



Meeting the Design Challenges of Smart Metering

A smart meter is an electronic device that records and reports, via some kind of communications network, the consumption of a utility service, such as the supply of electricity, gas, water, or heating/cooling. In this whitepaper, we explore the fundamentals of smart metering and some of the benefits and challenges that come with it.

Introduction

Smart meters eliminate the need for utility companies to manually read meters or provide estimated bills, and therefore have the potential to significantly reduce costs and increase customer satisfaction, while providing other benefits that will be outlined later in this article.

The first patents related to automatic meter reading were filed in the 1970s, but it wasn't until after the turn of century that any kind of significant smart meter deployments really began. Within the last decade or so a few countries, including Sweden, have essentially moved all electricity customers over to smart meters.

AMR and AMI

The first smart meter deployments, and many still today, used one-way, transmit-only communications. This automatic meter reading (AMR), was initially accomplished with walk-by or drive-by meter readers, but subsequently many utilities implemented fully automated, wireless or wired networks with neighborhood collectors or aggregators that would facilitate the

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connection of many meters to some kind of wide area network (WAN), e.g. a cellular network, so the monthly, weekly, or hourly meter consumption data could be reported back to the billing systems of the utility company.

Advanced metering infrastructure (AMI) is the name given to two-way communications networks, enabling not only remote meter reading, but also the control of meters and other equipment. AMI enables utilities to do things like connect or disconnect a customer, monitor and anticipate changes in electricity make it possible for control distribution and generation equipment to respond to demand, implementing the so called, “smart grid.” AMI can also be used to implement over-the-air (OTA) software updates, for example, to implement new communication protocols or to close newly discovered security gaps.



Smart Metering Equipment

Smart meters are available to measure the consumption of all different types of utilities; electricity, gas, water, and heating or cooling fluid. Originally utility meters used mechanical metrology (measurement), but today almost all new smart meter designs use non-mechanical, fully electronic designs, often referred to as static meters. The move from mechanical to electronic (static) meters goes hand in hand with the move to smart meters, in fact I have even heard some meter vendors in China use the term “smart meters” to refer to any kind of electronic meters, even those that don’t have communications capability.

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Electricity Meters

Electricity meters measure the flow of alternating electrical current into a building or premises. Residential meters are typically single phase, but commercial installations, and many homes in some northern European countries, such as Germany and Denmark, may require specialized meters for their three phase supplies. Traditional electromechanical electricity meters have mechanical dials that count the revolutions of a metal disc that rotates, through electromagnetic induction, at a speed proportional to the electrical power passing through the meter.

Smart meters however, are fully electronic and use current transformers, shunt resistors, or sometimes Rogowski coils or Hall effect sensors to measure current flowing through the meter. In addition to current, the meter also needs to continuously measure line voltage to enable it to calculate power consumed. Initially current transformers (CT)

were very common in smart electricity meters, and there are now a wide range of microcontroller (MCU) based devices dedicated to, and optimized for, implementing such meters.

CT based meters are falling out of favor for new designs, because of accuracy issues with current transformers due to their tendency to saturate with heavy currents, and also their susceptibility to tampering with the use of large magnets.

Gas, Water, and Heat Meters

Gas, water, and heat (or cooling) meters were all traditionally mechanical flow meters, but unlike electricity meters, there are many “smart” implementations of these meters that continue to use the same mechanical metrology principles. These meters may use various kinds of rotating impeller or piston to measure the flow rate. Gas meters can also be implemented using diaphragms and bellows that expand and contract as they fill with gas and then expel it, using a crank to create a rotating motion to turn mechanical dials. In some regions, many smart gas meters are implemented by simply adding an electronic module to a mechanical diaphragm meter. This gas meter module can read the mechanical dials and then transmit that reading to the gas utility company over a wireless communications network. This smart meter retrofit can be done in the field with deployed meters, or it can be done in the factory with brand new meters. These retrofit modules typically use some kind of optical encoders, such as Gray code, to enable reading of the mechanical dials. Similarly, many smart water meters may use mechanical metrology principles, with optical, magnetic or inductive electronic sensors to measure rotation and hence, flow rate. However, in a drive to increase accuracy and reliability, most, if not all new flow meter designs are of a “static” or fully electronic nature. Many static flow meters use ultrasonic principles, measuring the difference in time it takes for an ultrasonic sound pulse to travel upstream and downstream to infer the flow rate of the gas, water or other liquid. In addition, there are also some very effective implementations of water meters that use electromagnetic flow sensing, where application of an electromagnetic field across a pipe will induce a voltage that is proportional to the flow velocity in a conducting liquid (such as water).

Electricity, gas, and water meters may be familiar to most readers, but heat (or cooling) meters are less common. Heat meters are used in locations with district heating systems, where a centralized plant will generate hot water that is then piped to warm homes. Heat meters measure the quantity of hot water that flows into the home, and also the temperature of the water as it enters and also as it leaves the building. These are typically very similar to water meters, but with the addition of temperature sensors, and usually use the same kinds of metrology (mechanical or ultrasonic), although the dynamic range of the water flow rate may be much less than seen by a water meter. Similarly, cooling meters are used in district cooling systems to measure the flow and temperature of chilled water.

Heat Cost Allocators

A heat cost allocator (HCA) is another type of device that may be unfamiliar to many readers. These devices are used in multi-tenant residential and commercial buildings to measure the heat output of each radiator, enabling the fair cost allocation of a shared heating system. In this way, individual tenants pay bills that are proportional to their usage of the heating system, and not an unfair flat rate. Use of heat cost allocators is mandatory in many European countries, including Germany. HCAs have the additional benefit of encouraging energy conservation. If a tenant is paying a flat rate for their heating, they have no incentive to turn the heat down (or turn it off if they are away), they can simply open a window to cool off.

Originally, non-electronic HCAs used the principle of evaporation to measure radiator usage, but today’s electronic HCA have two temperature sensors, one to record the temperature of the radiator, the other sensor records the ambient temperature of the room. These two measurements enable the HCA to calculate the heat used by radiator.

Communications Equipment

In order to meet the minimum definition of “smart”, all these meters need a way to communicate consumption back to the utility provider (or the landlord in the case of heat cost allocators). This is typically achieved with wireless, radio frequency (RF) communication, although some electricity meter deployments use power line communications (PLC) to send data over the electricity wires, but this method appears to be going out of favor due to interference and other

network issues. There are also some short range, wired communication protocols, for example M-Bus, that are used when there are a large group of meters, typically water or heat, are co-located, for example in the basement of a high-rise apartment building.

Usually wireless meters in a neighborhood or multitenant building communicate to some kind of local collector, aggregator, or border router which also has a wide area network (WAN) connection to complete the communications link to the utilities back office billing systems. This WAN connection is often wireless, typically cellular (e.g. 3G/4G/LTE, etc.), but it could also be some kind of wired or fiber connection. Usually, each collector will provide “field area network” (FAN) access to tens or even hundreds of meters. Finding a location and powering the collector can be a challenge for some utilities, but this isn’t a concern for electricity suppliers since they will have substations and distribution transformers conveniently located in the neighborhood.

In-Home Display

The in-home display (IHD) is one last type of smart metering equipment we should mention. These devices have direct wireless connections to the smart meters in the home, typically using a Zigbee mesh network, and can display utility usage rates, both cumulative and instantaneous (e.g. gas usage for the month to date is \$35, current electricity usage is at a rate of \$0.63 per hour, etc.). In home displays are common in homes that are part of the GB Smart Energy deployments of smart meters, where all electricity and gas meters are able to connect to a Zigbee home area network (HAN). They are also available from some utilities in north America, where many electricity meters also deployed with built in Zigbee HAN capability.

Communications Technologies

FAN

As I have alluded to, there are many different types of communications technologies used in smart meter deployments. Typical installations use a sub-GHz field area network (FAN) with a star or mesh topology, using proprietary protocols running on Industrial, Scientific and Medical (ISM) unlicensed frequencies. Many of these proprietary protocols may be based on the IEEE 802.15.4g physical layer standards, and many AMI equipment vendors are adapting their products to be compatible with the standards adopted by the Wireless Smart Ubiquitous Networks (Wi-SUN) alliance, with the first Wi-SUN compliant equipment certifications expected in 2018. Wireless Meter-Bus (wM-Bus, EN 13737) is another ISM-band FAN technology that is quite common in many European countries, both for utility meters and also for heat cost allocators. The WIZE Alliance (backed by GRDF and SUEZ in France) has built on the wM-Bus to develop and promote a 169 MHz ISM-band LPWAN technology for water and gas meters.

There are many different types of communications technologies used in smart meter deployments.

Some AMI vendors (e.g. Sensus, now part of Xylem, and Kamstrup of Denmark) even own frequency spectrum licenses in certain countries that allow them to transmit at higher powers than are permitted on ISM-bands, enabling them to provide longer range, licensed band networks to their utility customers.

LPWAN

Because of concerns locating and powering the neighborhood aggregators required to connect field area meter networks to the wide area network, some utilities, enabled by some meter vendors, are using equipment with WAN capabilities built directly into the meter. This may consist of machine-to-machine (M2M) connection using 2G, 3G or 4G cellular technologies. Until recently, most M2M cellular solutions have generally been too expensive and too power hungry for widespread use and have generally only been used where absolutely necessary. However, the new

NarrowBand IoT standard in 3GPP Release 13 (NB-IoT, a.k.a. LTE Cat NB1), is beginning to move both power and cost in the right direction, towards making licensed band cellular WAN solutions more suitable to smart metering applications. In addition to NB-IoT, there are a number of competing unlicensed band Low Power Wide Area Network (LPWAN) technologies vying for the attentions of utilities, meter vendors, and other smart city and IoT applications, including LoRaWAN, Sigfox, Weightless, and Telensa.

There is currently a lot of debate about LPWAN vs FAN connectivity in the utility industry. Certainly, most electricity utilities, whether municipal or investor owned, seem to have gone in the FAN direction to date for most smart metering deployments.

The thing about smart metering communications is that it is not, and likely never will be, a one-size-fits-all proposition. Even if an electricity utility has invested in its own AMI field area network, it will almost certainly need to connect to some outlying customers with alternative communications technology, such as cellular. This is one reason why many meter designs are modular, with the communications section separate from the metrology part of the meter, usually each section on its own circuit board, with the communications section often having a modular form factor to enable easy field installation and replacement by a utility technician. Certification is another reason why metrology and communications are kept separate in most meter designs.

There are very strict certification requirements for metrology (to ensure accuracy), and while there are also certification requirements for most wireless communications systems, they are certified by completely different organizations. Furthermore, while it is unlikely that the metrology part of a smart meter will ever need a software update, it is quite likely that evolving communication requirements, or more ominously, newly discovered security flaws, could warrant the requirement to deploy software updates to communication subsystems. Of course, manually deploying such software updates would be prohibitively expensive, so there is a desire to now include in smart meters the ability to deploy OTA updates. At a minimum, OTA support requires a doubling of the amount of program memory, usually flash, and appropriate security capabilities in place to prevent unauthorized software updates from being installed on the device.

So while most meters have two separate subsystems today, one for metrology, one for communications, each with their own MCU, it seems like there would be cost and power benefits to combining these two subsystems into one, to take advantage of one of the newer wireless SoC devices that integrate full wireless transceivers, often dual band sub-GHz and 2.4GHz, with a power full MCU and peripherals. Unfortunately, to date, there are few, if any, such instances of single chip meter designs. This is mostly down to the need for modularity of radio communications described above. I expect the first meters to use a single wireless SoC will be heat cost allocators, since these almost always use Wireless M-Bus communications, and have very simple metrology, but there may be the potential for simple gas and water meters to use a similar single SoC design.

The HAN (Zigbee, etc.)

A third class of communication network that is important in many smart metering deployments is the Home Area Network or HAN. The Zigbee Alliance, working with the Electric Power Research Institute (EPRI) and others, developed the Smart Energy profile of their 2.4 GHz ISM-band IEEE 802.15.4 mesh networking specification. Smart meters are now being deployed in North America and the UK that include Smart Energy compliant Zigbee radios. In the UK, Zigbee radios are specified as the required HAN in the smart metering equipment technical specification (SMETS) for all home equipment used in the GB Smart Energy program which has a stated goal to put 50M smart electricity and gas meters in 23 million homes in Great Britain by the end of 2020. The GB deployments have a Zigbee radio in every smart electricity and gas meter, and also an in home display and the communications hub that connects every home's HAN to the WAN.

The goal (not yet achieved with first generation SMETS1 equipment) is that every one of the more than forty energy (electricity and gas) retailers in the UK will use interoperable equipment, making it easy for customers to switch energy suppliers without needing to change their metering equipment. This goal has not yet been realized with the first generation SMETS1 equipment deployed through 2018, but it will become possible when second generation, SMETS2 equipment installations begin before 2019. In addition to enabling easy supplier switching, SMETS2 also adds a requirement for a unique 868 MHz Zigbee radio in order to address locations where 2.4 GHz radio propagation may be difficult. While smart meters in Great Britain use Zigbee HAN communication alone, North

American smart electricity meters deployments often include a Zigbee radio in addition to the more typical sub-GHz FAN radio. Curiously, anecdotal reports indicate despite often deploying Zigbee enabled meters, very few North American utilities are turning on this HAN capability today.

Zigbee isn't the only HAN technology in use, in Japan electricity utilities have adopted a Wi-SUN HAN technology called ECHONET, referred to Route B by Tokyo Electric Power Company (TEPCO).

What about Wi-Fi, Bluetooth and Z-Wave?

While smart meters use a very wide range of wireless networking technologies, there are three well known standards that are notable by their (almost) complete absence in AMI networks: Wi-Fi, Bluetooth, and Z-wave. Wi-Fi likely isn't used because currently the power consumption may be too high for battery powered meters, and, perhaps more importantly, utilities do not want to have to rely on their customer's Wi-Fi networks. The power issue may be addressed in the future by new low power Wi-Fi implementations, so it is possible that we may one day see some use of Wi-Fi in smart meters.

It is possible to imagine a use case for Bluetooth providing consumption information to a customer's smart phone, but even with new Bluetooth Low Energy (BLE) products, the power consumption and cost is likely prohibitive. Furthermore, Bluetooth is not really necessary for this use case since customers could get the same information on their devices via a utility provided portal on a web page, or even better, a via smart phone app. A more interesting use case might be to use BLE to enable a utilities technician to provision and perform maintenance on the meter. Some meters offer this capability today using infra-red data association (IrDA) communications, or near field communications (NFC). BLE could be used to enable a better maintenance interface to the meter, and one that could be implemented on a standard smart phone, and doesn't require specialized IrDA equipment.

Furthermore, it can be relatively inexpensive to add BLE capability to a meter that already has a 2.4 GHz radio for Zigbee, especially if Zigbee is implemented using one of the latest generation of multi-protocol capable wireless SoCs, such as Silicon Labs Mighty Gecko family.

The Impact of Multiprotocol Wireless

An interesting use case for [multiprotocol wireless connectivity](#) is to enable mobile device-based provisioning and management of meters by utility technicians. In this scenario, meters would simultaneously support a utility company's desired FAN or LPWAN protocol and BLE. By enabling simultaneous Bluetooth communication, meter functionality is enhanced and technicians could now use a mobile app to directly setup the meter, gather metrology information, and perform maintenance in the field. These new capabilities simplify daily tasks and have the potential to deliver cost savings to public utility companies. Adding BLE connectivity to a meter can be relatively inexpensive if a multiprotocol chip or SoC such as Silicon Labs [Wireless Gecko](#) is specified.

Smart Meter Market Size

Electricity meters are currently the most widespread type of smart meter, and some countries, such as Spain, Italy, and even China, are approaching a saturation point where almost every existing home has a smart electricity meter installed. It is estimated that worldwide around 100M new smart electricity meters are installed every year, but this number may be slowly declining due to the saturation of some markets. However, it is likely that new meter deployments will continue at similar rates as electricity utilities update their advanced metering infrastructure networks to add more smart grid capabilities.

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The smart grid will implement things like demand response to enable the electricity supply to almost instantaneously respond to changes in demand, or even anticipate such changes if devices like home thermostats can be used to notify the utility of their plans to turn on or off heating or cooling equipment, before actually doing so. Such advanced smart grid functionality requires higher data rates and lower communications latency than is required for simple consumption reporting. For this reason, the latest generations of electricity meters tend to have much greater communications capabilities than other types of meters.

Even if the deployment rates of smart electricity meters may be declining, the rates at which smart gas and water meters are being installed is definitely increasing. There are far fewer gas and water utilities that have completed rolling out smart meters to their customers, and far more opportunities for vendors of these meters to grow their businesses. Annual shipments of both these meter types were likely below 15M in 2017, but shipments could potentially double within the next five years.

Worldwide heat cost allocator shipments are likely in the 20M unit range (+/- 50%), and it would seem that this market is going to be flat for the foreseeable future, since the market is likely close to saturation, and most new shipments are for replacement units, typically necessary every 8-12 years, primarily driven by the need to replace batteries.

In-Home displays are currently shipping at a good rate in the GB Smart Energy program, where every home that gets a smart meter also gets an IHD. The recent UK government figures show a total almost 1.2M smart electricity and gas meters were deployed in the third quarter of 2017. They don't report the number of homes that got one or two smart meters, but it is likely that this number is about 0.75M homes, all of which would have got an IHD, an annualized shipment rate of 6M. Since the total cumulative GB smart meter deployments totaled only about 8.5M at the end September 2017, there is still a long way to go to reach the original goal of 50M smart meters deployed in all GB homes and small businesses by 2020. This indicates that there is likely strong growth potential for sales of IHDs and other smart metering equipment for the GB market.

Powering and Designing the Meter Electronics

High data rate, low latency communications can be expensive, requiring radios than implement advanced modulation schemes such as orthogonal frequency division multiplexing (OFDM), that not only require expensive devices, but also require more power than lower data rate implementations. Fortunately, power consumption is not usually an issue since electricity meters have their own power supply (which may be supplemented by a backup battery to enable a meter to provide notification of, and monitor, a power outage).

However, there is no such built-in power supply available with other smart meters, and gas, water and heat meters, as well as heat cost allocators, are almost always battery powered. For these battery powered meters, power consumption of the electronics must be minimized in order to maximize the battery lifetime. Fortunately, there are specialized battery chemistries, such as Lithium Thionyl Chloride ("LTC", LiSOCl_2), that are capable of lasting as long as 20 years, as long as the electronics does not drain the battery before then. Utilities do not typically want their customer to change batteries in their meters, and sending a technician to replace a meter battery (or more likely the entire meter) is very expensive, so it is essential that these meters have battery lives in the range of 10 to 20 years. Despite this, there are some gas utilities in China that use standard consumer AA size batteries in their indoor meters, and require the customer to replace the batteries, about every 12-18 months, in order to ensure continuity of their gas supply (i.e. no battery, no gas!).

Because of the need to maximize battery life, smart meter electronics designers place a lot of emphasis on power consumption when selecting the components to use on their designs, and are often willing to spend more money on a device that uses less power, since the alternative is to spend more on a larger battery. The best designers also realize that there is more to power consumption than just looking at datasheet specifications like radio receive power, or CPU sleep current. A low power radio may not reduce your power consumption if the data rates are really low, or if it is very susceptible to interference and can require a lot of transmission retries. Similarly, an MCU that has a very low sleep current may actually burn much more power if it has to fully wake up every time it needs to register sensor input, compared to an MCU with direct memory access schemes which its peripherals to capture and store data samples while the CPU remains asleep. Investing in power advanced management circuits can also offer great

dividends in terms of extending battery life, especially when it comes to optimizing the voltages for each part of the smart meter system.

As an example, an LTC battery is nominally 3.6V, but a radio power amplifier (PA) likely doesn't need more than 3.3V, while CPU core might operate most efficiently at 1.0V, and the analog peripherals on an MCU with that CPU need a 1.8V supply in order to perform within specification. All these different voltages can be provisioned very inexpensively using low drop out (LDO) regulators, but at the cost of wasting battery capacity, especially in the case of the 1.8V and 1.0V supplies, which could be much more efficiently generated using switching buck regulators, ideally with everything except the passive components fully integrated onto the MCU.

Smart Metering Ecosystems and the Business Models

Smart metering ecosystems and the business models can be as diverse as the products and technologies used in smart metering. The utilities that deploy smart meters are often owned by local municipalities, or the state, or they can be part of an investor owned company. These companies may provide a single utility to their customers, or they may be multi-service providers delivering any combination of electricity, gas, water or heat. In order to implement smart metering, these utility companies need to acquire not only the meters, but also the network infrastructure to enable these meters to communicate, and the back-office meter data management (MDM) systems and software that finally provides a monthly bill to the consumer. They may buy or lease, some or all of the products and systems require to run their business.

Many AMI vendors offer the option to build and lease networks for their customers, as do MDM vendors. Several vendors offer a one stop shop to their customers, offering everything necessary to implement smart metering, and some of those vendors are offering a metering-as-a-service (MaaS?) business model to their customers. This allows the utility to focus on what they do best, providing a utility service, and managing their customer base of homes and businesses, while the meter and AMI equipment vendor can take care of managing meters, networks and all the data from those meters.

In addition to metering and communications equipment manufacturers, and MDM systems providers, there are others ecosystem players that need to be understood in many markets. There may be government regulators that are driving the requirement for meters and the regulations regarding the requirements for those meters. As well as metrology, governments also heavily regulate communications, selling frequency spectrum licenses and dictating how unlicensed bands can be use.

Standards bodies such as the Institute of Electrical and Electronics Engineers (IEEE) and Internet Engineering Task Force (IETF) are key to defining base communications requirements, and then bodies like the Wi-SUN alliance add on to this by defining how to use IEEE and IETF standards in ways that ensure multivendor communications interoperability. Then there are organizations to define data interoperability at the applications such as the DLMS User Association responsible for "Device Language Message specification" and "COmpanion Specification for Energy Metering" (COSEM).

Summary

The world of smart meters is dominated by variety. There are a wide variety of meter equipment types, using a wide variety of metrology and communications technologies, with equipment sold by a large number of manufacturers world wide (well in excess of 200 equipment vendors). In smart metering no technology, no standard, and no company will completely dominate.

For the field area network wireless M-Bus is common in Europe, and some significant deployments in North America and Asia may become Wi-SUN compliant, some utilities want to avoid the FAN entirely and put LPWAN capability directly into their meters. Metering equipment vendors need to be able to build products that support a wide range of communication technologies for the FAN, HAN and LPWAN, and also need to have expertise in metrology and low

power design techniques. Regardless of wireless protocol selection, [multiprotocol connectivity](#) is a viable option to reduce design costs, enhance product functionality, and improve end user experience. The rewards for successful design implementations are significant, with more than 100 million units already deployed. To date, no vendor has anything close to a 10 percent market share worldwide, offering a great deal of future opportunity to many smart meter vendor companies across the globe.