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Abdelaziz Ahmed-Nacer

► To cite this version:

Théo Docquier, Ye-Qiong Song, Vincent Chevrier, Ludovic Pontnau, Abdelaziz Ahmed-Nacer. Generating substation network simulations from substation configuration description files. 13th Junior Researcher Workshop on Real-Time Computing (JRWRTC), Nov 2019, Toulouse, France. hal-02971306

HAL Id: hal-02971306

<https://hal.science/hal-02971306>

Submitted on 19 Oct 2020

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Generating substation network simulations from substation configuration description files

Théo Docquier
University of Lorraine - CNRS
- LORIA - SCLE SFE
Nancy, France
theo.docquier@loria.fr

Ye-Qiong Song
University of Lorraine - CNRS
- LORIA
Nancy, France
ye-qiong.song@loria.fr

Vincent Chevrier
University of Lorraine - CNRS
- LORIA
Nancy, France
vincent.chevrier@loria.fr

Ludovic Pontnau
SCLE SFE
Toulouse, France
ludovic.pontnau@scle.fr

Abdelaziz Ahmed-Nacer
SCLE SFE
Toulouse, France
abdelaziz.ahmed-nacer@scle.fr

ABSTRACT

The IEC 61850 standard has become the reference standard for substation configuration in smart electric grids, introducing data and service models to achieve interoperability between the network nodes. As the standard is currently based on the switched Ethernet architecture, there is a lot of work on its performance evaluation for guaranteeing real-time constraints. However, there still lacks a link between the substation configuration and its underlying Ethernet performance models (analytic or simulation). For bridging this gap, we propose in this paper a tool, called Simulation Tool for Analysis of substation netwoRkS (STARS) allowing the performance evaluation of any substation configuration through automatic generation of the corresponding simulation model from the Substation Configuration Description (SCD) file. STARS is based on the OMNeT++ simulator allowing the mapping of a real IEC 61850 system configuration to simulation parameters. It also provides a simple network configuration interface. This paper gives an overview of the STARS features through a simple example and points out its future evolution towards co-simulation of substation control algorithms, network performance, and electric grid behaviors.

1. INTRODUCTION

The need for power utilities in terms of distribution, transport, security and quality of service is growing with the years.

In this context, **substations** constitute the critical part within a smart grid. Their main goals are to ensure the correct power distribution through the grid, and to react to any abnormal situations. To meet these requirements, substations are composed of multiple **Intelligent Electronic Devices** (IED), each of them dealing with specific tasks such as the monitoring of voltage/current at different points of the substation or the control of the state of primary equipment (high voltage switches, circuit breakers, transformers...).

Because of the growing number of IEDs within substations, architectures tend to move from traditional hardwired solutions to digital frame based architectures. In such a context, the **IEC 61850** standard is specifically defined to meet these challenges. Major contributions of the standard on

Transfert time class	Transfer time [ms]	Application examples:
		Transfer of
TT0	>1000	Files, events, log, contents
TT1	1000	Events, alarms
TT2	500	Operator commands
TT3	100	Slow automatic interactions
TT4	20	Fast automatic interactions
TT5	10	Releases, status changes
TT6	3	Trips, blockings

Table 1: Performance requirements for different IEC 61850 applications.

the interoperability can be summarized in three parts: **1)** defining a complete model for electrical components (e.g., power/current/voltage transformer, circuit breaker) using an object-oriented paradigm, **2)** allowing the configuration of all equipment belonging to a substation with a language and representation format, and **3)** introducing the Ethernet standard for the communication between the equipment and the specification of performance requirement (Table 1).

The configuration part introduces the XML based Substation Configuration Language (SCL), described as both a language and a representation format. IEDs and the Substation architecture are fully described respectively by the IED Configuration Description (ICD) and Substation Configuration Description (SCD) files. These two files use the Data Object Model (DOM) defined by the IEC 61850 standard and encode them with an SCL format.

For the communication part, the standard uses switched Ethernet networks as the main basis for the communication architecture. To ensure data communication, three main protocols are introduced: *Generic Object Oriented Substation Event* (GOOSE) a layer 2 protocol used for fast messages transmission, *Sampled Measured Value* (SMV) a layer 2 protocol for periodic sample transport on the network and the *Manufacturing Message Specification* (MMS) a protocol above the TCP/IP layer used for reporting and slow messages transmission.

Contributions of the standard are illustrated Figure 1. The configuration part details the node and communication descriptions of each IED while the network part brings the use of Ethernet standard plus the previously described protocols (MMS, GOOSE & SMV).

However, neither the Ethernet standard nor the specified protocols define mechanisms to guarantee the architecture's **determinism** or the **real-time requirements**. Furthermore, the SCD file does not contain any indication about the network architecture's structure i.e., how to interconnect IEDs and devices with each other. This leads to the issue of the network architecture design. Even if the configuration and the communication are already described in the SCD file, the possibilities for the architecture design are multiple. Examples of issues are about the number of switches to use and how to interconnect them, the VLAN configuration or the bandwidth allocation. If the architecture design is not correctly carried out and e.g., the delay of an important message (e.g., a trip order) is too high, it could lead to serious situations, both economically and humanely.

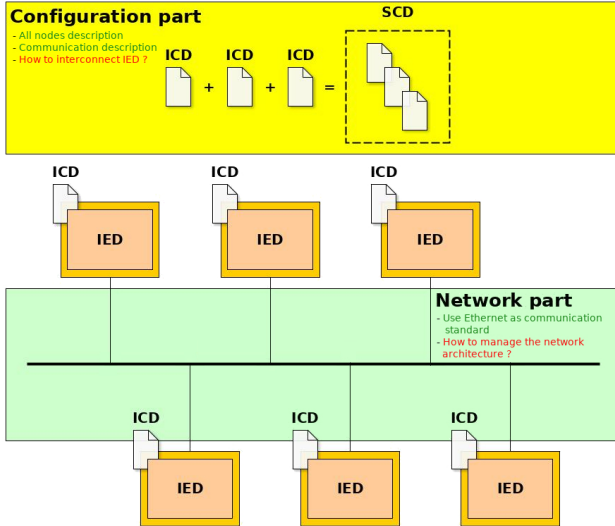


Figure 1: IEC 61850 contribution for configuration and communication part.

Since the communication architecture plays a critical role in substation operations, it must be as reliable as possible. Therefore, it appears a need to have tools that can **1)** take into account an SCD file containing IEDs and their properties and **2)** build a network architecture with all IEDs and evaluate the performance to guarantee real-time constraints.

At the best of our knowledge, no work has ever considered the configuration part along with the communication part in their works, i.e., taking a real configuration with an SCD file, how to model the network architecture accordingly and how to assess it.

In this paper, we present our approach considering the modeling of the network architecture as well as the mapping of an actual IEC 61850 SCD file to simulation parameters. We finally give an example of simulation and result analysis. The rest of the paper is organized as follows. Section II discusses about the recent works on the substation communication modeling. We describe STARS in Section III and give an overview of its utilization in Section IV. Section V concludes the paper.

2. RECENT WORKS

In the literature, modeling substation communication is

based on two main approaches: analytic and simulation.

Analytic modeling: Mathematical models are used to represent the communication architecture. These models are used to determine the worst-case parameters (e.g., delay, backlog) or a statistical approximation for a given scenario. Previous works have been done on the modeling of the MMS protocol [1] or on the modeling of GOOSE and SMV at the same time with priority policy [2] both using Network Calculus approach. However, no existing work has taken into account the whole IEC 61850 protocols or existing configuration. Moreover, the pessimism for the worst case scenario always increases drastically as the complexity of the substation grows, making Network Calculus difficult to use for complex cases.

Simulation: It consists to choose one network simulator and then develop the model. Recent works have been performed to model and simulate IEC 61850 architecture using the OM-NeT++ simulator. In [3] the three IEC 61850 protocols are implemented while the work made in [4] only focuses on GOOSE and SMV. However, neither of them introduce the configuration part of IEC 61850, as their works focus on the development of specific IEC 61850 network communication models.

For the rest of the paper, we focus on the simulation part.

3. DESCRIPTION OF STARS

3.1 Global description

To allow a simple utilisation of a performance evaluation tool, it appears necessary to have two elements:

User interface (UI): act as the "input" of the tool. It allows to specify the network architecture, the data model configuration (from the SCD) and simulation parameters;

Operation core (OC): act as the "engine" of the tool. It takes the input parameters coming from the UI and runs processes to obtain expected results.

The tool can be viewed as a black box system. The only tasks for the user are the configuration of the network architecture plus simulation parameters and the loading of the SCD file corresponding to the substation system configuration the user wants to evaluate.

Figure 2 gives the conceptual view of STARS.

3.2 User Interface

STARS UI composition is described by the left part Figure 2. It consists of a sequence of operations the user has to do *via* the interface before starting the simulation. These operations are as follows:

SCD loading: loads the SCD file related to a specific substation;

Node description: instantiates each IED of the architecture. Instantiation must be consistent regarding the SCD content as all the IEDs are already described with their configurations;

Switches description: instantiates each switch of the architecture;

Architecture: describes relations between each node and switch composing the architecture;

Scenario description and simulation setting: configures the simulation and scenario parameters. For scenario, the user can configure the number of fault (e.g., thunderbolt on the substation, overload) during the simulation or the period between two faults. For simulation, the user can configure

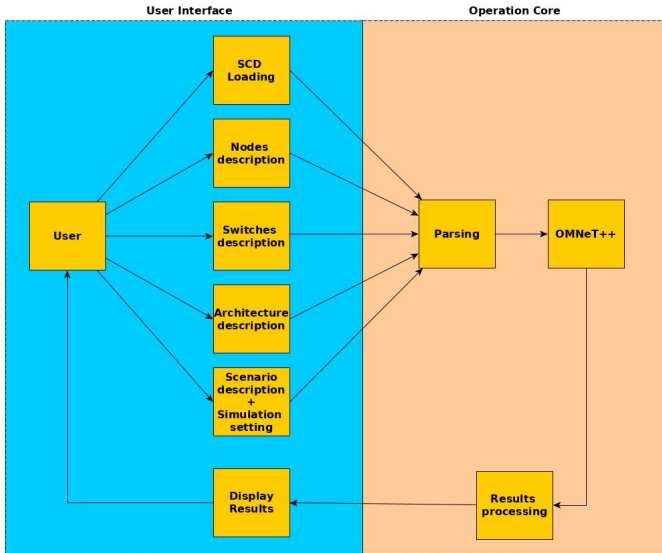


Figure 2: Conceptual view of STARS.

the simulation time and delay thresholds for which the user will be notified if the actual delay exceeds them.

The UI is also responsible for the display of results (e.g., delays, packet loss, buffer utilization) with graphs once the simulation is completed.

3.3 Operation core

The STARS OC composition is described by the right part of Figure 2. It is made of three fully automated operations: **Parsing**: information collected during the configuration part is parsed into files that can be understood by the simulator; **Simulating**: the result of the parsing operation allows to run the simulation;

Computing result: the obtained results are analyzed and processed, then passed to the UI to display the information.

We chose the OMNeT++ simulator for the simulating operation. We used the model developed by [4] which is available on the internet for the substation modeling. We added some improvement such as a light version of the MMS protocol, a better mechanism for GOOSE repetition pattern¹ and the possibility to have multiple Application Service Data Units (ASDU²) carried by one SMV frame.

To run a simulation, OMNeT++ needs three different files (according to the user guide manual³):

Simulation program: containing the compiled code for modules, simulation kernels and messages. This part contains the core of the model description;

NED (Network Description): containing modules (e.g., IEDs, switches, servers ...) and their interactions (e.g., link capacities, propagation delay, frame loss rate...);

INI: containing the simulation parameters (e.g., the simulation time) and the parameter descriptions of all modules in the network (e.g., frame sizes, emission periods...).

¹Algorithm used by the GOOSE protocol to ensure the data exchange reliability. It consists of several repetitions of the same message several times.

²An ASDU can be considered as a group of samples.

³Available at <https://doc.omnetpp.org/omnetpp/manual/>

In order to provide the INI and NED files to OMNeT++, we develop two parsers whose role is to extract the required information from the SCD file and generate the NED and INI files. As the model does not change, the simulation program is already compiled and ready to use. As soon as the NED and INI files are generated, the simulation can be run. Once the simulation is completed, the result needs to be displayed. To do so, we developed a third parser taking the result file produced by OMNeT++ and extracting the main values. Once extracted, the results are displayed to the user as illustrated Figure 4. A report containing the result displayed is also automatically created.

4. STARS'S CAPABILITIES

To illustrate the capabilities of STARS, we consider an SCD file coming from a substation benchmark and describing a real case study. The substation is composed of 17 IEDs. We start by loading the corresponding SCD file into Calc Software. The next step is to define a communication architecture. We consider a network topology with two interconnected switches called "Switch_1" and "Switch_2". All links on Switch_1 are set to 1 Gbps while all links on Switch_2 are set to 100 Mbps. The link between the two switches is set to 1 Gbps. At this stage, we can describe the obtained architecture with Figure 3.

All node behaviors (i.e., protocols used for communication, data to send and the sending periods) are fully described in the INI file where the information is collected from the SCD. In this simple scenario, the parser does not parse SMV from the SCD yet, and future additional work will implement it. GOOSE traffic is emitted by each node (except SUP nodes) to all other nodes. MMS traffic is emitted by each node to one of the declared MMS receivers. In our SCD file, only SUP nodes, ACC.1 and ACC.2 are considered as MMS receivers. GOOSE messages have a higher priority than MMS ones. Before running, we need to configure the scenario and simulation parameters. We choose the following scenario: 10 successive faults appear on the grid with a 1 ms interval, triggering GOOSE and MMS events. For the configuration of simulation parameters, we set the simulation time to 0.2s.

Once the previous step is completed, we can start the run process from Calc Software. Remaining processes (describe subsection 3.3) are handled by the OC part of STARS.

After the simulation is completed, the results can be retrieved as depicted in Fig. 4. For the given SCD and the simulated scenario, we can observe that the maximum delay for GOOSE traffic exceeds the 3 milliseconds limit for trip messages given in Table 1 (all APR nodes). Since APR nodes are set to 100 Mbps, we can speculate that the problem comes from an insufficient bandwidth. If this speculation proves to be true, then we have identified the problem that can be solved to meet the real-time requirement by replacing, for instance, the 100 Mbps link by a 1 Gbps one.

5. CONCLUSION AND FUTURE WORKS

The main issues addressed in this paper is to design and assess a substation communication architecture while taking into account a real substation configuration. To meet these requirements, STARS brings the following features:

Real configuration consideration: the obtained results are based on real SCD files;

```

<?xml version="1.0"?>
<!-- SCD Template -->
<SCL xmlns="http://www.iec.ch/61850/2003/SCL" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <Header id="TEST" version="01/04/2019 11:18:46" revision="" nameStructure="IEDName" toolID="CS SCL 61850">
    <Communication>
      <IED desc="ArkensCP" manufacturer="SCLE SFE" name="SUP 3" type="ArkensCP" owner="TEST">
        <IED desc="ArkensCP" manufacturer="SCLE SFE" name="SUP 4" type="ArkensCP" owner="TEST">
        <IED desc="ArkensCP" manufacturer="SCLE SFE" name="SUP 5" type="ArkensCP" owner="TEST">
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        <IED desc="ArkensCC" manufacturer="SCLE SFE" name="ACC 1" type="ArkensCC" owner="TEST">
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        <IED desc="ArkensCC" manufacturer="SCLE SFE" name="ACC 15" type="ArkensCC" owner="TEST">
        <IED desc="ArkensPR" manufacturer="SCLE SFE" name="APR 7" type="ArkensPR" configVersion="3.1e" owner="TEST">
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        <IED desc="ArkensPR" manufacturer="SCLE SFE" name="APR 13" type="ArkensPR" configVersion="1.0e" owner="TEST">
        <IED desc="ArkensPR" manufacturer="SCLE SFE" name="APR 14" type="ArkensPR" configVersion="3.1e" owner="TEST">
        <IED desc="ArkensPR" manufacturer="SCLE SFE" name="APR 16" type="ArkensPR" configVersion="1.1f" owner="TEST">
      </Communication>
    </Header>
  </SCL>

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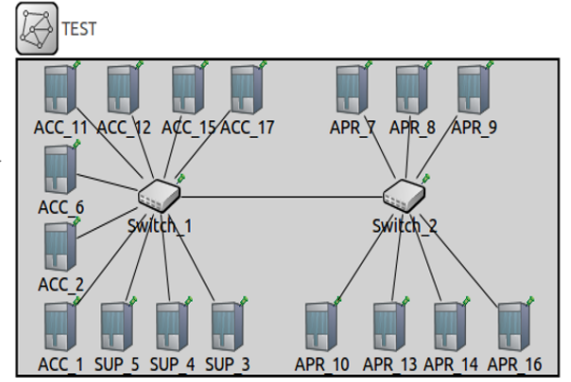
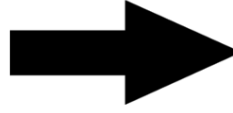


Figure 3: Conversion from SCD file to OMNeT++ model.

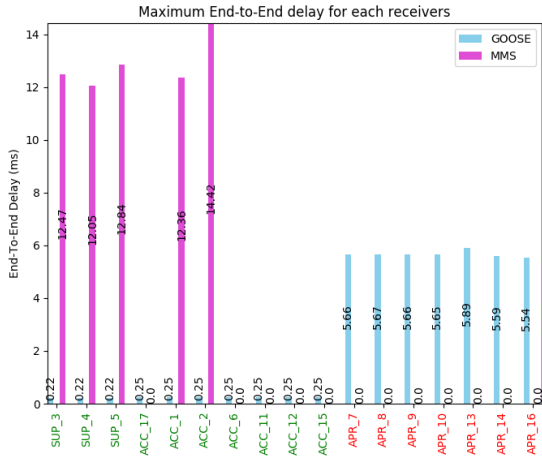


Figure 4: Example of a GUI result at the end of the simulation process

Network modeling and investigation: possibility to model a network architecture and assess it in case of non-compliance with real-time requirements. This allows users to detect a potential performance issue and points of failure, and deal with them;

Usable by non-expert: spreadsheet interface to design the network architecture, load the SCD, set the simulation parameters and run the simulation with results at the end;

Automatic Configuration: the SCD file is automatically parsed into files understandable by OMNeT++ reducing the time of the simulation configuration.

The main perspective is the improvement of our IEC 61850 model by integrating the new IEEE Time Sensitive Networking (TSN) standard, the latter describing mechanisms and protocols to guarantee determinism for Ethernet-based architecture. Some works have already been done [5], where a simulation model for TSN standard is proposed. TSN is also investigated by the IEC 61850-90-13 draft about deterministic networking for substations to improve overall performance of the communication network by using network resources efficiently. In addition to TSN study, an investi-

gation on scheduling theory to formally describe how to set network parameters for network optimization is planned. Finally, we plan to investigate the co-simulation of our already made communication network model with control and electrical models with the help of the MECSYCO software [6] to improve results by integrating different fields of expertise to be as close as possible to the reality.

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