ELECTRIC POWER RESEARCH INSTITUTE

Toward a World Standard Advanced Meter Application Layer Protocol

An Analysis of the Current and Possible Future State of the Industry

2018 TECHNICAL REPORT

Toward a World Standard Advanced Meter Application Layer Protocol

An Analysis of the Current and Possible Future State of the Industry

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Abstract

This report surveys the currently most widely used advanced meter application protocols and examine what would be required to create a single unified standard. It gives an overview of the technical attributes of the candidate standards, DLMS/COSEM and ANSI C12.22, and describes a plausible path by which the industry might arrive at a single world standard.

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PRIMARY AUDIENCE: Utility metering personnel; meter and software manufacturers

SECONDARY AUDIENCE: Utility regulators; third-party software and system integrators and consultants

KEY RESEARCH QUESTION

There are currently many meter application-layer protocols in existence. This research examines the question of what might be gained by unifying a single world standard and how such a result might be achieved. What are the candidate standards? What are the costs and benefits, to all stakeholders, of unifying?

RESEARCH OVERVIEW

This research surveyed existing meter application-layer protocols, by first considering a few fundamental attributes: the protocols must be standardized already, widely used in industry, and have security mechanisms built in. After this was accomplished, and technical merits examined and described, an examination was performed to analyze what would need to change to achieve a goal of a single unified standard and the costs and benefits of such a transition. Finally, a plausible path to the realization of such a goal was sketched.

KEY FINDINGS

- Globally, the two candidate protocols are DLMS/COSEM and ANSI C12.22 (page 1-1)
- Both DLMS/COSEM and ANSI C12.22 are technically sufficient for the most common metering applications (page 4-1)
- DLMS/COSEM has a larger array of security mechanisms, such as X.509 Certificates and digital signatures, than ANSI C12.22. (page 2-1)
- The testing and certification programs for DLMS/COSEM appears to be more mature than that of ANSI C12.22. (page 3-1)
- Although the path to a single world standard is not simple or easy, it does appear to be achievable if industry consensus is achieved and maintained. (page 5-1)

WHY THIS MATTERS

As the AMI industry matures and as more utilities elect to deploy meters, standards will play an important role in the overall success of these deployments. By carefully and objectively considering a possible unified world standard for meter application-layer protocols, utilities and manufacturers will be better equipped to plan for devices and systems that will not only serve today's needs but to also meet future requirements in a safe, secure, accurate and affordable way.

HOW TO APPLY RESULTS

Utilities and manufacturers can apply the results of this research by examining their own business and planning and evaluating them in the light of the proposed future state in this report. Does a standardized meter application protocol make sense for your business, and if so which standard would deliver the largest benefits and the least cost?

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI's Advanced Metering Research in project set 161F is developing an open source reference implementation of the DLMS/COSEM protocol that will be released 4Q2018. Interested readers are invited to watch for webinars explaining this result.

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Section 1: Meter Application Protocols

Electric meters are an important and fundamental component of the modern integrated grid. In addition to the traditional duty of measuring energy usage, modern meters typically measure demand, current, voltage and a host of other quantities, often logging these measurements in hourly, quarter-hourly or even finer time increments. Efficient use of data requires getting it to the right places accurately, securely and on a timely basis.

In the past, monthly billing data reads were done by a human meter reader who would physically visit every meter and record the energy use indicated on the dials of the meter. In more recent years, the trend has been to use an Advanced Metering Infrastructure (AMI) to use various communications mechanisms and media to retrieve data from the meters without physically visiting them. AMI communications have employed over-the-air radio frequency (RF), powerline carrier (PLC), telephone line, fiberoptics and other media. Due to varying physical, economic, regulatory and architectural considerations, no single underlying technology has yet been universally adopted. However, much in the same way that a computer can use a single web browser *application* over many different kinds of underlying *network* technologies (such as Ethernet or Wi-Fi), some meter application protocols may be used over diverse underlying communications technologies.

The OSI model

One widely used conceptual model used to describe and classify the different portions of a communications protocol is called the Open Systems Interconnection model, often shorted to "the OSI model." (ISO/IEC 1994) The layers of this model are summarized in Table 1-1 Summary of OSI model layers. The model, originally published in 1984, describes seven distinct layers, although in practice, the top three layers (Application, Presentation and Session) are often combined into a single piece of software called an application. In this conceptual model, each layer *instance* can be thought of as communicating with a peer instance at the same layer via underlying layers. For example, imagine the scenario that, communications expert A at one utility wished to send a printed physical copy of this report to a peer communications expert B at a different utility. In this scenario, the two people A and B are, analogous to peer instances of an *Application protocol*. One could imagine that A would print the document on a printer, physically gather the pages and put them together into an envelope. If we assume that A and B both have assistants, C and D respectively, then perhaps A hands the envelope to C and requests that it be sent to C. We can think of C and D as peer instances of a *Transport protocol* (recalling, as noted above, that the top three layers are often combined together). Assistant C may choose a postal service, a package delivery service, a bicycle courier or some other underlying *Network protocol* to get the package delivered. One key feature of this is that the application layer protocol instance might neither care nor specify which underlying network protocol is used. This independent operation of layers is an important feature of the OSI model as well. Finally, we presume that by whatever means, the physical package arrives and is picked up by assistant D who might unwrap the original packaging and deliver just the contents, the envelope containing the physical printed report prepared by A, to person B, completing the transaction.

Key points to remember about the OSI model, then, are that we can think of the layers as being independent, that it effects communication from one layer instance to a peer instance, and that it accomplishes this by interacting directly only with the layer immediately adjacent.

Table 1-1
Summary of OSI model layers

Layer	Name	Example Protocol
7	Application	HTTP (web browser)
6	Presentation	HTTP (web browser)
5	Session	HTTP (web browser)
4	Transport	TCPv6
3	Network	IPv6
2	Data Link	IEEE 802.11 (Wi-Fi)
1	Physical	IEEE 802.11 (Wi-Fi)

Another important aspect to remember about the OSI model is that it's just a conceptual model to aid in understanding and classifying protocols, but neither a regulation nor law of nature. This means that many useful real protocols, including the ones mentioned as example protocols in the table, don't necessarily completely and faithfully match the model exactly.

Currently used meter application-layer protocols

As described in the previous section, the purpose of an application-layer protocol is to support a domain-specific application using a high-level protocol (that is, one that is above layer 4, the Transport layer, in the OSI model). There are many application layer protocols in use for the metering domain. Some are proprietary and some are standardized. Some provide robust security mechanisms while others have none. In the context of this report, proprietary protocols or those which do not have security mechanisms are unlikely to satisfy worldwide requirements; for this reason, only non-proprietary meter application protocols with at least some security mechanisms are considered. For similar reasons, protocols which can operate over a network, rather than solely point-to-point protocols are also the only type considered here. Worldwide, this leaves us with two principal contenders for a potential world standard AMI application layer protocol. They are IEC 62056-5-3, also known as DLMS/COSEM (IEC 2017) and ANSI C12.22, also published as IEEE 1703 (ANSI 2012).

DLMS/COSEM and ANSI C12.22 are the leading AMI meter application layer protocols.

The scope of both protocols is similar; both protocols tend to be implemented in both meters and in a head-end system and are little used outside that realm. That is, as the head end system receives data, it is often translated into some other format for sharing with other systems within the utility and beyond. Both protocols also have robust security mechanisms and are designed for networks. In the following sections, each of these protocols will be described in some technical detail. Later sections will describe some of the expected effects of choosing a single protocol and conclude with a section describing the state of the industry today and some paths that might be taken toward a single world standard AMI meter application protocol.

Section 2: DLMS/COSEM

The DLMS/COSEM is Device Language Message Specification (DLMS) and COmpanion Specification for Energy Metering (COSEM). Together, these two pieces describe both an object model (COSEM) and the communications protocol to interact with these objects. In the COSEM context, "object" is intended in the sense of a software object as commonly used in a widely-used computer programming paradigm called "object-oriented programming (OOP)" In OOP, a collection of data and the operations (often called "methods") that can be done with it are defined together as an object. An example object in COSEM is the Data Profile Object. The Object interface defines a generic interface to set parameters and request data (the methods) and associated various identifiers allow the contained data to be interpreted as, for example, either a load profile record or a power fail event log. The intent is to allow a regularized interface to objects which simplifies both the use and understanding of COSEM objects by people.

The protocol portion, DLMS, is defined in terms of the OSI model described above. That is, the layers are explicitly mapped to OSI model layers and for each layer, the interfaces to layers above and below are explicitly defined. Here too, the intent is to make the both use and understanding of the protocol easier for human beings.

The DLMS/COSEM protocol is developed by the DLMS Users Association, which then feeds this work to the IEC[1] for standardization as the IEC 62056 series of standards. The DLMS Users Association is a membership organization that also maintains a conformance testing and certification program.

Security provisions

Earlier versions of DLMS/COSEM protocol provided for AES-128 in GCM mode as well as key wrapping for key distribution. The current version now includes more advanced cipher suites based on NSA Suite B, X.509 certificates and elliptical curve digital signatures for authenticating the origin of messages. With these security features, data compression via ITU V.44 was also added. The mechanisms for key distribution, certificate verification and key agreement are all explicitly provided for and specified in the standard. (IEC 2017)

[1] Specifically, for the relevant portions of DLMS/COSEM considered here and published as the IEC 62056 series of standards, the work is standardized via IEC Technical Committee 13, Working Group 14.

Adoption and certification

As mentioned earlier, the DLMS Users Association maintains a conformance testing and certification program. Their web site currently lists over 1000 certified products from dozens of companies distributed throughout the world. (DLMS Users Association 2018)

The largest utilities in France and Spain have standardized on DLMS/COSEM and have developed Companion Specifications to meet their requirements. A Companion Specification, in the realm of DLMS/COSEM is the equivalent to a profile in some other standards; that is, it is a selection of a subset of options within the standard to facilitate interoperability. Several open source implementations exist, but most appear to be the head-end side rather than the meter side. (MeterLinq 2014) (Gurux 2018) (Rabine 2018)[2]

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[2] EPRI is currently creating a new open source implementation that is intended to be released at the end of 2018. It will implement code for both the head-end system and for the meter. The protocol does not itself specify such a split, but code for a general-purpose computer running a desktop operating system (the head-end) and code for an embedded system with real-time requirements (the meter) tend to be written and structured very differently.

Section 3: ANSI C12.22

As described in the Forward section of the standard document, the ANSI C12.22 protocol "is intended to accommodate the network messaging requirements of an advanced metering infrastructure." (ANSI 2012) The fundamental unit of data transfer within ANSI C12.22 is the *table*. These tables are the same as those described in ANSI C12.19 (ANSI 2012). A table is simply a collection of similarly themed data items within a meter. Example tables are Standard Table 1 "General Manufacturer Identification Table", Standard Table 6, "Utility Information Table", Standard Table 23, "Current Register Data Table" and Standard Table 63, "Load Profile Status Table." The standard describes over 100 standard tables, grouped for human convenience into "Decades," although the protocol does not use the concept of Decades. The standard also includes a numeric range reserved for Manufacturer Tables. The intent for this range is to accommodate innovations and features that may be implemented within a meter, but are not yet standardized.

The two essential operations performed on Tables are provided via the Read and Write services. The standard also provides other services that assist in establishing a communication session (Identification, Logon, Logoff, Security, Wait) and still others that are used for the establishment and maintenance of the device's connection to the underlying network. Both one-way and two-way communications are supported as are both session-oriented and sessionless communications.[3]

Security provisions

The ANSI C12.22 protocol uses standard encryption ciphers and mechanisms, namely AES-128 in CTR mode with CMAC mode for authentication combined into a mode that is called EAX' (EAX prime). It is, as the name suggests, derived from another mode named EAX, but adapted for use with variable-length messages.

[3] The technical distinction between session-oriented and sessionless communication is subtle, but essentially, in session-oriented communication, a session is established, used to transfer data, and then torn down. In sessionless communications, each individual message is used to convey any required security tokens and associated data and each message is interpreted individually without regard to ones that came before or after.

The EAX' mode, is secure when used in the context of C12.22 but cannot be used securely in contexts which require the encryption of data that is shorter than the key length of 16 bytes for AES-128. (Minematsu, et al. 2012)

While the standard describes the means of using encryption and decryption and a means for extending the standard to include other cipher suites and mechanisms, it does not include descriptions for key establishment or distribution.

Adoption and certification

All of the major North American meter manufacturers and several communications manufacturers participated in the creation of the ANSI C12.22 standard. A survey done just before the first release of the C12.22 standard in 2008 indicated somewhat tepid industry response with over half of the surveyed AMI vendors either not having considered implementing the standard of having considered but not yet started implementing. (EPRI 2008) Three of the manufacturers are known to have implemented the standard in at least some of their devices. Two of them, Itron and Honeywell (formerly Elster), have made their implementations available as open source. (Itron 2008) (Elster Solutions 2016)

One Canadian company has formed a testing and certification entity, however, no certifications, testing procedures, or product listings are publicly available from that web site. (ECMX 2009)

Section 4: Using a Single Protocol

Before the standardization of communications protocols for meters, each manufacturer had its own unique protocol or protocols. Understandably, this effectively prevented interoperability among devices from different manufacturers. Standardizing communications protocols for metering devices has been an ongoing process for decades.

As succinctly stated by a European standards body, "Standards provide people and organizations with a basis for mutual understanding, and are used as tools to facilitate communication, measurement, commerce and manufacturing." (CEN/CENELEC 2018) This mutual understanding can better enable devices from different organizations to communicate effectively and accurately with each other and can reduce integration and operation costs by not requiring unique software for each kind of device. Having global standards which accommodate essential local needs is, in many ways, the ideal situation. (NEMA 2015)

Either DLMS/COSEM or ANSI C12.22 could be used meet the technical requirements for most regions.

Because both ANSI C12.22 and DLMS/COSEM have been used successfully and internationally for some years, it seems likely that the essential technical requirements for most regions could be met adequately by using either set of standards. This section asks the question, "What, if anything, is there to be gained by using a single standard worldwide?" In the following sections, which talk about benefits and costs, these benefits and costs are not exclusively, or even primarily, purely financial in nature.

Potential benefits of a single global standard

One potential benefit to a single global standard would be that manufacturers and software developers would no longer have to produce multiple versions for different regions. Many of the major meter manufacturers internationally create meters for multiple markets. If a single world-wide meter application protocol were used, it would simplify the process for producing meters, software and other related equipment internationally. It may also lower the barrier to international distribution for some companies which do not today participate in multiple markets. All of these would benefit not only manufacturers, but also system integrators, utilities and end user rate payers by reducing costs and eliminating some of the difficulties of getting disparate systems communicating effectively and accurately.

Another benefit of a single global standard is that utilities would have more choices of software and equipment due to the increased competition among interoperable devices and software. With a single global standard, software created for one region could be used in others without having to rewrite or adapt existing software application layer protocols. Here again, the expected benefit would be in reduced costs to both utilities and the rate-paying public.

Better security might also be another benefit, especially in regions in which both standards are currently used. A single utility using a single meter application layer protocol would be better able to standardize an appropriate set of security policies and mechanisms than one which had to accommodate multiple protocols.

International innovation could be more easily shared among utilities if there were a single global meter application standard. For example, Eskom in South Africa has over 4.2 million meters prepaid meters currently in use (Eskom 2018) and has experiences with prepayment systems and equipment for many years. Their experience and expertise may be easier for utilities in other regions to benefit from if the meter application protocol were the same globally. This would benefit not only the utilities, but also their customers and vendors. It could also help consulting firms which have successfully addressed particular needs in one region to translate their expertise to other regions.

Potential costs of a single global standard

Analogously to the situation with meter application-layer protocols internationally, AC distribution systems across the globe tend to use either 50Hz or 60Hz as their fundamental frequency. Japan uses both frequencies, with eastern Japan using 50Hz and western Japan using 60Hz. In the aftermath of the terrible Tohoku disaster in 2011, the unification of frequency standards in Japan once again became a topic of popular discussion. The reasons cited for not doing so were that such a conversion would be "too expensive and too difficult" and a "political nightmare" in trying to choose which frequency to use. (Gordenker 2011)

Financial expense and difficulty are also two potential costs of moving to a single world standard. Changing any particular system from one to the other communications standard would entail financial costs because change is not free. However, it is generally much less expensive to change software than hardware, so as newer meters with over-the-air upgradeable firmware become more common, this cost should continue to reduce. At least one meter-related standard has already explicitly defined such requirements. (NEMA 2009)

If a system were to be converted from one standard to use the other, either the change would have to be accomplished all at once or a phased approach could be used to operate both in parallel for some period as individual devices and systems were changed. The all-at-once approach eliminates the potential difficulties in running systems in parallel but may entail a higher risk if any portion of the conversion encountered a problem. The phased approach would allow for small-scale pilots and incremental testing to reduce risks, but may mean a higher overall cost due to the time spent by utility and/or vendor personnel in effecting the conversion. In some ways, utilities are already experiencing this kind of dilemma, however, each time they elect to do any meter firmware upgrade, so it is expected that the ongoing accumulation of industry experience with such upgrades is likely to be useful here.

For any utility which already had in-house expertise in one protocol, the cost of conversion to using the other must include the time required to retrain personnel to be able to also become expert in the other communications protocol. This would not be unlike the situation today when a utility decides to change meter vendors. Since many of the tools used by utility personnel are created by manufacturers express for their own devices, such conversions may provide useful indicators of the cost of such retraining.

While both DLMS/COSEM and ANSI C12.22 are capable of all of the most common metering application requirements, they are not identical in capabilities. For example, the DLMS/COSEM protocol explicitly describes the provision of digital security certificates while ANSI C12.22 does not. For this reason, any utility which required, for either utility-determined or regulatory reasons, the use of digital certificates would have to work with vendors on an ad-hoc way to support them within ANSI C12.22 since their use is not standardized there. So another possible cost is that there may be locally required features in one protocol that are not present in the other. Here again, current experience with different vendors may be a useful guide since not all meters are capable of the same constellation of features; determining how to manage requirements in this environment may prove similar.

Section 5: Paths to a Single Standard

The first essential requirement to a single world meter application protocol is to achieve stakeholder consensus that this would be a desirable goal. In the absence of such consensus, it is unlikely that such a result would occur organically. For this reason, stakeholders, including utility, regulatory and vendor personnel should carefully consider the full set of consequences for both seeking such a goal and for not seeking it. Some of these consequences are enumerated in the previous section, but it is entirely possible that other factors exist or will exist in the future that have not been documented here.

If a single standard is indeed desired, there are numerous possible avenues and methods to achieve it. One obvious mechanism would be to choose an existing standard and begin moving toward its adoption, but such an endeavor would not reasonably be taken lightly. A careful examination of the match of local requirements to each candidate standards would be a useful first step. This report has provided some technical details on two known and existing potential candidates, DLMS/COSEM and ANSI C12.22 but it there may be others. Any gap analysis of the differences between requirements and the theoretical capabilities of each standard should also be paired with an examination of real implementations. That is, if a standard provides a vital feature but no existing implementation actually supports the feature, this, too is a gap that must be bridged if all requirements are to be satisfactorily met.

After analysis, it may be that gaps still exist. That is, either the standard or the requirements or the implementations or some combination of those must change. Each standardization body has its own set of rules and procedures for how to propose changes and how such changes get incorporated into the standard. As with most aspects of standardization, the most time consuming part tends to be in gaining consensus rather than the technical work of creating a proposal. Implementations may be easier and faster to change, depending on how willing and nimble the vendor happens to be.

Because the impact of meter application protocols tends to be limited to just the meters and the head-end system, with little impact to other systems or devices, such changes, if required, may require less time and effort than it may initially seem. This is especially true if the vendor has already created versions of the firmware and software that implement the targeted standard, as is often the case for the largest global meter vendors.

Given an understanding, for each stakeholder, of what would be required to move to a single world standard, each stakeholder could create a plan describing what steps would be taken. As with any useful plan, this would include not only a list of tasks to be accomplished, but the task sequencing and dependencies, required resources and at least some rough estimates of when they would begin and end.

The last step would be to for all stakeholders to execute according to their plans, coordinating as required. Although utilities and their vendors would likely have the most mutual dependencies of all stakeholders, other dependencies could exist, such as perhaps regulators depending on standards bodies to specify how security mechanisms would work in advance of requiring particular security outcomes.

In summary, one possible path to achieving the goal of having a single international standard meter application protocol would be:

1. Gain industry consensus on the desirability of that goal.
2. For each stakeholder entity, compare local requirements with those met by candidate standards.
3. Perform a gap analysis comparing requirements, standards, and existing implementations of standards.
4. Select one standard and verify consensus.
5. Plan the steps to move to the selected standard.
6. Execute plan.

It is appreciated that this may resemble the old joke about how to get to the moon.[4] However, it's also worth remembering that people actually did go to the moon, and that the first step was undoubtedly to stimulate the imagination by suggesting the idea and sketching out a means of getting there. This report is intended to be just that: a suggestion that such a journey might be possible and a sketch of how and why it might be achieved.

[4] The joke: Q: How do you get to the moon?" A: It's easy! First, you make a plan for how to get to the moon, and then you execute the plan.

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