C-DAX: A Secure and Resilient Communication and Information Infrastructure for Power Grids

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***Abstract*—In this paper, we describe the C-DAX project. The main objective of the C-DAX project is to define and implement a novel and scalable information platform for implementing a cyber-secure data and control cloud for power grids, called C-DAX. It will be validated to support various smart grid use cases and deployed for a trial in a live electricity network with real-world settings.**

***Index Terms*—Smart grid, information-centric networking, renewable energy, security, distributed energy resources.**

I. Introduction

TODAY, smart grid refers to the next-generation power grid designed to enhance the resilience of the grid to power flow disruptions, improve energy efficiency, and reduce carbon emissions. To accomplish these goals, the modern power grid will incorporate a wide variety of smart grid applications, e.g., distributed renewable energy sources, electric vehicles, and intelligent interactive customer applications.

However, one of the main obstacles in the way of the deployment of smart grid applications is the limited capabilities of today's utility communication infrastructure in terms of scalability, reliability, and security. The following incident illustrates the necessity to improve the communication and information infrastructure of current power grids.

In 2007, a helicopter accident lead to a blackout in Bommelerwaard and Tielerwaard in the Netherlands. The helicopter cut both the main and backup power line in the transmission system operator network. It took several days to repair the lines and restore power supply. Due to the lack of measurement and control by the distribution network operator, the isolated area implied that all still available distributed energy resources were not usable anymore.

The essential challenging requirements for smart grid deployment can be summarized as (i) integrate highly time-varying, non-deterministic renewable resources, (ii) enable controlling the load, which may be influenced by new, dynamic end-user behaviors, and (iii) provide highly adaptive resilience, minimizing outages. Meeting these requirements calls for the introduction of intelligence that needs to be supported by an integrated communication and information infrastructure, as part of an overall design combining sensing, communications, and control. The C-DAX project aims at providing and investigating such an infrastructure.

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II. Goals

In C-DAX, it is essential to investigate how the new concept based on ICN principles can be successfully applied as a communication and information infrastructure for the utility environment, capable of inherently supporting both legacy and future envisaged power grid applications. In addition, further research is required on cyber security, system resilience, and resource efficiency in future smart grid environments. Scientific and technical goals of the C-DAX project are briefly presented in the following.

A. Development of Use Cases for C-DAX on the Power Grid

The C-DAX project will investigate specific use cases in three application domains: low-voltage pervasive distributed energy resources, medium-voltage distributed energy resources and islanding, and retail energy transactions.

B. Advanced Design, Enhancement of the C-DAX Architecture and Prototype Development

The project will derive necessary requirements to be taken into account for the design of the overall C-DAX architecture to ensure that it is capable of supporting a wide range of smart grid applications. A prototype will be implemented, both as simulation and as field trial. The latter will evaluate the real-time performance of C-DAX when used to control operations in MSLiveLab, a real power distribution network owned by Alliander, a member of the C-DAX consortium..

C. Validation, Performance Evaluation, and Recommendations of C-DAX Configuration Guidelines

Today, the requirements for a future smart grid communication and information infrastructure are unknown. The considered use cases are used to derive models that quantify typical system requirements for different smart grid applications. Provisioning of the C-DAX infrastructure is subject to performance evaluations and configuration recommendations. This goal is completed by a strength/weakness analysis of C-DAX including comparison with alternative information infrastructures to show the benefits and drawbacks of C-DAX in a qualitative and quantitative way.

III. C-DAX Architecture

The foundations of the C-DAX architecture are based on the initial concepts developed at Alcatel-Lucent Bell Labs [1]–[3]. We describe the envisioned system architecture for the C-DAX platform with specific emphasis on the ICN communication paradigm.

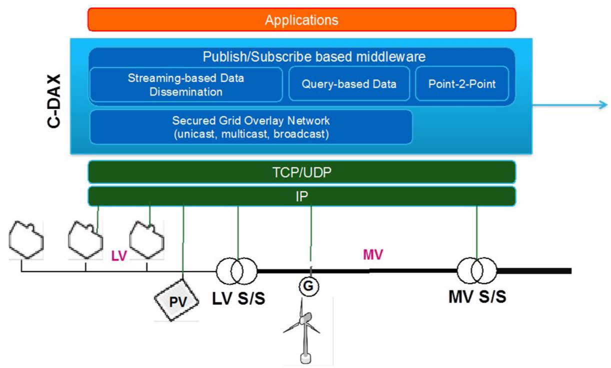

Fig. 1. The C-DAX design concept.

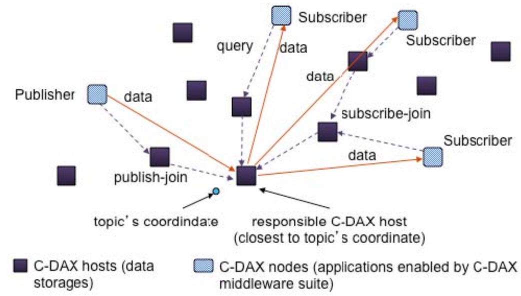

Fig. 2. Topic-group communication in C-DAX using geographic hashing and greedy forwarding.

A. Design Concept

C-DAX can be deployed over the current TCP/IP network and provides necessary interfaces for assessing the power information using different communication modes (see Fig. 1). All of these data access methods are critical components for the integrated information infrastructure to support both monitoring and control operations of the grid. C-DAX can be deployed in a scalable manner, meeting the necessary reliability and survivability requirements, and also supports an end-to-end security framework.

B. Core Components

The C-DAX network is an overlay network which consists of a Delaunay Triangulated (DT) graph having *C-DAX hosts* as vertices and transport layer connections between any two neighboring hosts as edges. The *C-DAX middleware* is a software library which provides smart grid applications with interfaces to the C-DAX network. Computing entities hosting smart grid applications are called *C-DAX nodes*.

C. Topic-Group Concept

In C-DAX, information is organized in so-called topics. A topic is defined by fields such as data type, location, and time. Each topic is stored on a certain C-DAX host. C-DAX nodes generating data for a specific topic send these data to the C-DAX host that is responsible for that topic. C-DAX nodes interested in a certain data express their interest for a specific topic, i.e., they subscribe to a topic, not a specific C-DAX host. This is known as the publish/subscribe paradigm and information-centric approach.

D. Geographic Hashing and Greedy Forwarding

Each C-DAX host is associated with Euclidean space coordinates and knows the coordinates of its directly connected neighbors. Topics are mapped to these coordinates using a geographic hash function (GHF), i.e., a C-DAX host closest to the topic's coordinate is responsible for it. Messages are forwarded on the overlay network based on the Euclidean coordinates using the closest next C-DAX host (greedy forwarding).

An example for communication in C-DAX is illustrated in Fig. 2. A publisher wants to store information for a specific topic in C-DAX while three subscribers want to retrieve information about the same topic. The publisher first calculates the topic's coordinate using GHF and then forwards the publish-join message to the closest C-DAX host which forwards it to the C-DAX host responsible for the topic. The subscribe-join message of the upper left subscriber is forwarded over two intermediate C-DAX hosts before it eventually reaches the C-DAX host responsible for the topic.

E. Resilience

C-DAX comes with a simple resilience concept. For each topic, a primary and secondary C-DAX host exists. The C-DAX host which is closest to a topic's location serves as primary host while the second-closest C-DAX host serves as secondary C-DAX host. The overlay network takes care that data is always forwarded correctly. When the primary fails, the secondary host takes over and takes care that all data is properly replicated to other C-DAX hosts to protect topics against another failure. When the failed host comes back again, the original responsibilities are restored.

F. Security

Access to C-DAX hosts is secured by a trusted network of secure control servers which are deployed within the security perimeters of utilities. Fine-grained access control up to the level of topics can be enforced. The security framework adopted by C-DAX covers both information and data security, and transaction level security with necessary authentication for parties engaged in the transaction.

IV. Conclusion and Future Work

We presented the motivation and goals for the C-DAX project and briefly sketched its communication and information infrastructure. The next steps in the C-DAX project are to capture requirements derived from smart grid application use cases. Based on these requirements, we define the C-DAX architecture. We implement a prototype of the information and communication infrastructure, validate the prototype and assess its performance. Selected applications are eventually examined as a field trial in a life electricity network called MSLiveLab by Alliander.

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