Model-based Interoperability Solutions for the Supervision of Smart Gas Distribution Networks

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***Abstract*—Supervision systems for smart gas distribution networks are heterogeneous environments consisting of various types of systems. One of the key challenges is the exchange and the aggregation of data between such components. Although these systems of systems use standards to achieve a significant level of interoperability, centralized standard-based solutions do no fully address existing industrial issues. Based on the experience and developments realized in an industrial-academic French national project, this article proposes the use of model-based engineering principles to support interoperability between systems in order to achieve supervision goals. The proposed SmartHub, which distinguishes between configuration and operating data exchanges, is described through its application on two real-word industrial scenarios.**

Keywords— smart environment; smart gas; interoperability; data aggregation; model-based engineering;

I. Introduction

Distributed systems are widely spread in many industrial/enterprise environments. In a given context, different systems (hardware and/or software) may coexist and bring to the environment their own set of capabilities: sensors, actuators, data analyzers, data repositories, visualization, etc. The supervision and integration of these systems to achieve common goals leads to large complex systems often called Systems of Systems SoS [1]. These SoS include emerging smart environments such as smart grids, smart gas, smart cities, etc. [2, 3]. A number of challenges arise from the heterogeneity of such systems which need to manage different platforms, standards, semantics and communication mechanisms. This includes behavior, semantic and syntactic interoperability issues [4].

This work takes place in a French national project[1] for the real-time management of a smart gas distribution network. One of the main project's objectives is the development and integration of additional systems in the current supervision platform. In particular, gas quantity/quality sensors need to be associated to decision-making processes in order to drive the injection of "green gas" into the distribution network. The current architecture, mainly based on the use of a single standard (OPCUA [5]), requires many ad hoc developments whenever new systems have to be integrated. Therefore the objective of this work is to develop and study the viability of a modern interoperability framework, based on modeling principles, in order to ease the integration of new components and operational requirements. The envisioned solution, still in the early phases of development, is sketched through its application on two industrial scenarios.

This paper is structured as follows: section II introduces the context of the Gontrand project and the various systems that currently constitute the smart gas environment. A brief introduction to modeling techniques is also presented. In section III, we first present the foundations of our model-based hub and describe its application on two industrial scenarios from the project. Section IV discusses some related work, and finally section V concludes with some insights on ongoing and future work.

II. Context

In the coming years, the injection of "green gas" in the national gas distribution network will have a great influence on its supervision and management. One of the objectives of the Gontrand project is to manage in real-time the quantity and the quality of gas at each injection point of the gas network. To fulfill this objective, various components are to be developed and integrated: an intelligent gas analyzer, a machine-to-machine platform, a decision-making process, a global supervision system, etc. This project is conducted by GDF SUEZ and a consortium of 9 industrial and academic partners in the fields of engineering (gas analyzing), telecom (communications), and computer science (software engineering, supervision, and assisted decision-making). In this article, we will focus on the interoperable integration platform.

The current GDF architecture uses Supervisory Control and Data Acquisition (SCADA) [6] systems. SCADA systems are widely used to monitor and control remote equipment. It includes the full chain from the equipment control module to the acquisition server and up to the human machine interface (HMI). The acquisition server aggregates the data from various devices and passes commands to this equipment. A HMI is directly connected to this server to monitor and command the equipment. However, for business and equipment reasons, various SCADA systems may coexist in a given environment.

[1] Gontrand FUI project: www.advancity.eu/info-fui-17

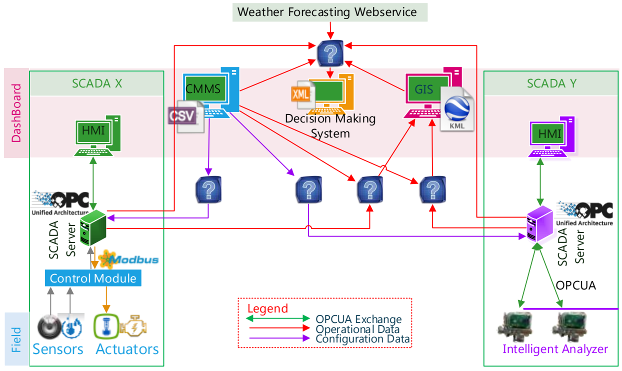

Fig. 1. Example deployment for the supervision system of a smart gas distribution network

One of the viable technical solutions for implementing SCADA is the OPC Unified Architecture (OPCUA) industry standard. It provides a wide range of capabilities and is often seen as a potential solution in the industrial evolution (Industry 4.0 [7]), Internet of thing (IOT) and smart environments [8]. OPCUA defines communication mechanisms and abstract information models that allow domain-specific data models creation. Using OPCUA, the acquisition server needs to be configured whenever new equipment is added to its pool.

Additionally, a number of other systems take part in the environment such as Geographic Information Systems (GIS), Computerized Maintenance Management Systems (CMMS), weather forecasters, computer-assisted decision-making systems, and others. A central dashboard room must be able to supervise these various components.

Figure 1 illustrates an example of such a deployed environment. All of these systems may need to contribute and receive data in order to achieve global operational goals, and these components do not usually share the same communication and format standards for data exchange. Here are some examples of such scenarios:

- A new equipment is added in the field. This information may be provided by the CMMS component in a CSV file. The corresponding acquisition server must be reconfigured using the OPCUA standard.
- An alarm is generated by the SCADA indicating a problem with an equipment. Using the localization information from the CMMS, an indicator is to be displayed on the map provided by the GIS component.
- A simulation must be run on the gas network in order to evaluate the viability of green gas injection at some point. This requires the aggregation of various data sources: network topology (GIS and/or CMMS), weather conditions (weather forecaster), and current distribution status (SCADA components).
- An assisted decision-making process requires the visualization of global indicators from aggregated data.

These scenarios allow for a first important level distinction between data exchanges. On the one hand configuration data is to be shared whenever the system integrates new components. On the other hand operating data is exchanged at runtime for the achievement of global supervision objectives.

Based on our industrial partners feedback, our first evaluation shows that these issues are currently handled using *ad hoc* developments centralized in the SCADA dashboard component (acting as the question marks on Figure 1). These solutions, which involve numerous human manual interventions, are time-consuming, error-prone, and lack both flexibility and generality.

III. Related Work

Interoperability is an essential requirement for smart environments since it guarantees correct integration of systems and assets [9]. Several workgroups and organization steer their efforts towards solving this issue of interoperability using a layered architectural approach such as the GridWise Architectural Council [10] or the Smart Grid Architecture Model [3].

Within these architectures, domain-specific standards have been proposed at the syntactic and semantic layers to guarantee information interoperability. For instance, for the electricity domain, the Common Information Model (IEC 61970, 61968 and 62325) [11] defines components of the electrical power systems and their relationships. In the oil and gas industry several standards coexist, such as ISA-95 [12], B2MML (Business to Manufacturing Markup Language), MIMOSA [13], ISO-15926 [14], or PRODML [15]. OPCUA [5] is a generic standard for data integration platforms. Work has been done the electricity domain for the mapping of CIM to OPCUA [16]. However studies [17] show the limitations of these standards for smart gas networks. [17] also proposed the use of a model-based integration framework using PRODMML as the central metamodel. In contrast to these unification approaches, in our work, we seek federated interoperability solutions which do not impose the use of a centralized unified domain-specific standard. Model-based engineering (MBE) [18], which naturally promotes separation of concerns, could support such a federated approach.

In MBE, everything is a model. The OMG proposes a 3-layer architecture [19] . Its main principles are illustrated in Figure 2. Models are described through modeling languages (metamodels), themselves described by an auto-descriptive

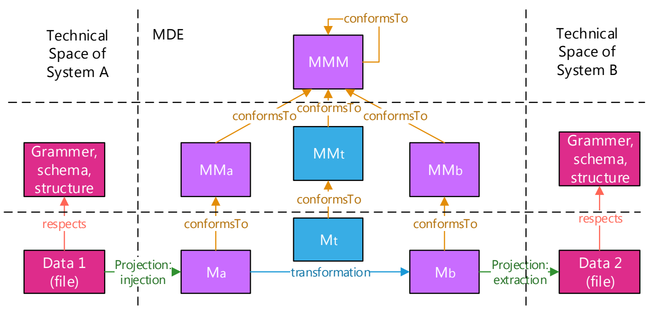

Fig. 2. Model Driven Engineering main concepts

meta-language (the metametamodel). Model operations, such as rule-based model transformations, allow for various types of model manipulations. Interoperability between systems is achieved through projections between specific technical spaces and the chosen modeling environment. MBE has been shown effective to handle semantic and syntactic interoperability between various standards and languages.

In the following, considering the specific scenarios and issues of our smart gas environment, we propose to study solutions, based on model-based engineering principles, to ease data exchange at both configuration and operating levels while preserving the decentralized nature of the global system.

IV. A Model-based Hub for Data Exchange

In this section, we sketch a solution based on modeling principles to realize a flexible mediator, dubbed "SmartHub", able to realize the various data exchanges required in our smart gas environment. We then describe its application on two industrial scenarios.

We have defined a number of features desirable for such a component:

- It must be able to aggregate data originating from various sources which use different communication and data format standards. Symmetrically, it must be able to produce and communicate data for various components.
- It must be able to work at both the configuration and operating levels.
- It should not be a centralized mandatory component, i.e., it should not prevent direct communication between components when this is already possible.
- It should ease the integration of new components through a flexible interface definition

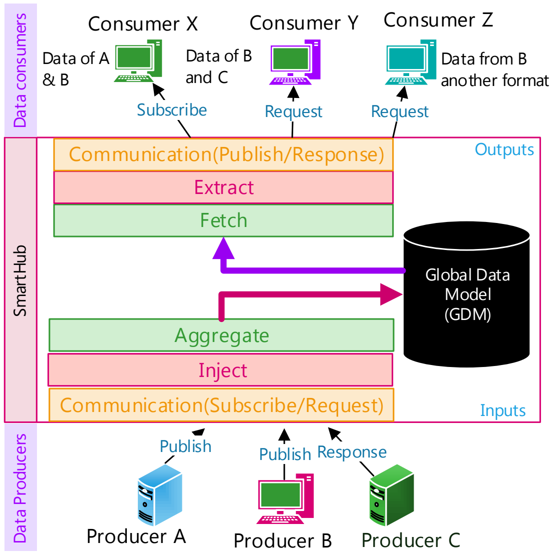

Fig. 3. SmartHub main principles

Fig. 4. Exchange of configuration data between CMMS and SCADA

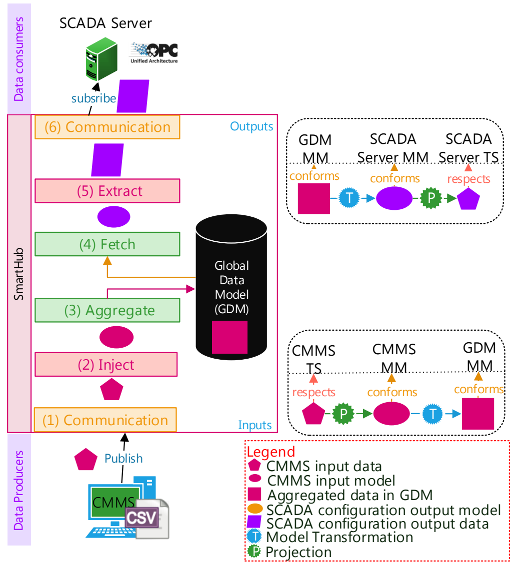

Fig. 5. Configuring SCADA servers with equipment information

A. *SmartHub main principles*

Figure 3 illustrates the main principles that constitute the SmartHub:

- An adaptable layer manages various communication protocols in order to connect to the different systems. It currently supports various subscribe/request and publish/response standards.
- An extensible layer, based on a repository of supported data formats and syntactic/semantic rules, handles the projection of data between components technical spaces and the modelling environment.
- A global data model (GDM) allows the aggregation and fetching of specific data through a set of operational rules. Although the description and evaluation of this GDM is out of scope of the paper, it can be noted that it relies on an inner distinction between configuration data (meta-data, system components, etc.) and operating data. Although its generalization is considered, it is currently specific to the studied smart gas environments.

In the following, we describe its application on a configuration data exchange scenario and an operating data exchange scenario.

B. *Configuring SCADA servers with equipment information*

In this scenario, roughly sketched in Figure 4, the maintenance system (CMMS) holds the equipment information required to configure the OPCUA SCADA servers. Following the principles described in the previous subsection, a number of operations, illustrated in Figure 5, are performed by the SmartHub:

1. The CMMS sends the new configuration data (here, a CSV file) through a simple request/response mechanism.

2. The SmartHub looks into its projection repository to inject the data as a model.

3. The SmartHub applies the (predefined) operational rules to aggregate the data into the GDM.

4. Fetching rules are applied to obtain the data required by the target components from the GDM.

5. For each target component, considering its data format and the projection repository, a corresponding data file is extracted. In our case, a set of OPCUA files are generated. Although it is out of scope of this paper to describe it fully, it should be noted that OPCUA particular semantics require a complex chain of model operations.

6. Finally, this data is exchanged through the corresponding communication mechanism (here a simple publish/subscribe standard).

C. *Displaying alarms from a SCADA server on a GIS*

In this scenario, roughly sketched in Figure 6, runtime data must be aggregated from both an OPCUA SCADA server and a CMMS component and then delivered to a GIS component. Following the same modeling principles, a number of operations, illustrated in Figure 7, are performed by the SmartHub:

1. The SCADA server raises an OPCUA alarm obtained through a publish/subscribe mechanism.

2. Using the projection repository, the alarm data is injected into the modeling environment. The GDM might already have the localization data required for the GIS system from a previous configuration data exchange. If not, the SmartHub may request additional localization information from the CMMS, which is then also injected into the modeling environment.

3. According to the operational rules, (both) data is aggregated into the GDM.

4. Fetching rules allow the production of a model containing the necessary target data.

5. Thanks to the projection repository, the data is formatted according to the target component requirements (here a KML file).

6. Finally, data is sent to the GIS through publish/subscribe.

D. *Architecture Implementation*

In this work, we have chosen the Eclipse Modeling Framework (EMF) [20] to support the implementation of the SmartHub solution. EMF supports model and data interchange via the XML Metadata Interchange (XMI) format. Metamodels are defined using the ECORE language. Projections have been realized using a combination of the Acceleo tool [21] and EMF's built-in XSD/XML support. The aggregation and fetching rules have been implemented using a combination of the rule-based ATL tool [22] and direct java manipulation. Indeed, our persisting framework requires incremental capabilities that are hardly handled by current transformation tools [23]. Finally, communications are supported through specific Eclipse plugins. Evaluation and selection of the various available tools with regard to our whole set of industrial scenarios is under investigation.

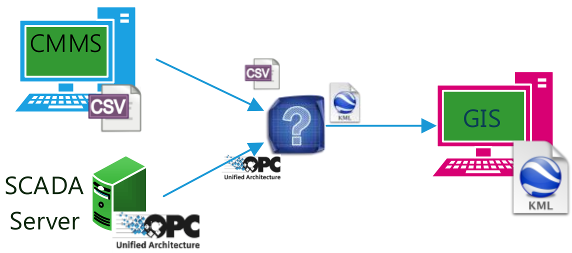

Fig. 6. Displaying alarm on GIS

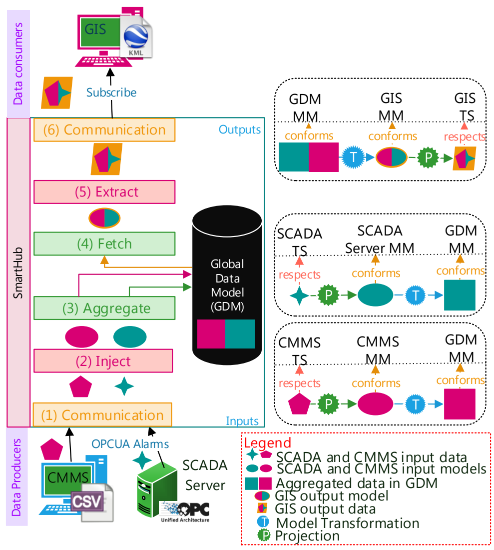

Fig. 7. Displaying an alarm from SCADA on the GIS

V. Conclusion and Future Work

In this paper, we have studied interoperability solutions between heterogeneous systems for an existing industrial smart gas environment. In particular, in a bottom-up approach, we have exhibited various scenarios in which we distinguish between configuration and operating data exchange levels. Rather than relying on a unifed standard, we suggested a federated model-based software engineering solution able to handle various standards, presented its main principles, and described its application on two industrial scenarios.

The proposed SmartHub is still in its early phases of development. A number of theoretical and practical issues have arised which are subject to ongoing and future work. At the modeling level, we currently investigate the generality of our global data model. Indeed, our experience shows that though many concepts are independent from the application domain, some specifics still need to be considered. We currently use a two-level (configuration/operating) generic metamodel which is extended with smart gas networks considerations. We plan to fully describe and formalize this modeling architecture. At the implementation level, the smartHub requires model operations with advanced features such as incrementality and synchronization mechanisms. We thus wish to study the viability of existing tools to replace some of our *ad hoc* developments. Finally, a number of operational issues (hub data persistence and historization, generality of aggregation/fetching rules, performance) are still under investigation.

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