A Modularized and Distributed Simulation Environment for Scalability Analysis of Smart Grid ICT Infrastructures

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ABSTRACT

Various ICT system architectures for Smart Metering, Demand Side Management and Distributed Energy Generation are currently being evaluated in numerous pilot projects, which analyze the applicability of wireless, wired and powerline technologies for managing decentralized demand and supply components on distribution network level. In order to analyze the scalability of the proposed ICT system architectures, a detailed simulation model and a comparison of different access and inhouse technologies in combination with a variety of traffic engineering approaches is necessary. Depending on the technology and use-cases, the upcoming Machine-to-Machine (M2M) traffic volume leads to an additional load, which can significantly lower the Quality of Service (QoS) of communication networks and affects the reaction rate provided by these network for both Smart Grid application and additional services. To analyze this influence, this paper introduces a distributed simulation environment for investigating the arising traffic volume caused by Smart Grid services in order to enable a detailed network analysis depending on the used technologies. Furthermore, the simulation environment provides the ability to generate large scaled scenarios based on a geographical database, administrate multiple channel models using a revision based repository and combine both features in an automatic, predefined simulation with auto-resolved dependencies using Web Services.

Keywords

AXIS2, OMNeT++, Distributed Simulation, Smart Grid

1. INTRODUCTION

Launching commercial Smart Metering products is one first step towards the Smart Grid. Whereas Smart Metering considers the transfer of metering values over wide area communication links for billing and accounting, additional services like controlling distributed energy resources and inducting renewable energy sources put the energy provider in the position to pool those entities to a virtual cluster called virtual power plant. These virtual power plants have to be managed efficiently by reliable and secure ICT networks to retrieve full potential [4]. Current approaches for accessing the households for an integration into a Smart Grid infrastructure are discussed by taken into account wired technologies (e.g. DSL and cable), wireless technologies (e.g. GPRS, UMTS, WiMAX, LTE) and Powerline Communications (Broadband and Narrowband PLC). In order to enable an interoperable and heterogeneous multi-technology communication network, these approaches need to be evaluated in realistic scenarios.

In this paper, a distributed simulation environment for investigating the arising traffic volume caused by Smart Grid services is introduced in order to enable a detailed network analysis depending on the used technologies. Furthermore, the simulation environment provides the ability to generate large scaled scenarios based on a geographical database, administrate multiple channel models using a revision based repository and combine both features in an automatic, predefined simulation with auto-resolved dependencies. The architecture of the proposed simulation environment is based on a Web-Service approach using Axis2 SOAP framework [1] in order to enable a distributed development of simulations as well as a distributed and modularized management of modules and channels for OMNeT++.

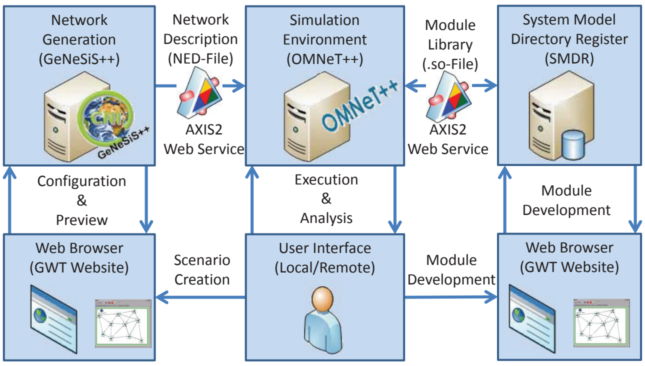

Figure 1: Simulation Framework Architecture based on AXIS2 Web Services

2. RELATED WORK

Modeling communication networks for Smart Grid applications is usually done by well-known discrete-event simulation tools used for simulating telecommunication net-

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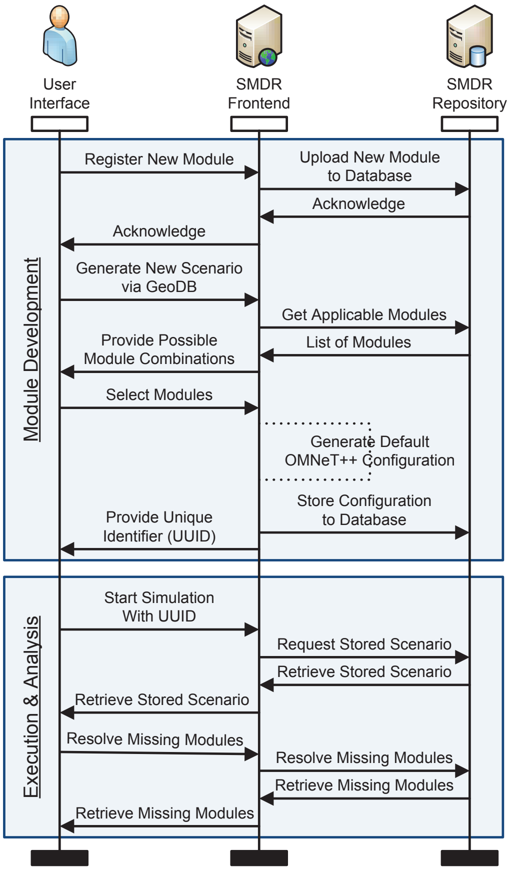


Figure 2: SMDR Sequence Chart

works.An overview on related work is given within this section, whereas none of the known simulators supports a modularized approach for heterogeneous network infrastructures as presented in Section 3.

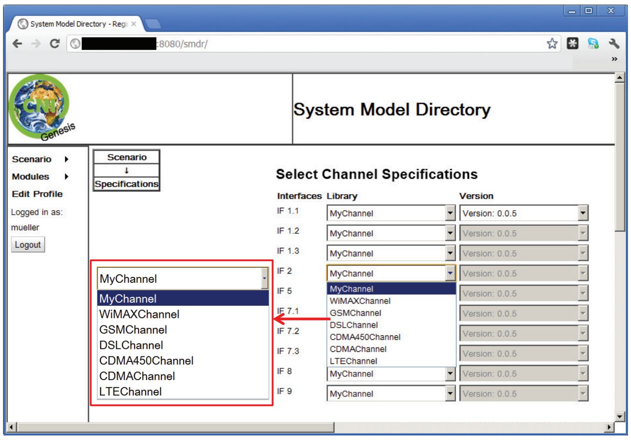
The discrete-event simulator OMNeT++ [14] is a modular extensible and component-based open source framework which has been recently used for modeling communication networks and distributed systems for Smart Grid applications. Related work shows the capabilities of an integrating solution for communication and energy components in one simulation environment [9] [10]. The performance evaluation of RF-Mesh based Smart Metering and Demand Side Management infrastructures are presented in [12] and [7]. Powerline-based approaches for a Smart Grid ICT infrastructure are discussed in [11] and [6].

Another well-known open-source network simulator is the Network Simulator 2 (NS-2), and its successor, Network Simulator 3 (NS-3). In terms of evaluating ICT infrastructures for the Smart Grid several approaches are discussed in related work dealing with NS-2/3, e.g. the improvement of existing infrastructures based on 802.11s Mesh Networks for Smart Metering [5]. In order to investigate the interaction between the ICT and energy networks, several approaches for co-simulation using NS-2 are discussed in literature [3].

The market for commercial network simulators is mainly dominated by two network simulators. First, there is the OPNET Modeler, developed by OPNET Technologies. The main applications of OPNET are network planning, optimization and evaluation of large corporate networks. The other commercial network simulator is QualNet, which is been developed by *Scalable Network Technologies*, a spin-of company funded by the UCLA (University of California) Computer Science Department. Due to its development under the financial support of DARPA (Defense Advanced Research Projects Agency, U.S. Department of Defense), its objective in simulation of military scenarios and the research focus of the UCLA research group, Qualnet focuses on an efficient distributed simulation of large-scaled simulations of heterogeneous communication network topologies with several 10000 nodes. In the context of Smart Grid several approaches using QualNet are discussed in literature [13].

3. DISTRIBUTED SIMULATION FRAMEWORK

In order to meet the requirements for a simulation platform, which is able to simulate multiple technologies, a distributed simulation environment based on OMNeT++ has been established by providing distributed development services. The environment consists of a **Ge**nerator for Large-Scale **Ne**twork **Si**mulation **S**cenarios for OMNeT++ (*GeNeSiS++*) and a System Model Directory Register (*SMDR*) providing configuration and revision controlled model storage databases (cf. Figure 1) as described in Section 3.2. For



[redacted]:8080/smdr/

System Model Directory

Logged in as:
mueller

Select Channel Specifications

Interfaces	Library	Version
IF 1.1	MyChannel	Version: 0.0.5
IF 1.2	MyChannel	Version: 0.0.5
IF 1.3	MyChannel	Version: 0.0.5
IF 2	MyChannel	Version: 0.0.5
IF 5		Version: 0.0.5
IF 7.1		Version: 0.0.5
IF 7.2		Version: 0.0.5
IF 7.3		Version: 0.0.5
IF 8	MyChannel	Version: 0.0.5
IF 9	MyChannel	Version: 0.0.5

Figure 3: SMDR Browser-based Frontend

comparing the different optimization approaches and network planning methods, a geographic system design framework (*GeoDB*) has been integrated [12]. In order to resolve dependencies for the generated scenarios, the *GeNeSiS++* Framework consists of a server component, referred as the *GeNeSiS++ Server*, which connects to the GeoDB and generates scenarios based on the selected scenario configuration in the GUI (cf. Figure 3). Additionally a client component, referred as the *GeNeSiS++ Client*, has been integrated into OMNeT++ implementing the Axis 2 interfaces to the backend services on the one hand. On the other hand the *GeNeSiS++* Client is able to parse the generated scenario configurations and resolves inter-module dependencies based on revision-controlled information in the NED file by retrieving missing modules from the *SMDR* database. Due to the geo-based positions of the communication nodes, close to real world scenarios were investigated in order to analyze the impact of the algorithms.

3.1 GeNeSiS++ Framework

The developed geo-position scenario generator acquires the coordinates according to available GIS databases [12].

This avoids a manual, time-consuming static generation and configuration of each node. In our approach, we use geographic positions of real locations, e.g. houses, as input parameters for the automatic network generation. This ensures a close to reality network topology for scalability analysis. The overview of the simulation environment is presented in Figure 1. Initialization, generation and configuration of the network are executed by a Google Web Toolkit (GWT)-based user interface. A set of preconfigured geographic positions (north-west and south-east corner coordinates), predefined reference scenarios and default configurations are provided by the *GeNeSiS++* server via the Web Service interface.

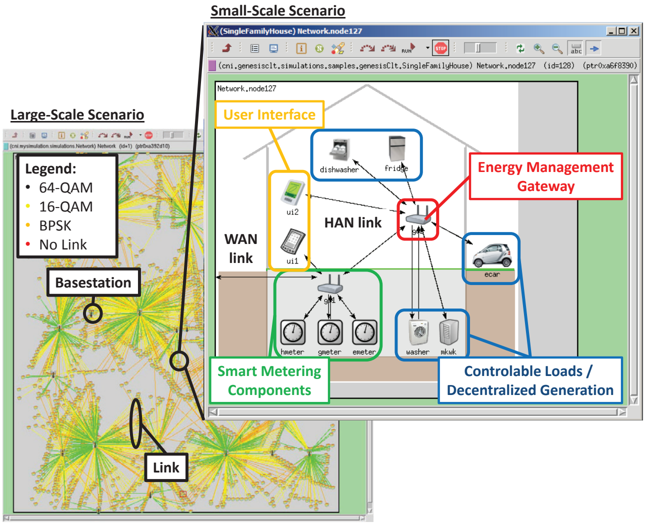


Figure 4: Geo-based Large-Scale Wireless Scenario and Small-Scale Inhouse Scenario

3.2 System Model Directory Register

This chapter describes the simulation management framework, which can be divided into three interconnected services, which provide the main functionality used to run a distributed simulation using the *SMDR*. All entities can be placed on different machines providing a Apache Tomcat application server for hosting the GWT-based configuration interface (cf. Figure 3). A MySQL database server for storing all necessary models and the *GeNeSiS++* framework provides the ability to generate the real-world scenario. The design of the services enables execution in a distributed environment, where each service runs separately in the *SMDR* backend environment to improve performance. The *SMDR* services are realized by Web Services, built on the Apache Axis2 SOAP framework [1] for configuring the scenarios and administrating the modules, which are divided into lower and higher layer technology models.

3.2.1 Lower Layer Technology Models

The transmission channels are modeled by analytic channel models using radio propagation models, link budget calculation and link adaption for different technologies and are provided by channel modules for Wireless Access Networks (GSM/GPRS, UMTS, LTE, WiMAX), Wired Access Network (xDSL, DOCSIS, FTTx), Powerline Access Network (Broadband and Narrowband PLC) as well as Home Area Networks (ZigBee, WM-Bus, Bluetooth, Wi-Fi). The channel models require parameters for distance, housetype, number of inner walls, orientation, etc. The channel behavior of the system models are validated by laboratory measurements.

3.2.2 Higher Layer Technology Models

The upper layer traffic generation models are modeled as simple modules representing the inhouse components of the ICT infrastructure as shown in Figure 4. As input parameter the message frequency, traffic type (Metering, Management, Tariff, etc.) and application can be specified in order to analyze the system behavior for different scenarios.

3.3 Reference Scenarios

An exemplary large-scale scenario for an urban deployment with more than 10.000 nodes located in the city of Mülheim a.d.R., Germany is shown in Figure 4. The presented scenario consists of different housetypes (single, double and multi-family houses) and different infrastructure components (PLC data concentrator, RF base stations, wired concentrators and multiplexers). The inhouse energy and ICT components represent the higher layer traffic generators of the Smart Grid infrastructure and are modeled as shown in Figure 4.

4. PERFORMANCE ANALYSIS

The results shown in Figure 5 represent the validation of smart metering data traffic generator based on the Smart Message Language [8] used for transferring smart metering values on TCP layer. As can be seen, theses values are transmitted in rather small packages with a high message frequency, which requires a sufficient QoS management for the used transmission technology. For evaluating the influence of different wireless technologies the presented environment provides the capability to rapidly replace the used wireless access technology to analyze possible technology based bottle necks. The influence of wireless technologies on Smart Grid scenarios is given in Figure 6. In this scenario multiple wireless links in the frequency of 3.5 GHz are illustrated for Mobile WiMAX links by colored lines between the base stations and the inhouse components of the Smart Energy houses. The link quality, respectively the chosen modulation scheme, is shown in different colors. Thereby short distance links have a lower attenuation, whereby a higher modulation can be used and a higher transmission rate can be provided accordingly. Longer distance links with higher attenuation use lower modulation schemes and can provide lower transmission rates or either no links is available.

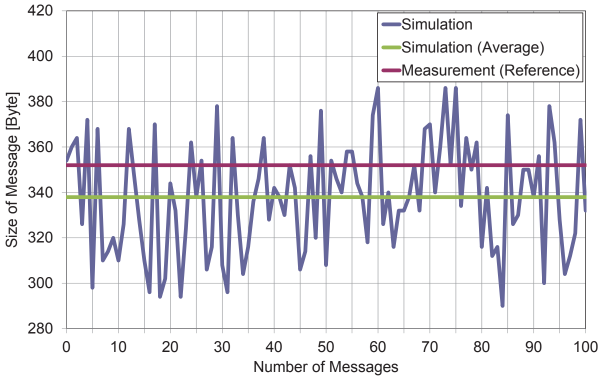


Figure 5: Analysis of Metering Data Format (SML-getListResponse)

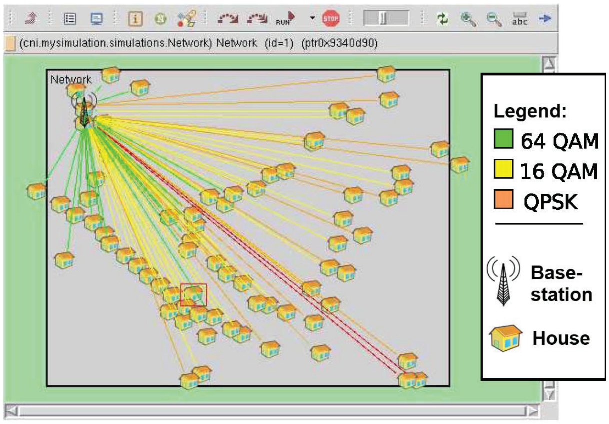


Figure 6: Geo-based Scenario with 802.16e (Mobile WiMAX) Infrastructure

5. CONCLUSIONS AND OUTLOOK

In this paper we presented a novel approach for a modularized OMNeT++ simulation environment based on a Web Service on-demand module management. This simulation environment has been developed in order to investigate the topology specific influences on scalability for different technologies and various traffic patterns for Smart Grid applications. An exemplary analysis for a suburban scenario with more than 10.000 different households combining detailed Home Area Networks has been presented.

Our on-going work focuses on the evaluation of different technologies for the presented use cases in order to obtain network planning heuristics for Smart Grid ICT networks and optimization approaches for existing infrastructures.

Although this work is related to the investigation of Smart Grid ICT networks, it can be seen as a proof-of-concept to enable a generic modularized OMNeT++ development environment. A generic modularized solution would have a great impact on the OMNeT++ community, as it would ease the scenario generation and comparison and evaluation of multiple technologies without having to replace the interfaces and modules manually.

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6. REFERENCES

[1] Apache Axis2^{TM}. Apache Axis2/Java Version 1.61 Project Homepage, February 2012.

[2] BMWi Federal Ministry of Economics and Technology. E-DeMa - Development and Demonstration of Decentralized Integrated Energy Systems on the Way Towards the E-Energy Marketplace of the Future, January 2008.

[3] T. Godfrey, S. Mullen, R. C. Dugan, C. Rodine, D. W. Griffith, and N. Golmie. Modeling Smart Grid Applications with Co-Simulation. In *1st IEEE International Conference on Smart Grid Communications (SmartGridComm)*, pages 291–296, Gaithersburg, Maryland, USA, October 2010. IEEE.

[4] C. H. Hauser, D. Bakken, and A. Bose. A Failure to Communicate: Next Generation Communication Requirements, Technologies, and Architecture for the Electric Power Grid. *IEEE Power and Energy Magazine*, 3:47–55, March 2005.

[5] J.-S. Jung, K.-W. Lim, J.-B. Kim, Y.-B. Ko, Y. Kim, and S.-Y. Lee. Improving IEEE 802.11s Wireless Mesh Networks for Reliable Routing in the Smart Grid Infrastructure. In *2nd Workshop on Smart Grid Communications co-located with International Conference on Communications (ICC)*, pages 1–5, Kyoto, Japan, June 2011. IEEE.

[6] H. Kellerbauer and H. Hirsch. Simulation of Powerline Communications with OMNeT++ in (static) Smart Grids. In *4th International Workshop on OMNeT++ co-located with International ICST Conference on Simulation Tools and Techniques (SIMUTools)*, Barcelona, Spain, March 2011. ICST.

[7] B. Lichtensteiger, B. Bjelajac, C. Müller, and C. Wietfeld. RF Mesh Systems for Smart Metering: System Architecture and Performance. In *1st IEEE International Conference on Smart Grid Communications (SmartGridComm)*, pages 379–384, Gaithersburg, Maryland, USA, October 2010. IEEE.

[8] Martin Wisy. *SML, Smart Message Language Version 1.03*. VDE, November 2008.

[9] K. Mets, T. Verschueren, C. Develder, T. L. Vandoorn, and L. Vandevelde. Integrated Simulation of Power and Communication Networks for Smart Grid Applications. In *16th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, pages 61–65, Kyoto, Japan, June 2011. IEEE.

[10] K. Mets, T. Verschueren, F. D. Turck, and C. Develder. Exploiting V2G to optimize residential energy consumption with electrical vehicle (dis) charging. In *First International Workshop on Smart Grid Modeling and Simulation (SGMS) co-located with IEEE International Conference on Smart Grid Communications (SmartGridComm)*, pages 7–12, Brussels, Belgium, October 2011. IEEE.

[11] R. Mora, A. Lopez, D. Roman, R. Sanz, F. Lobo, F. Carmona, D. Mora, A. Cabello, A. Sendin, and I. Berganza. Demand Management Communications Architecture. In *20th International Conference and Exhibition on Electricity Distribution (CIRED)*, pages 1–4, Prague, Czech Republic, June 2009. IET.

[12] C. Müller, S. Šubik, A. Wolff, and C. Wietfeld. A System Design Framework for Scalability Analysis of Geographic Routing Algorithms in Large-Scale Mesh Networks. In *Third International Workshop on OMNeT++ co-located with International ICST Conference on Simulation Tools and Techniques (SIMUTools)*, Malaga, Spain, March 2010. ICST.

[13] S. L. Ullo, A. Vaccaro, and G. Velotto. Performance Analysis of IEEE 802.15. 4 based Sensor Networks for Smart Grids Communications. *Journal of Electrical Engineering: Theory and Application*, 1(3):129–134, 2010.

[14] A. Varga and R. Hornig. An Overview of the OMNeT++ Simulation Environment. In *First International Conference on Simulation Tools and Techniques for Communications, Networks and Systems (SIMUTools)*, pages 60:1–60:10, Marseille, France, March 2008. ICST.