Komplexitätsbewältigung verteilter Smart City Systeme durch Model Driven Engineering Konzepte
Addressing the Complexity of Distributed Smart City Systems by Utilization of Model Driven Engineering Concepts

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Kurzfassung

Model Driven Engineering basierend auf dem europäischen Smart Grid Architecture Model (SGAM) hat sich als ein Best-Practice-Ansatz zur Realisierung komplexer Smart Grid Projekte erwiesen. In diesem Beitrag wird eine Erweiterung dieses Ansatz für Smart City Systeme vorgeschlagen. Es wird dargelegt, dass durch die Komplexität der beteiligten Domänen, jede Anwendungsdomäne in einem individuellen Application Domain Cube (ADC) dargestellt werden sollte. Diese ADC sind in ihrer Struktur dem SGAM sehr ähnlich, besitzen jedoch domänenspezifische Dimensionen. Es wird ein Mechanismus hinzugefügt, der es ermöglicht Zusammenhänge zwischen den Anwendungsdomänen in Smart Cities zu adressieren. Der hier entwickelte Ansatz wird durch ein Beispiel, welches verschiedene Domänen abdeckt, veranschaulicht.

Abstract

Model Driven Engineering based on the European Smart Grid Architecture Model (SGAM) has proven to be a best-practice approach in realizing complex Smart Grid projects. In this paper, an extension of this approach towards Smart City Systems is proposed. It is argued that with the complexity of the involved domains, each application domain should be represented in an individual Application Domain Cube (ADC), similar in structure to the SGAM, but with dimensions applicable to the domain. A mechanism is added to address interrelations between application domains in Smart Cities. The proposed approach is illustrated by an example covering different domains.

1 Introduction

The term “Smart City” describes the intelligent cooperation of numerous, typically distributed systems and participants in order to serve a certain purpose. Hereby, the “certain purpose” can be related to different *application domains*, such as energy supply, traffic or public health.

Due to the nature of these systems, their development, operation and maintenance are very complex tasks and involve numerous stakeholders from different disciplines and domains. In respect to the involved domains, like, e.g., public energy supply, these systems are part of a critical infrastructure and hence, besides the operational complexity, these systems have to fulfil strict quality requirements like reliability, availability, maintainability, safety and security. These requirements are subsumed under the term RAMSS.

As the nature of a Smart City invokes the involvement of the inhabitants of a city, the requirement of privacy arises. As this is a critical aspect for acceptance, privacy needs to be treated “by design”, similar to the P-RAMSS requirements, as discussed in [5].

Following these considerations, the realization of Smart Cities requires the development of systems with a certain level of robustness and the need for new concepts and methods arises. These concepts, on the one hand, have to support the engineering along the whole development process and, on the other hand, have to deliver a basis that allows the validation and verification according to certain Key Performance Indicators (KPI). Moreover, a holistic view over different application domains is necessary.

In the field of Smart Grids similar challenges exist. As pointed out in [2], the concepts of Model Driven Engineering (MDE) deliver a suitable approach for this challenge. It is argued that two things are elementary for the implementation of an adequate, domain-specific MDE approach. First, an architectural framework is needed that delivers a common basis for the description of such systems and second, an engineering process that mentions all involved stakeholders, needs to be formalized and implemented. For systems, operating in the field of energy supply, valuable work from the Smart Grid Coordination Group exists and can serve as a suitable basis. The introduced Smart Grid Architecture Model (SGAM) [10] delivers a framework that aligns the architecture of Smart Grid systems on three dimensions (viewpoints). In combination with the basic Model Driven Architecture (MDA) process [6] as proposed by the Object Management Group (OMG), this framework can be used to elaborate an appropriate engineering framework that delivers support for the development process and a basis for KPI evaluations.

Motivated by the good experiences made with MDE in the context of Smart Grid systems, this paper contributes a concept on how to adopt the Smart Grid MDE approach for usage in the development of Smart City systems. Therefore, the underlying DSL is extended on basis of a newly created Generic Smart City Architecture Model (GSCAM).

The remainder of this paper is structured as follows. Section 2 describes the existing approach for the utilization of MDE in the Smart Grid by utilizing the SGAM as basis for a Domain Specific Language (DSL). Moreover a proposed concept for extending the SGAM to Smart Cities is discussed in reference to it's applicability. In Section 3 a new concept is introduced, on how to extend the existing SGAM for usage in Smart Cities. The proposed approach utilizes the SGAM concepts for the development of a *Generic Smart City Architecture Model* (GSCAM) as holistic basis for Smart City systems. Furthermore, it is described how the SGAM based DSL from [2] can be extended in reference to the GSCAM. To make the concept better understandable, a simple demonstration example that combines the application domains energy, traffic and health is presented in Section 4. Finally, in Section 5 the concept ist discussed and necessary work on the way to realizing MDE in development of Smart City systems is outlined.

2 Related Work

In domains that are challenged by engineering of complex *Systems of Systems* (SoS) the concepts of *Model Driven Engineering* (MDE) are established for years. Basically, these concepts utilize models to enable different viewpoints for different stakeholder and to allow for an iterative engineering process on a consistent basis. A well known and broadly accepted approach is specified by the *Object Management Group* (OMG) as *Model Driven Architecture* (MDA) [6]). The MDA aims at separating the *functional* and the *technological* aspects of a system to be built. It defines different viewpoints to be created on the way to realizing a system, such as the *Computation Independent Model (CIM)*, the *Platform Independent Model (PIM)*, the *Platform Specific Model (PSM)* and the *Platform Specific Implementation (PSI)*.

Another aspect in context of MDE besides the engineering process is the usage of a common semantics for modelling. Beyond the utilization of general modelling languages, such as UML [8, 7] or SysML [9], the usage of *Domain Specific Languages* (DSLs) is popular. Such DSLs typically are extensions to general modelling languages have proven to be very useful for gaining efficiency.

In the recent past, some approaches for utilization of MDE in the Smart Grid appeared, such as [1], [3] or [4]. Another interesting concept was presented in [2]. This approach is based on the broadly accepted *Smart Grid Architecture Model* (SGAM) that was introduced by the *Smart Grid Coordination Group* (SGCG) [10]. The SGAM, as depicted in Figure 1, delivers a possibility for a structured representation of Smart Grid systems in reference to the three aspects *Interoperability (z-axis)*, *Domain (x-axis)* and *Zones (y-axis)*. The single layers in this architecture model de-

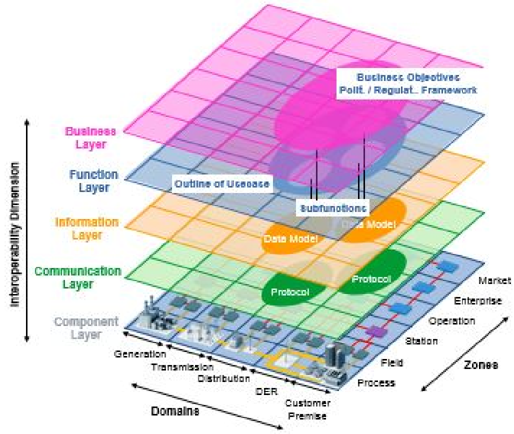

Figure 1 The Smart Grid Architecture Model (SGAM) [10]

scribe the different aspects of required interoperability, the domains decompose the energy supply chain in a hierarchical manner and the zones reflect the automation pyramid. Considering the structure of the SGAM, it becomes clear that only the *Domains* axis is related to the Smart Grid application domain. The other two axes are of a more general type and not specific to the Smart Grid. In [2] the concepts of the SGAM are used as basis for the implementation of the publicly available *SGAM-Toolbox*[1]. The slightly improved metamodel of the DSL is depicted in Figure 2.

In the upper two layer, the functional aspects (*Business- and Function-Layer*) are considered whereas the lower three layers show the technological aspects (*Information-, Communication- and Component-Layer*). This concept allows a clear separation between the functional and the technological aspects of a system, as required by the MDA.

Beyond the utilization for modelling, the SGAM has proven to be suitable as basis for a common understanding of Smart Grid systems. Following these good experiences, in the recent past discussions started on how to expand the SGAM for application to Smart Cities. One particular concept following this idea was presented in [11] and is shown in Figure 3. In this extension, the Interoperability Layer and the Zones remain unchanged whereas the Domains axis is adopted to reflect different, Smart City relevant application domains. To be more precise, every domain along the Domains axis represents a certain application domain. For example, all energy aspects are treated as one single domain without further refinement.

[1] www.en-trust.at/SGAM-Toolbox

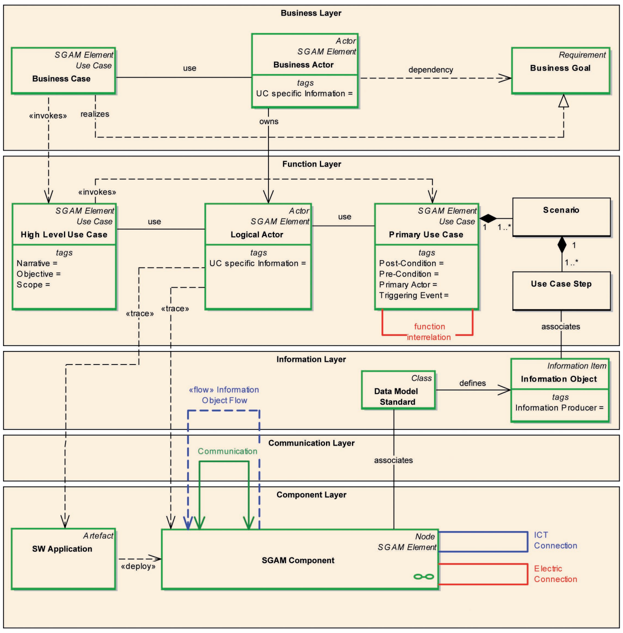

Figure 2 SGAM Toolbox Metamodel [2]

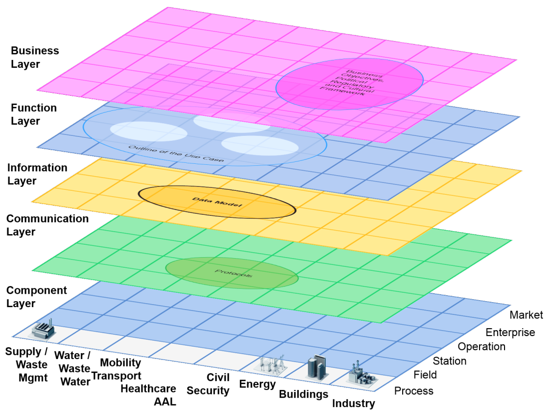

Figure 3 Smart City Infrastructure Model (SCIAM) [11]

3 Approach

As discussed in Section 2, the utilization of Model Driven Engineering (MDE) delivers promising results for managing the technical complexity of Smart Grid systems. The common semantics, provided by the SGAM based Domain Specific Language (DSL), and the consistent engineering approach presented in [2] have proven to be of great value. Considering the Smart Grid as one particular *Application Domain* (AD) of Smart Cities, it appears feasible to expand these concepts for application to the development of Smart City system architectures.

The main challenge for this task is the appropriate adoption of the utilized DSL. To be more precise, the SGAM as underlying architectural model needs to be expanded in a way that reflects the different ADs of Smart Cities. Before this can be done, it is necessary to gain awareness of the SGAM's key aspects in order to remain valid within the extended model.

One of the main aspects of the SGAM is it's capability for a structured representation of Smart Grid systems, which is a key element for a common understanding. The nature of the SGAM as a three dimensional cube allows a differentiated view on particular system models according to the three aspects *interoperability*, *domains* and *zones* as described in Section 2. Considering this in detail, it becomes clear that only the *domain* axis reflects AD specific information. To be more precise, the structure of the domain axis allows for a hierarchical decompositon of the energy domain into the five levels *Generation, Transmission, Distribution, Distributed Energy Resources* and *Customer Premises*. This hierarchical decomposition of the considered AD has proven to be of great value for understanding and architecting particular systems and should remain valid in the extended architecture model.

In addition to the considered aspects it is important to understand the specific needs of a Smart City architecture model. Contrasting to the SGAM that is related to only one AD (energy), the architecture model for Smart Cities requires to cover various, different domains. Moreover, it should allow for analyzing similarities, dependabilities and interdependencies between different ADs in order to provide a holistic view. Hence, it requires a tight integration of different ADs. This requirement is opposed by the nature of a Smart City. As a Smart City is an open environment rather than a delimited system, the need for easy extension to new ADs, such as traffic, health and others, occures. Hence, the general requirements for an MDE approach are supplemented by the need for a holistic view over different application domains and the capability for integration of new AD's.

Following these considerations, the intended extension of the SGAM needs to have a generic character according the different ADs. Moreover, the capability for a hierarchical decomposition of every AD needs to remain valid. As these requirements are not met by the proposed SCIAM [11], a new concept for a Generic Smart City Architecture Model (GSCAM) that allows for a holistic representation of Smart City systems is developed and described in the following Section.

3.1 Generic Smart City Architecture Model (GSCAM)

As discussed earlier, the SGAM as architecture model for the AD *energy* is suitable and should remain unchanged. Moreover, it should be integrated into a more comprehensive architecture model that reflects different AD's and allows for a holistic view. Hence, it appears justified to introduce a new dimension called *Application Domain*. To be more precise, the resulting architecture model comprises various *Application Domain Cubes* (ADC) with each of them reflecting a specific AD. For example it could contain one ADC for energy (the SGAM), one for traffic, one for health and so on. These ADC are structured in a similar way to the SGAM, which means they reflect the same concept with interoperability layer, domains and zones. The interoperability layer and the zones are the same as in the SGAM, whereas the domains reflect a hierarchical decomposition of the specific AD, similar to the one from the SGAM. The structure of the GSCAM is presented in Figure 4.

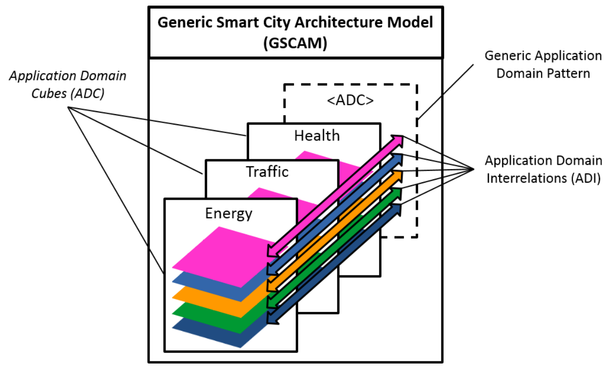

Figure 4 Generic Smart City Architecture Model (GSCAM)

As the concept of ADCs is of a generic nature, it can be extended to new application domains simply by integrating a new ADC. The individual ADCs are related with each other by means of *Application Domain Interrelations* (ADI). These ADI's enable a holistic view on Smart City systems over different application domains for both, functional and architectural aspects.

To make the concept more clear, a short example is given. Let's assume a given system for public e-car charging that is modeled within the energy ADC (the SGAM). This system comprises (among other elements) public charging stations (architectural aspect). One of the *Primary Use Cases* (PUCs) that is fulfilled by the charging stations is *Detection of connected cars* (functional aspect). During this PUC, it is detected when an e-car is connected. This information is communicated to higher services along the *zone* axis within the SGAM. Now, this system should be exploited within the *Traffic ADC* as information source for management of parking sites. Thus, the ADIs between the energy and the traffic ADCs can be used to integrate both, the *PUC (Detection of connected cars)* and the *component (e-car charging station)* in the concerning architecture model for the *parking site management.*

3.2 GSCAM Implementation

Similiar to the concepts from [2], the described GSCAM should serve as a basis for the creation of a particular *Domain Specific Language* (DSL). This DSL can directly be utilized in the *Model Driven Engineering* process as described in [2].

As mentioned earlier, the GSCAM constitutes an extension to the SGAM. Hence, it is feasible to create the GSCAM based DSL simply by extending the SGAM based DSL from [2] with the concept of ADs. The implementation of the GSCAM DSL is realized – identically to the SGAM DSL – as UML profile. A brief overview about the most relevant elements is given in Figure 5. Contrasting to the layer oriented view of the original SGAM DSL in Figure 2, the depiction of the GSCAM DSL emphasizes a representation that highlights the structure of the architecture model rather than the used elements and their relations as they remain unchanged.

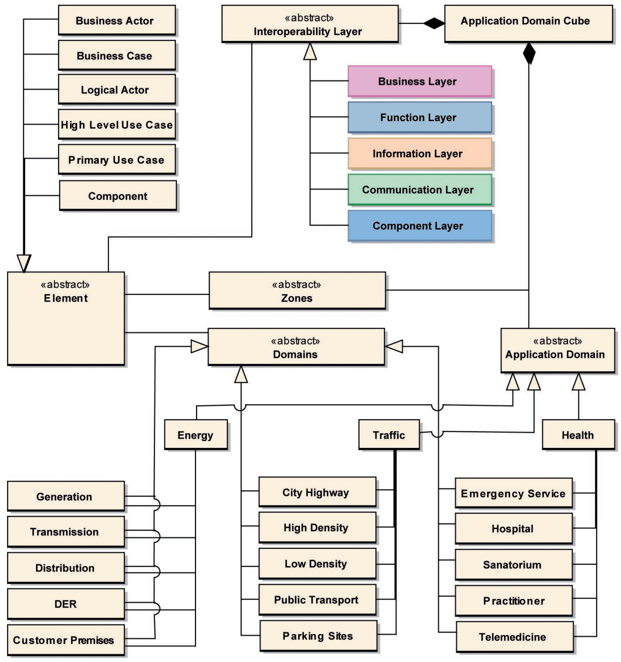

Figure 5 Generic Smart City Architecture Model (GSCAM)

Considering the original SGAM DSL (Figure 2) it becomes clear that all relevant elements used for modelling are derived from the general stereotype *SGAM Element*. For the implementation of the GSCAM this stereotype has been renamed to *Element*, which is domain independent. Similar to the SGAM DSL, this element is associated with certain interoperability layer, domains and zones.

In the implementation of the GSCAM, the metamodel of the DSL is extended in a way that associates the individual domains with a particular *Application Domain*. The Application Domain, together with layer and zones, constitutes the *Application Domain Cube* (ADC).

The realization of *Application Domain Interrelations* (ADI) is done by allowing particular elements to be associated with different ADs.

Even if the GSCAM has a generic nature, the depicted implementation considers three particular ADs. For the energy application domain, the domains from the SGAM remain unchanged. For the other two ADs, *traffic* and *health*, specific domains are introduced that allow for a hierarchical decomposition of systems. The domains for the AD *traffic* are *City Highway, High Density (Areas), Low Density (Areas), Public Transport* and *Parking Sites*. For the *health* AD, the domains *Emergency Service, Hospital, Sanatorium, Practicioner* and *Telemedicine* are proposed.

4 Demonstration Example

For a better understanding of the presented ideas and to demonstrate the capabilities of our approach, a simplified example is presented. In this example, different *High Level Use Cases* (HLUC) from three Application Domains (AD) are modeled by utilizing the SGAM-Toolbox from [2] in combination with the GSCAM DSL as described in Section 3. This example should demonstrate how a holistic view on the whole system and across different AD's can be gained. Moreover, it demonstrates how synergies can be identified and taken into account during system architecture.

The first HLUC from the AD *energy* deals with Demand Side Management (DSM). It assumes a scenario where the customer is willing to shift the activation of certain electric loads (e.g., a heatpump) in reference to the Distribution System Operator's (DSO) needs. The technical infrastructure in the customer premises is realized as a general Home Automation (HA) technology. The DSO has access to certain functionalities of this HA (activate or deactivate the heatpump) over a Gateway in the internet. Some kind of user participation is possible by means of a Human Machine Interface, which for example allows the customer to communicate his willingness for shifting his loads to the DSO. In addition, the customers is also willing to shift the loading of his e-car. It is assumed that the e-car charging station is in a public area (for example on the street) but the e-car can be assigned to a certain customer.

The architecture of this system is depicted in Figure 6, which basically consitutes the *Component Layer*. Due to the limited space, also the *Communication Relations* from the *Communication Layer* are overlayed in this layer. Moreover, some selected *Primary Use Cases* (PUC) that are associated with particular components are shown there. To keep the image compact, the PUC's are not located within their associated domains and zones.

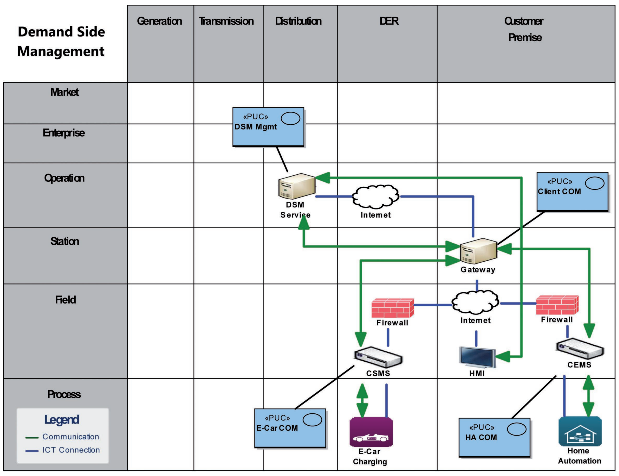

Figure 6 Demand Side Management

The second system is taken from the AD *Traffic Management*. It focuses on *Parking Site Management* and assumes that the information from the e-car charging stations can be exploited to obtain information about the present parking situation. This information can be used in the overlying *Parking Site Management System* and the *Traffic Management System*.

The architecture for this system can be found in Figure 7 and follows the same conventions as the architecture of the DSM system.

Considering the two discussed systems and the depicted architectures, it comes clear that some synergies occur. To be precise, the technical architecture between the E-Car Charging system and the Gateway is the same and hence, can be used for both scenarios. Moreover, also the two PUCs *E-Car COM* (associated with the *Charging Station Management System, CSMS*) and *Client COM* (associated with the *Gateway* can be integrated in both of the HLUC's.

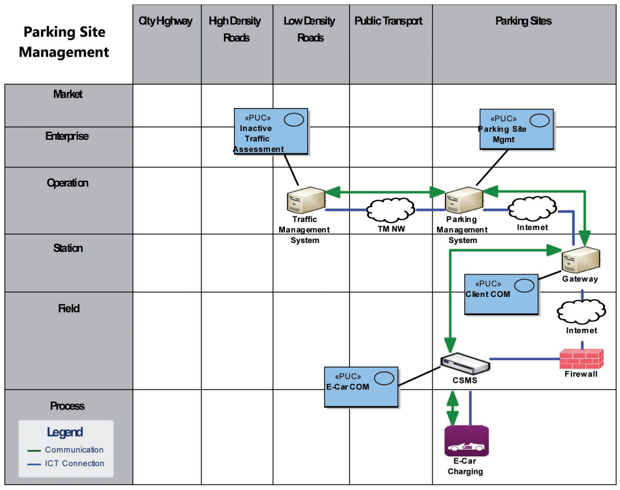

Figure 7 Parking Site Management

It is important to notice that both systems are part of one and the same model and so a holistic view is enabled. For example, taking a more detailed look to the Gateway element would yield all relations of both scenarios as the same element is used there.

In the third scenario, two HLUCs from the AD *Health* are considered. One HLUC deals with tele consultation of a practitioner and the second focuses on detection of emergency situations, such as an elderly being helpless after falling. The tele consultation HLUC simply realizes a communication system between a patient and a practitioner, whereas the second one is more sophisticated. In this HLUC, the information of some Home Automation should be exploited to detect emergency scenarios. For example, if the Home-Automation detects that for a longer period of time no interaction with the inhabitant takes place, this can be interpreted as indicator for a potential emergency case. This scenario is of special interest in respect to the ongoing demographic development that leads to a high increase of elderlies living alone.

The architecture of this system can be found in Figure 8

Similiar to the aforementioned scenario some synergies can be found. To be more precise, the communication infrastructure between the Home Automation and the Gateway can be reused. Again, this scenario is also part of the same model and the very same elements are used.

The usage of the same elements in the model is crucial in order to develop holistic system architectures. For example in both scenarios, the Energy and the Health AD the CEMS is used for communication between the Home Automation and the overlying services. An isolated view on the CEMS from the perspective of the Energy AD would yield to requirements that would not be sufficient for the emergency detection scenario. For example, for the DSM scenario it would be sufficient to only communicate data from

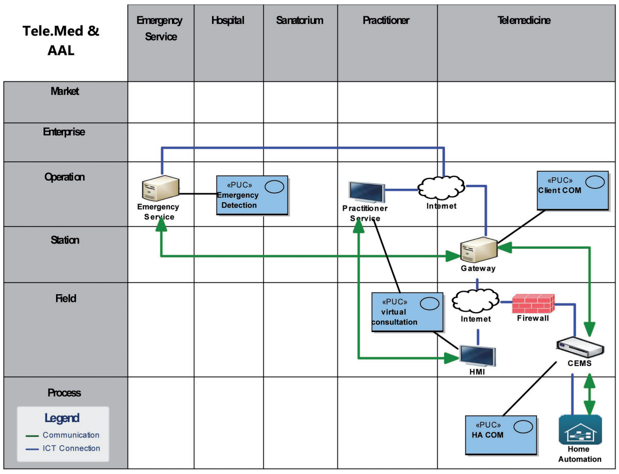

Figure 8 Telemedicine and Ambient Assisted Living (AAL)

the heatpump with a low frequency. Contrasting to this, the emergency detection scenario requires a high frequent communication of numerous sensors (e.g., light switches, motion detectors and others) in order to detect the absent of user interactions. Thus, designing systems in respect to only a specific AD would lead to parallel infrastructure instead of integrated and cost-efficient systems.

However, even if the infrastructure is suitable for usage in different scenarios, a new challenge arises. For example, the data needed for the Emergency Detection needs to be of more granularity and communicated in realtime. By reusing existing infrastructure this means, that this data is potentially available also for other services, such as DSM which can be seen as critical to privacy issues.

5 Conclusion and Future Work

The work proposed in this paper points out the need for enhanced methods, such as MDE, in order to gain a holistic view on Smart City systems. Due to the close relation to the field of Smart Grids, it draws a reference to existing concepts in this area. It is shown that the existing concepts can be extended to be applied for the development of Smart City systems. Basically, the SGAM is extended to the GSCAM in order to reflect the different application domains involved in Smart Cities. Moreover, the paper contributes the implementation of a DSL on basis of the GSCAM. This DSL is utilized to demonstrate the applicability in context of a simplified demonstration example that covers the ADs energy, traffic and health.

However, even if the presented concepts sketch a possible way on how to emphasize MDE in the field of Smart Cities, they do not claim to be a “ready to use” methodology. They rather can be seen as a first step on the way. Going on this way, one of the most important tasks will be a meaningful decomposition of the domains for every AD. Therefore it will be necessary to integrate domain experts from every AD in order to derive a commonly accepted decomposition, similar to the one from the SGAM that is derived from the NIST Conceptual Model [10].

Acknowledgment

The financial support of the Josef Ressel Center by the Austrian Federal Ministry of Economy, Family and Youth and the Austrian National Foundation for Research, Technology and Development is gratefully acknowledged.

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