INTEROPERABILITY STRATEGY FOR AN AMI DEPLOYMENT IN THE US

Iker URRUTIA
Iberdrola – Spain
iurrutiag@iberdrola.es

Iñigo LARUMBE
Iberdrola – Spain
ilarumbe@iberdrola.es

Phil MORNEAULT
Avangrid - US
phil.morneault@avangrid.com

Paul SISSON
Avangrid - US
paul.sisson@rge.com

Ed BEROSET
EPRI – US
eberoset@epri.com

Tim GODFREY
EPRI – US
tgodfrey@epri.com

ABSTRACT

This paper explains the novel interoperability and interchangeability strategy adopted by Avangrid Networks (US subsidiary of Iberdrola) in the smart metering deployment in New York State (US). In the case of Avangrid AMI (Automated Metering Infrastructure) interoperability means various elements from several providers will be deployed on different segments of the network architecture, and are expected to operate seamlessly. From the perspective of protocols, they will have to be open standards to guarantee interoperability at all layers of the OSI model. Interchangeability means that, further to interoperability, any element (meters and network devices) could be in fact replaced by the equivalent from a different manufacturer, at any time, and be expected to keep the functionality that standards prescribe. The paper describes the strategy and the reason behind the adoption of it, detailing the steps that will be taken in order to successfully achieve the goal, which will make the project the first fully interoperable AMI network deployed in the US.

INTRODUCTION

Although most AMI systems and devices comply with some standards, interoperability in the current US market largely remains an unrealized goal. This is due in part to the widespread use of proprietary protocols and data structures combined with ineffective or non-existent certification processes for some of the potentially relevant standards. However, Avangrid believes interoperability will accelerate the digitization of the grid in a cost effective way, and want to pursue this path, following the successful experience [1, 2] in Spain. This strategy is facilitated through the existing work performed by standards organizations [3, 4] and industry alliances [5, 6], which have developed open standards as well as proper certification processes.

The existence of real interoperability in the AMI market would be leveraged by all the industry, reducing the cost of the technology and accelerating the evolution as well as the enhancements and implementation of additional functionalities. Major benefits of interoperability for the utilities are:

- Reduced risk of single vendor dependency
- Incremental leverage to negotiate future system enhancements and influence technological evolution
- Expanded knowledge and control of the solution, both in the Telecommunications arena (Radio Frequency technology) and in the application (metering use cases and advanced functionality)
- Increase control of Cyber Security strategy
- Accelerate development of new use cases and applications
- Allow the use of open and flexible platforms for meter field operation and maintenance

In order to achieve the aforementioned interoperability, Avangrid will select two major AMI manufacturers to deploy an interoperable AMI network with compatible network devices (i.e.: Collectors), NICs and meters, from both manufacturers. The project will require the use of standards-based implementations at all layers of the protocol stack, from Physical to Application. Cybersecurity is also guaranteed through open standards, combining a robust digital certificate-based authentication with strong encryption at the network level, as well as implementing application-layer security. In this paper, we will explain the specific steps the organization will take to achieve true interoperability and guarantee cyber security best practices are in place for an AMI deployment.

Following the introduction, Section 2 covers the overall system architecture proposed for the AMI solution, compared with existing non-interoperable systems currently available in the market. Section 3 identifies the protocols selected for the different layers of the protocol stack while Section 4 describes the certification and testing phase, key for the success of the deployment. Finally, Section 5 gathers the conclusions of the paper and the proposed next steps.

SYSTEM ARCHITECTURE

The pillar on which interoperability will stand is the existence of a Radio Frequency (RF) Mesh Field Area

Network (FAN) that will use open protocols mainly defined by the IEEE and the IETF. The targeted architecture is represented in Figure 2. Overall, the structure is very similar to other AMI deployments based on non-interoperable technologies (Figure 1). From the system point of view, the solution includes a single Head End System (HES) responsible for communications with the end-points. The HES will also interface with other corporate systems, such as Meter Data Management (MDM), Outage Management System (OMS), etc. These interfaces do not differ from a standard AMI solution.

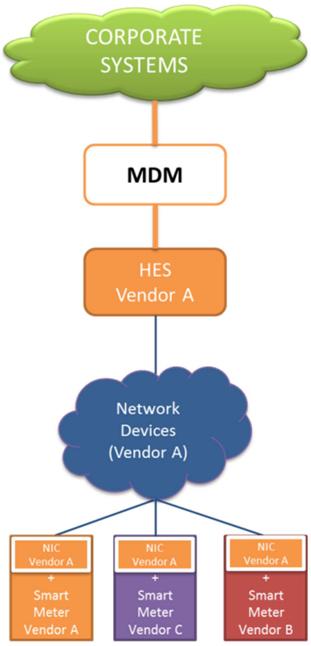

Figure 1. Non-Interoperable AMI Architecture

However, the novelties reside downstream from the HES to the end-points. For the purpose of this paper, end-points mean the combination of a meter and a Network Interface Card (NIC) compliant with the protocol stack detailed in section 3. Actually, the main difference between two architectures is represented by the introduction of network devices and NICs from two different vendors, while the non-interoperable solution relies on a single vendor for these devices, although combinations with other manufacturers' smart meters are possible and exists in the market.

As explained in the introduction, the AMI network will be formed of devices, collectors and end-points, from at least two different manufacturers coexisting in the same FAN. The HES will be able to communicate with any end-point using the same protocols described in section 3. For the HES, it is transparent which manufacturer's is each end-point because the HES will address all the meters in the same way, which is substantially different from existing non-interoperable systems. Figure 2 identifies the aforementioned architecture assuming there will be two manufacturers, called A and B respectively.

The distribution of collectors and end-points per manufacturer could vary without impacting the performance and functionality of the system. Also, the introduction of additional manufacturer´s devices, either collectors or end-points, should not impact the system.

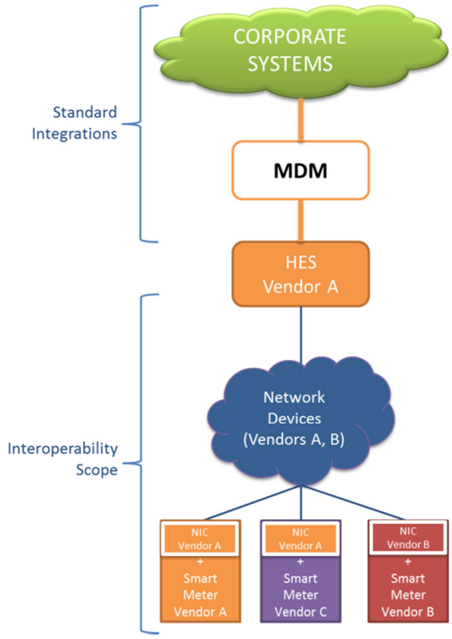

Figure 2. Interoperable AMI Architecture

PROTOCOL STACK

As stated earlier, in order to achieve the envisioned interoperability deployment, the first step is selecting the protocols to be used at the different layers of the OSI model, or more specifically, the TCP/IP protocol stack traditionally used in most modern AMI implementations, also the selected stack in this case. Together with the protocols, profiles will be defined where needed. Selected protocols are open and public standards and offer a robust certification process to guarantee compliance with the corresponding specifications.

Based on these characteristics, the previous experience in similar deployments in Europe and the maturity of the organizations promoting these technologies, the selection for the application layer is DLMS/COSEM (IEC 62056) and the selection for the telecommunications layers is Wi-SUN (based on IEEE 802.15.4), which will specify soon a profile for DLMS/COSEM (a liaison between Wi-SUN Alliance and DLMS User Association was established in Q3 2017). The complete protocol stack is shown in Figure 3 and explained in the reminder of this section.

The PHY layer will be based on Wi-SUN FAN 1.0 profile specifications. As of today, version 1.0 includes several modes out of the 915 MHz MR-FSK PHY of IEEE 802.15.4g (now subsumed into IEEE Std. 802.15.4-2015 Low-Rate Wireless Networks) plus it defines new ones. The mandatory mode in IEEE 802.15.4-2015 is the 50 kbps one (filtered 2FSK with modulation index 1 and channel spacing of 200 kHz), so that will be the one to initially base interoperability on.

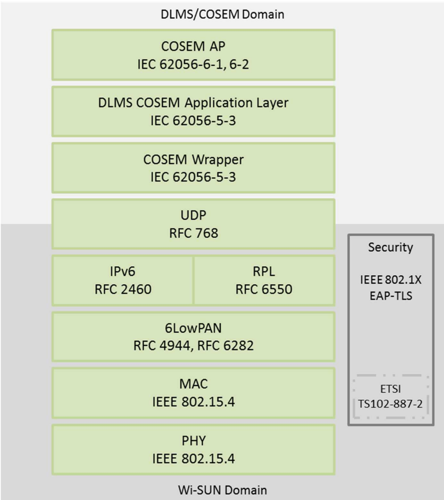

Figure 3. Protocol Stack

The MAC layer will be based on Wi-SUN FAN 1.0 profile specifications. When several options exist (such as support of TCP in addition to UDP, and support of Node to Node Pairwise (N2NP) Authentication and Key Generation), an agreement will be reached by parties on the exact profile to be implemented for Avangrid.

RPL (RFC 6550) shall be used as the routing protocol (as described in Wi-SUN FAN profile specification). 6LoWPAN, IPv6 and UDP will be supported as mandated by Wi-SUN Alliance. For Cybersecurity, specific protocols complying with Wi-SUN FAN specs will be used: IEEE 802.1X and EAP-TLS (RFC 5216) using IEEE 802.1AR with certificate formats based on X.509 PKI certificates (RFC 5280).

In the first phase of the implementation, network management will not be part of the interoperable solution, due to the complexity and variety of functions normally available through network monitoring systems (NMS). Therefore, a management system per vendor will be required in order to manage the network devices and network interface cards of both vendors. However, in the medium term, as scoped in the Wi-SUN FAN 2.0 market requirements document, network management will be included in the standard. Therefore, in the medium term, it is the expectation to include a single NMS in the architecture.

A specific DLMS/COSEM (IEC 62056) profile (companion profile) shall be used as the application protocol according to the latest editions of colour books. The Green Book defines the architecture and protocols, the Blue Book the OBIS codes needed for DLMS profile implementation, the Yellow Book the use cases and testing procedures and finally, the White Book the glossary of term used in the other colour books.

CERTIFICATION AND TESTING

As explained in the previous section, one of the requirements to select the technologies has been the availability of a robust certification process, performed by independent third parties (laboratories), to certify that implementations are compatible with the specifications. Both DLMS/COSEM and Wi-SUN are offering certification processes.

In the case of Wi-SUN, the certification process availability was announced in October 2018 and first certified products are already available in the market. In the case of DLMS/COSEM, the certification process needs to be developed based on a specific profile, as it will be defined as part of the project. In this regards, the Company will specify the expected functionality in terms of COSEM objects to be implemented by the meters (companion profile). The manufacturers implement these objects and go through the established third party certification process to verify adherence to specification.

However, after these certifications are earned and before starting deployments, an Avangrid interoperability verification process will be put in place. The manufacturers, together with the collaboration of EPRI (arbitrates results as an impartial observer), will complete the process to verify functionality, standards compliance as well as full interoperability and interchangeability. The reason to add this additional process is to guarantee not only compliance with specifications but also interoperability, not always guaranteed in traditional certification processes.

In order to verify the interoperability, four different testing stages, called milestones, will be established, as described in the following paragraphs. The manufacturers will need to demonstrate achievement of each milestone to move to the next one. In the case of identified interoperability issues, a recommendation of changes will be provided, based on the technical understanding of the standards. Causes of non-interoperability could be due to 1) Discrepancy in vendor implementation of the standard, or 2) Issue with the standards themselves (ambiguity or allowing multiple interpretations). In case 1) the process will identify the vendor deviation from the standard. In Case 2) an agreement between the parties would be required in order to determine the resolution and implementation. In this case, also a notification to the organization maintaining the specification will be sent with the corresponding recommendation to reflect the agreed changes.

Milestone 1 - Wi-SUN PHY Layer Evaluation:
This stage will include Physical (PHY) layer testing

between two manufacturers' Wi-SUN equipment that already has Wi-SUN PHY Certification. The two devices will be installed in RF shielded boxes, with RF cable and variable attenuator between them. A splitter port will provide access for a spectrum analyzer in order to better identify potential issues. The testing will exercise all PHY operating modes specified in the WI-SUN PHY Specification, Annex B FAN Profile. Therefore, the modes in Table 1 will be tested.

PHY Mode	Symbol Rate KS/sec	Modulation Index
Operating Mode# 1a	50	0.5
Operating Mode# 2a	100	0.5
Operating Mode# 3	150	0.5
Operating Mode# 5	300	0.5

Table 1. PHY Operating Modes

Testing will be conducted for the FCC regulatory domain (North America in Wi-SUN specs) and it will require access to test modes provided by the device manufacturer and/or chipset provider (defined in PHY Spec Section 8 "*PHY Test Mode Requirements*"). The test modes should enable configuration of the PHY modes, operating frequency, channel bandwidth, modulation index and other PHY parameters, and allow transmission and reception of known test patterns to allow measurement of bit and packet error rate. Since the radios don't generally support continuous transmission modes used to test true Bit Error Rate (BER), testing will require turning Forward Error Correction (FEC) and Cyclic Redundancy Codes (CRC) off in the radios, and send long packets of test patterns. From the received packets, the content will be compared and a BER value will be calculated. In addition, Frame Error Rate (FER) will be tested using typical frame sizes, to evaluate the effectiveness of FEC (if implemented).

As a summary, the activities to be included under this milestone are:

- Create Test Plan for PHY testing. It will go beyond the Wi-SUN PHY Interoperability Test Specification that is used for certification, avoiding overlaps. These tests will focus on optional or extended modes and settings, and the abilities of the devices to identify and correctly handle them.
- Design and Setup Test Bed for PHY testing. It will be based on the Wi-SUN FAN certification test bed but reduced for the more limited scope of PHY testing. Generally, the test bed consists of a control computer that executes test scripts derived from the certification test plan and a set of test bed devices from multiple manufacturers. For the Wi-SUN FAN certification, the test bed includes 14 devices in shielded enclosures, cabled together using SMA connectors, RF cabling, splitters and attenuators. For the PHY interoperability milestone, the number of devices will be reduced.
- Execute testing of data exchange, PER and BER for each operating mode.
  - For modes where data exchange succeeds, test received sensitivity for each operating mode in middle of band channel. Measure RF power from transmitting DUT and use RF attenuator to drop receiver level to where BER increases to 20%.
  - Repeat sensitivity tests at band edge channels.

<u>Milestone 2: Wi-SUN MAC Layer Evaluation:</u>

This stage is intended to complement and minimize duplication of Wi-SUN FAN certification testing, while identifying potential interoperability gaps. The testing will exercise practical use cases including simultaneous application layer protocols (such as DLMS/COSEM) with other simulated traffic representing multi-services shared networks (simultaneous IP networks, varied QoS per application, etc.). It will also include multi-node concurrent throughput testing to characterize any variances in MAC implementation (CSMA back-off, Energy Detect, etc.). Also, the testing will examine mixed network operation with "pure Wi-SUN" devices operating concurrently with vendor devices' extended modes (if implemented) for possible impact on compatibility and interoperability. Devices under test are expected to supply TBU (test bed unit) and non-TBU (Production) versions of devices, or documented processes to enable and access TBU certification modes on production devices.

As a summary, the activities included under this testing stage are:

- Specify test plan: it will contain the optimal subset of test cases from Wi-SUN certification, based on information received from device makers including any adoptions or modifications to the test harnesses. At a minimum, the test plan will include discovery, mesh formation, multi-hop routing, security procedures and error handling.
- Specify Test Bed and Harness Setup
  - Compared to the PHY test bed, a larger number of devices are required to test the MAC. These tests include device discovery, mesh formation, and multi-hop routing. As the test plans are finalized, it will be determined if the test bed will require the full set of 14 devices or less
- Perform Testing with DUT pair of two vendors
- Perform Application Layer Testing, identifying unknown traffic
- Perform Throughput Tests
- Perform Latency tests with mixed-vendor scenarios (validate optimal routing for border to edge as well as edge to edge use cases)

- Perform Multi-Application test with multiple IP networks and QoS
- Coexistence test with vendor-extended modes

Milestone 3: Laboratory Interoperability Demonstration
This milestone is intended to demonstrate end to end interoperability in a laboratory environment, testing all the layers of the protocol stack from physical to application, including the Head End System (HES).
As a summary, the activities to be included under this milestone are:

- Determine test cases and test bed
  - Up to 10 test cases will be evaluated
- Evaluation of vendor A DLMS implementation against HES, executing test cases defined
- Evaluation of vendor B DLMS implementation against HES, executing test cases defined

If the deployment includes other vendor's meters integrated with Vendor A NICs (see figure 2, Meter Vendor C), these devices will start the interoperability verification process in Milestone 3, because Milestones 1 and 2 are evaluating NIC functionality already tested for Vendor A NIC.

Milestone 4: Field Interoperability Demonstration:
This milestone is intended to demonstrate end to end interoperability in a field deployment. It is basically replicating Milestone 3 in a field environment instead of laboratory. Therefore, the main difference from the previous milestone is the test bed, but the rest of the items remain the same. The most important consideration for this testing is the potential impact on customer experience due to experimenting in real field installations. However, this problem will be mitigated by the level of confidence obtained with the previous milestones. If required, other alternative approaches, such as the installation of the meters in non-customer sites (i.e: poles) or the installation of dual socket adapter (aka. serial adapters) for the new meters will be considered.

CONCLUSSIONS

Avangrid strongly believes that interoperability will accelerate the digitization of the grid in a cost effective way, and want to pursue this path. In order to complete an interoperable AMI deployment in New York State, the aforementioned strategy will be followed, using the established certification programs complemented with strong functional testing, critical to enabling true interoperable products for the Smart Utility. As hundreds of millions, and soon billions, of intelligent and connected devices are used to optimize the management of critical infrastructure and resources, and to provide new services, interoperability will be critical to assure affordable and secure solutions in a rapidly evolving environment.

The proposed strategy will contribute to a broader realization of interoperable Smart Grid solutions for utilities across the Americas, along with the inherent benefits of interchangeability.

The company will soon start executing the plan described in this paper. For the successful implementation, full cooperation of EPRI and the selected vendors will be required, due to the intense schedule of testing proposed, which could impose some implementation challenges. However, the active participation of most AMI vendors in standards organizations such as Wi-SUN alliance and DLMS UA is a clear indicator of their commitment to interoperability. The moment is now.

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