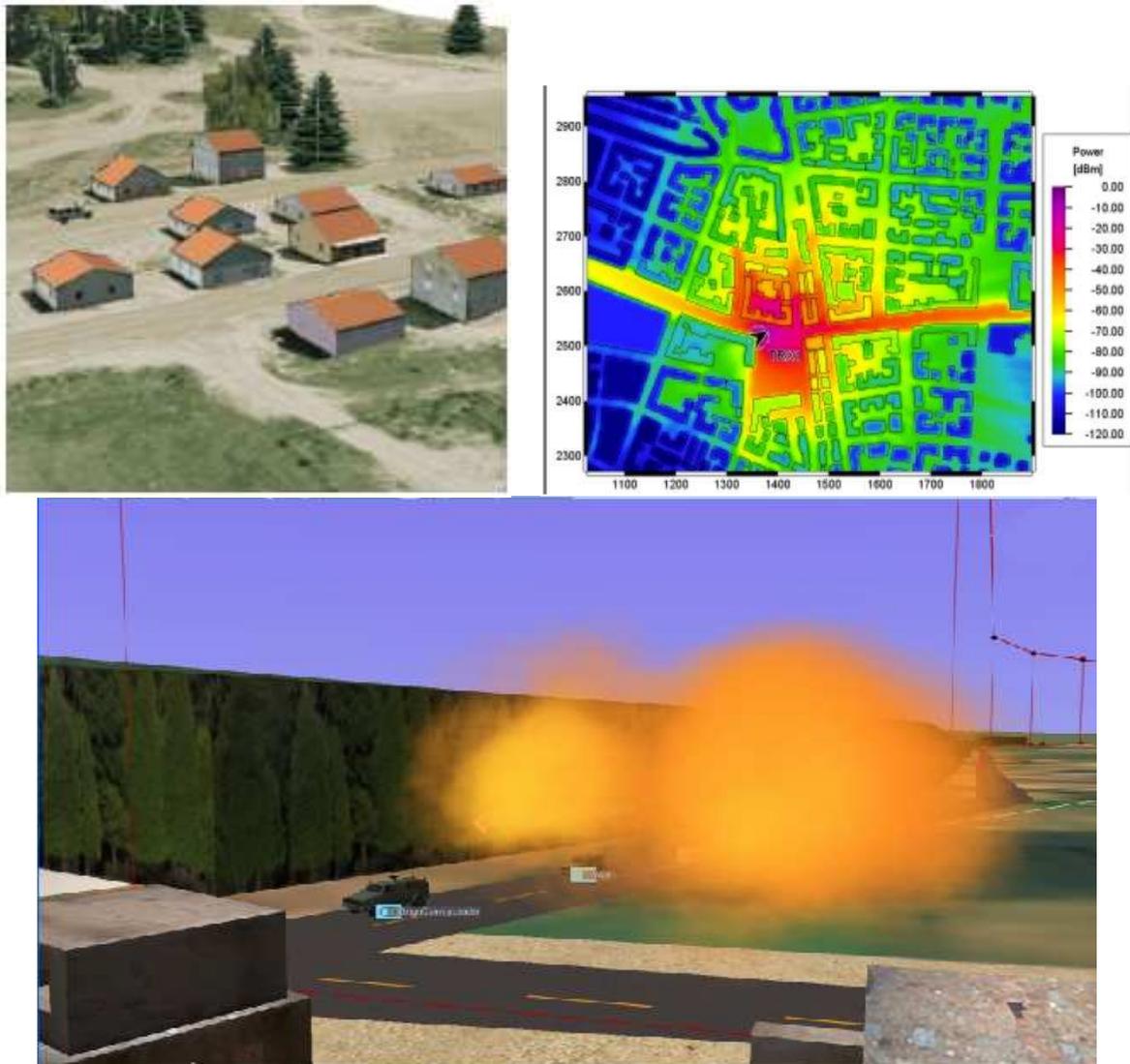


Figure 3: Screenshots of the services GOIS (top left), KESS (top right) and WES (bottom)



Figure 4: Real system AAT *GEPARD* (left) and virtual target simulation dome in Greiding (right)

3.1 Use of Weapon Effects Service (WES)

The Weapon Effects Service (WES) is used to deliver uniform weapon effects to all involved systems, concerning effects against platforms and infrastructure, e.g. buildings. For this experiment, the constructive simulations ABSEM and PABST and the virtual simulations GeneSys and GenPlatSim were used. The following results were obtained:

1. It could be established that the WES, triggered by an interaction *MunitionDetonation*, evaluates the damage effects of platforms and communicates the results into the federation via a new interaction *WeaponEffect*.
2. The simulation systems could deactivate their internal evaluation of damage effects, and deduce the damage effects of their own entities from the interaction *WeaponEffect*.
3. It turned out that the granularity of damage effects in the interaction *WeaponEffect* is very coarse. In the future, a more detailed description of damage effects will be introduced.

3.2 Use of Communication Effects Service (CES)

The Communication Effects Service (CES) is used to deliver uniform communication effects to all involved systems. For this experiment, the constructive simulations ABSEM and PABST and the virtual simulation GenPlatSim were used. The following results were obtained:

1. It could be established that the CES determines the probability of a radio connection, depending on the exact positions of sender and receiver.
2. Fair-fight conditions could be improved by applying the CES to the communication between both, blue and red platforms, modeled by different simulation systems.
3. Fair-fight has to be improved in the future by applying the CES also to the communication that is modeled internally in a simulation system.

3.3 Use of Geo-referenced Environment, Object and Infrastructure Service (GOIS)

The Geo-referenced Environment, Object and Infrastructure Service (GOIS) is used to deliver uniform information about the environment to all involved systems. The GOIS serves two use cases: *initialization* and *dynamic change*. In the use case *initialization*, an application can query the initial state of all buildings in an area of interest, before starting a simulation run (*pull*). In the use case *dynamic change*, the GOIS will inform applications about changes of buildings that occur during the simulation (*push*).

For this experiment, the virtual simulations GeneSys and GenPlatSim were used. The following results were obtained:

1. GOIS is able to manage buildings and their damage state, and can provide the relevant information to a client either after a *pull* or by a *push*.
2. The damage of buildings after a *MunitionDetonation* was determined in close collaboration with the WES: environmental data were sent from the GOIS to WES, modified by the WES, and sent back to GOIS. In this way, damages of buildings can be cumulated.

3.4 Coupling of simulation systems with real systems

In this experiment, several real systems were put into a synthetic environment:

1. a real anti-air tank *GEPARD*, joined into the HLA-federation via a special proxy service,
2. the reconnaissance system AMFIS for the evaluation of UAV data, joined to HLA via a Recce-proxy.
3. the C2-system FIS-H, joined into the HLA-federation via a C2SimProxy.

The synthetic environment was simulated by the constructive simulation ABSEM, the virtual platform simulation GeneSys and the *target simulation dome*. The connection between the real systems and the synthetic environment is established by several gateways: the *GEPARD*-proxy, the Recce-proxy, and the C2SimProxy (see figure 5).

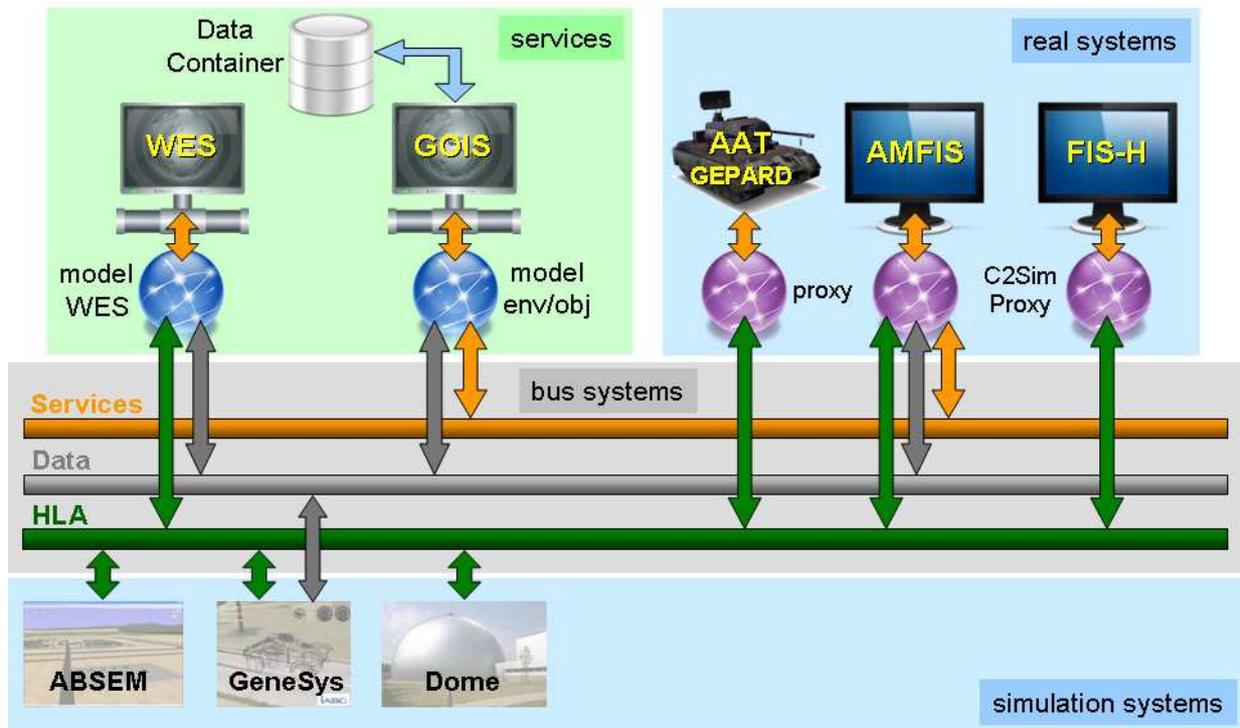


Figure 5: Implementation of the architecture (here: coupling of simulation systems with real systems)

The systems were distributed over five locations in Germany and connected via a WAN.

An important observation during this experiment was that long latency times in the WAN corrupted the experimental results, e.g. position and detonation information were delayed in such a way that fair-fight conditions could not be guaranteed anymore by the WES. Possible solutions have to be examined in the future: stringent evaluation of time tags, or strict use of time management.

The process model VEVA was tested the first time in this experiment. The results showed that VEVA is very useful for organizing the experimental activities. Two conclusions from this first experience with VEVA are that more steps are needed at some points of the workflow, and that more details should be defined, concerning the documentation and other artifacts, which have to be produced during the single steps.

3.5 Summary of the experiments

In summary, the following results were obtained:

1. All experiments were based on the proposed reference architecture.
2. The models of WES, GOIS and CES can be used as starting points for the development of corresponding S-COMs. In addition, an S-SOM can be defined for WES, and a WSDL for CES.
3. For each experiment, an implementation architecture, and a *Federation Agreements Document* were established. For all experiments, the VIntEL FOM was used (cp. footnote 5). The services KESS und WES and the simulation systems GeneSys, GenPlatSim and PABST were adapted to these specifications.
4. All functional services and time management were used successfully.

4.0 CONCLUSIONS

A reference architecture for the distributed integrated test bed *SD VIntEL* was established. Special emphasis is set on the use of services which provide uniform functionality to other components and shall be used by all simulation systems instead of their own internal logic to reduce the effects of unfair-fight. Different bus systems were introduced to logically and physically separate the predominant communication standards for C2 systems, distributed simulations, services, real systems, and other applications. Proxies were used to establish information exchange between different busses. This reference architecture was able to support all verification experiments.

Several experiments were conducted. For each experiment a specific implementation architecture was derived from the reference architecture. Several constructive and virtual simulation systems were adapted to the use of services, thus reducing unfair fight, e.g. in the cases of weapon effects and communication effects. The services could be reused across the various experiments.

As expected, it turned out that the use of services for the reduction of unfair-fight effects is not for free – the adaptation of simulation systems has to be taken into account. But it was established that is it very useful for the implementation of specific experiments to re-use not only simulation systems and services, but the architecture as well.

5.0 FUTURE ACTIVITIES

The final presentation of the VIntEL program is scheduled for 2013. Right now, the reference architecture is evaluated further by preparing and conducting more extensive experiments. The process model VEVA will be elaborated. One of the most important aspects of future activities will be a more detailed exploration of fair-fight problems.

Considering the conditions and provisions described, the future Bundeswehr M&S landscape might present itself as follows:

The simulation of tasks taken from the four areas of application is realized in test beds, in which the necessary basics, e.g. object and environmental data but also missions and framework conditions are deposited in data containers subject to revision control. They are complemented by an initialization service which deposits the start-up parameters of the simulators involved. These measures are essential for reproducibility and reusability.

All simulators involved in the test bed are limited to their core tasks, also in non-network operation, i.e. they simulate only what is not represented through common services. Thus, a large number of fair-fight problems can be resolved and costs can be saved. Furthermore, these test beds should be subjected to a VV&A process (*Verification, Validation, and Accreditation*) and be accompanied by a model management system.

All test beds are based on the *Bundeswehr Simulation and Testing Environment (SuTBw)*, which provides the technical foundations. In addition to the requirements for a test bed interoperability, SuTBw also defines the procurement standards for future simulations of the Bundeswehr, which are subjected to a pre-analysis that is supported by an agent-based simulation capable of data farming.

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This paper is dedicated to Dr. Hans-Peter Menzler, who initiated a lot of concepts which are now included in the architecture of *SD VIntEL*.

