

Demo: A Visualization Platform for Smart Grid Network

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Abstract—Smart grids are transforming electricity network management through the use of Advanced Metering Infrastructure (AMI). They facilitate the balance between production and consumption of electricity by providing real-time data and consumption control for the Distribution System Operator (DSO). However, the implementation details, which are often proprietary, are not readily available. This demo presents an innovative visualization platform to simulate a Low Voltage (LV) residential network of 48 smart meters. The platform provides a visual understanding of the communication dynamics in an AMI by reproducing message exchanges and simulating link disruptions. This demo presents the state-of-the-art G3-PLC protocol stack currently employed in the French AMI deployment and demonstrates the transmission of routing and application messages generated by LOADng and DLMS/COSEM, respectively.

I. INTRODUCTION

Smart grids constitute a major advance in the management of electricity distribution networks. They integrate advanced communication and control technologies to improve efficiency, reliability, and sustainability. Smart meters replace the traditional meters to offer multiple advantages. They enable Distribution System Operators (DSOs) to avoid the need for manual meter readings by automating and increasing the frequency of meter readings. They also provide precise measurements, such as voltage drops, at the request of the DSO or on the meter's own initiative. Moreover, smart meters enable remote interruption of home appliance.

In France, Enedis, the main DSO managing 95% of the distribution network, has been deploying its Linky smart meters since 2015. By August 31, 2024, according to the Commission de Régulation de l'Énergie (CRE), 37.3 million of these meters have been deployed. They are part of mesh networks, which are suitable for low-bandwidth, noisy, and long-range environments. This infrastructure could become crucial for maintaining a constant balance between production and consumption, with the rise of variable and non-dispatchable Distributed Energy Resource (DER), such as wind and solar power, and the growth in individual consumption, such as Electric Vehicles (EVs).

In this demo paper, we present a visualization platform composed of controllable LEDs representing a residential neighborhood with 48 smart meters. It provides a better understanding of message exchanges by reproducing realistic communication situations, described in detail in each section.

This work was funded by the French National Research Agency (ANR) under the project ANR EDEN4SG (ANR-22-CE05-0023).

TABLE I
G3-PLC PROTOCOL STACK BASED ON THE
DLMS/COSEM APPLICATION LAYER

Application Layer	DLMS/COSEM
Transport Layer	UDP
Network Layer	IPv6 / Routing (LOADng)
IPv6 Adaptation Layer	6LoWPAN
Data Link Layer	IEEE Std 802.15.4
PHY Layer	OFDM G3-PLC PHY (CENELEC A band)

II. THE LINKY ADVANCED METERING INFRASTRUCTURE (AMI) NETWORK

A. Architecture and Specifications

The Linky network, deployed by Enedis, relies on Power Line Communication (PLC) through the existing electricity grid. This approach enables the DSO to operate its electrical infrastructure as a stand-alone communications network, avoiding dependence on third-party networks. This independence reduces operating costs and minimizes the risks associated with using external services, while guaranteeing effective coverage, even in remote areas.

The development of the Linky network is based on collaboration with the G3 Alliance. Initially, Linky meters used the G1-PLC standard until 2016. Since then, Enedis has adopted the more advanced G3-PLC standard, which implements Orthogonal Frequency-Division Multiplexing (OFDM). Linky G3-PLC networks operate on three-phase 400 V Low Voltage (LV) networks. In France, they operate on the CENELEC A band (9 to 95 kHz). According to the G3 Alliance, the network offers a typical UDP throughput of 13 to 17 kbit/s and a one-hop delay of around 120 ms.

A G3-PLC network is built around two main elements:

- The Personal Area Network (PAN) Coordinator, acts as a central point and interfaces with the Wide Area Network (WAN) to transmit data to the DSO information system.
- The PAN devices (Linky smart meters).

B. G3-PLC Protocol Stack

In this section, the protocol stack of the G3-PLC is presented, see Table I. It uses OFDM G3-PLC (CENELEC A band) for the physical layer, IEEE 802.15.4 for the data link, and 6LoWPAN to adapt IPv6. It uses LOADng for network layer routing, UDP for transport, and DLMS/COSEM for application layer data management. A special focus will be given on the routing protocol LOADng and DLMS/COSEM.

1) *LOADng*: The Lightweight On-demand Ad hoc Distance-vector Routing Protocol - Next Generation (LOADng) is the routing protocol that enables smart meters to act as relays for data transmission in Low-power and Lossy Networks (LLNs). It is standardized in ITU-T G.9903 for G3-PLC [1]. Detailed in the IETF document [2], LOADng, introduced in 2011, is an evolution of LOAD (2005), itself derived from Ad hoc On-Demand Distance Vector Routing (AODV) [3], a reactive protocol for Mobile Ad hoc Networks (MANETs). Unlike Routing Protocol for LLNs (RPL) [4], a proactive protocol that constantly maintains routes, LOADng is reactive, creating routes on demand via messages like Route Request (RREQ), Route Reply (RREP) and Route Error (RERR). This results in higher initial latency when discovering routes, but reduces signaling and energy consumption in the absence of traffic. Compared to RPL, LOADng is better suited to dynamic networks such as Linky meters, where the topology can change frequently according to the frequency of the network, the time of day, and the type of equipment connected to the network.

2) *DLMS/COSEM*: The Device Language Message Specification (DLMS)/ Companion Specification for Energy Metering (COSEM) standard [5] ensures standardized communication for smart meter management. It forms the application layer of the Linky network. DLMS defines a universal message language for data exchange between devices, while COSEM specifies an object-oriented model for representing meter data. Similar to the Constrained Application Protocol (CoAP) [6], DLMS/COSEM is lightweight, runs on UDP, adopts a client-server model and is optimized for resource-limited devices such as smart meters or Internet of things (IoT) devices.

DLMS/COSEM's main messages include: Association Request (AARQ) and Association Response (AARE) to establish a connection, Release Request (RLRQ) and Release Response (RLRE) to close it, Abort (ABRT) to interrupt, and GET, SET, and ACTION to retrieve, modify or trigger operations on the server. In the Linky network, the meters act as servers, responding to requests from the concentrator, aka the client.

III. VISUALIZATION PLATFORM

This demo platform visually illustrates AMIs communications across a LV residential network, such as used for Linky smart meters. The topology of the LV network is shown in Figure 1. It highlights the propagation of messages in a PLC-based mesh network technology.

A. Hardware

The visualization platform uses an individually controllable RGB LED strip (WS2812B), cut out and reconstituted to form a tree-like graph representing a residential LV network. The cut-out segments have been soldered together with wires to reconstitute a single strip, ensuring continuity. This strip is controlled by an ESP32 microcontroller, and the whole assembly is powered by a 5V source. The colors of the LEDs distinguish between the different types of messages exchanged in the network (requests, responses, etc.), while

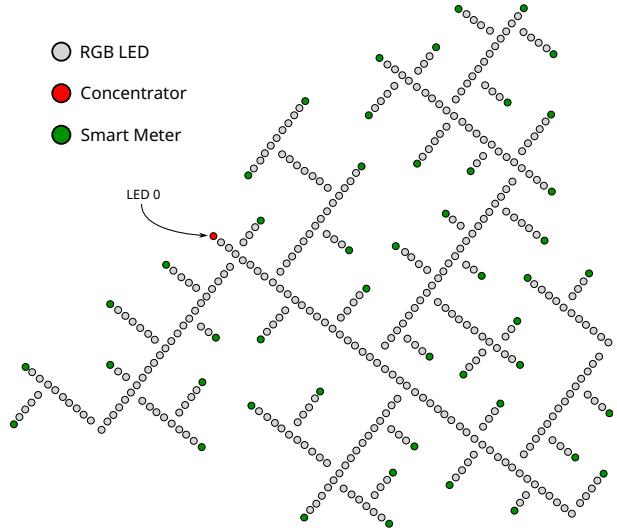


Fig. 1. LV Grid Topology of the Visualization Platform.

the variable brightness represents the attenuation of the signals, approximating real-world propagation conditions in an electrical network.

B. Software

The simulations are based on a static network topology, shown in Figure 1, therefore the tree structure of the network is hard-coded into the ESP32. Each branch is defined by a triplet {ID_led_start, ID_led_end, ID_led_parent}: ID_led_start and ID_led_end (values between 0 and 410) delimit the sequence of LEDs that compose the branch. ID_led_parent designates the ID_led_end of the parent branch (with -1 for the root).

LED 0 in Figure 1, colored in red, represents the concentrator (PAN Coordinator), while the 48 leaf LEDs, in green, are the smart meters (PAN Devices), identified by the ID_led_end absent from ID_led_parent. A Breadth-First Search (BFS) algorithm calculates the distances between LEDs, simulating communication paths. The visualization platform reproduces the night-time exchange of messages to collect consumption data from Linky meters, providing a realistic and visual simulation of smart metering networks.

IV. SIMULATED SCENARIOS

The platform visualizes several key communication scenarios in a G3-PLC-based smart metering network, shown in Figure 2. It first illustrates the exchange of messages during route construction via the LOADng protocol, showing how smart meters dynamically establish routing links in a mesh network. Next, it simulates the transmission of a DLMS/COSEM request between a client (concentrator) and a server (smart meter), demonstrating data collection. Finally, the visualization platform allows you to force the destruction of a routing link, simulating a failure or interference, to observe the automatic reconstruction by LOADng.

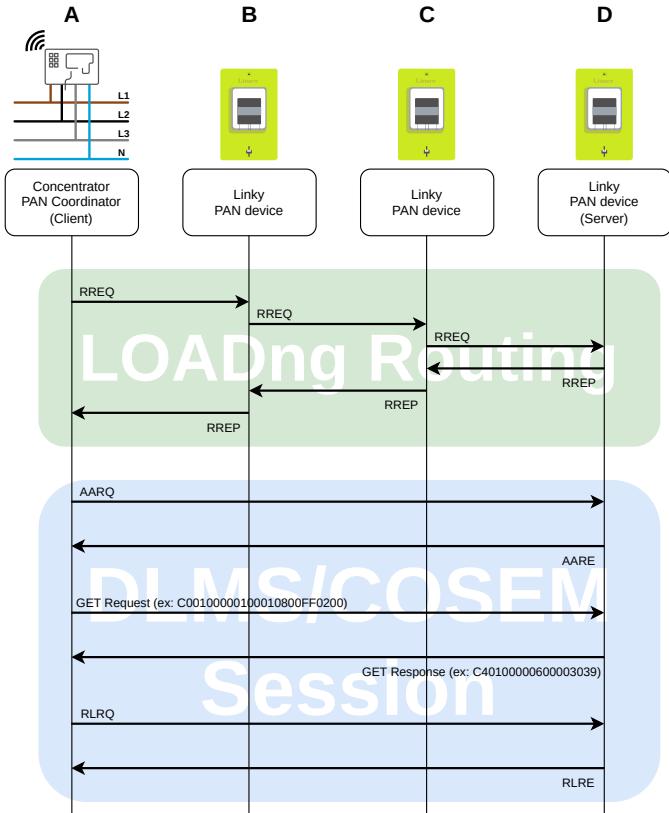


Fig. 2. Time Sequence Diagram of a G3-PLC message session.

A. LOADng routing

To establish a routing link between two nodes, for example, source node A and destination node D, with two relay nodes B and C, you must configure the routing tables for all nodes involved. A starts a RREQ broadcast to B, which forwards it to C, then to D. D responds with an RREP sent in unicast via C then B to A, establishing the route A → B → C → D. Each node updates its routing table at each step. If required, RREQ_ACKs confirm receipt of RREQs. If a link break event occurs (for example, between B and C), a RERR is sent to A by B to signal the failure, allowing for a new route discovery.

B. DLMS Application Protocol Data Units (APDUs)

In the DLMS/COSEM standard, a client, such as a concentrator, sends requests such as GET, SET, or ACTION to a server, i.e., a Linky smart meter, to retrieve the value of a specific attribute of a COSEM object, as illustrated in Figure 2.

The APDU of the GET request (Figure 3), illustrates this structure by specifying, via an attribute descriptor, the ClassId (0001 for Data), the InstanceId (OBIS code 1.0.1.8.0.255 for total active energy), and the AttributelId (02 for the value). Object Identification System (OBIS) codes, structured hierarchically (1.0.1.8.0.255), precisely identify metering data.

The corresponding response, see Figure 4, contains InvokeIdAndPriority (00) to associate the response with the request and the requested value (for example, 12345, or 0x3039).

```
<GetRequest>
  <GetRequestNormal>
    <InvokeIdAndPriority Value="00" />
    <AttributeDescriptor>
      <ClassId Value="0001" />
      <InstanceId Value="0100010800FF" />
      <AttributelId Value="02" />
    </AttributeDescriptor>
  </GetRequestNormal>
</GetRequest>
```

Fig. 3. GET Request APDU translated in XML.

```
<GetResponse>
  <GetResponseNormal>
    <InvokeIdAndPriority Value="00" />
    <Result>
      <Data>
        <UInt32 Value="3039" />
      </Data>
    </Result>
  </GetResponseNormal>
</GetResponse>
```

Fig. 4. GET Response APDU translated in XML.

DLMS APDUs encapsulates communication services in a compact format, guaranteeing standardized, interoperable interaction in smart meter networks.

C. DLMS/COSEM Session

The platform also simulates a DLMS/COSEM session, as shown in Figure 2. Client A (concentrator) wants to send a request to server D (Linky) to retrieve its consumption index. The client starts by sending an AARQ to the server, which responds favorably with an AARE. The session is established, and the client can make its requests. A GET request is generated and sent to the server, as detailed in Figure 3. The server then generates its response and sends it to the client, as shown in Figure 4. Once the customer has completed all their requests, it request to end the session with an RLRQ. The server responds favorably with an RLRE.

V. CONCLUSION

To conclude, the demo proposes a visual representation of network protocols used by smart meters. It could also be used for pedagogical purposes. A video has been made to showcase the demo, available here: https://gitlab.inria.fr/msilard/demo_smart_grid/-/blob/main/demo_g3_plc.mp4.

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