Study of communication systems for smart grids

Student: Vítor A. Morais
Supervisor: António Pina Martins

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Chapter 1

Communication systems

This chapter presents the relevant communication approaches used in Metering Systems. In first section the reader is introduced to the subject. The topologies and requirements of communications in metering systems are presented. Then, divided between the communications in Automatic Meter Readers (AMR) and in Smart Metering (SM) systems, are presented each technologies with all the important features, benefits and constrains. Standardization procedures are presented starting with the standards in Europe and ending with a brief coverage on the worldwide standardization methodologies. In the last section is intended to present the research opportunities in smart metering communication.

1.1 Introduction

The innovation and evolution in the communications gives a considerable credit for the practical accomplishment of the important features of the Smart Grid (SG). The advance development in the wired and wireless, as well as the opportunity to use of low cost interoperable devices are the main points for this increase in the innovation and evolution in the communications, [1].

The need for having an improved employment of power generation sources, expanded productivity, adherence to regulatory constrains, enhanced costumer experience and low carbon fuel dependence are the motivation for the Smart Grids and one of their crucial parts, the smart meters, [2].

Currently, the existent electrical utility systems have a hybrid combination of communication technologies. This technologies support a vast range of applications like as SCADA/EMS, distribution feeder automation, generating plant automation and physical security, [1].

Being the renewable energy power grids a distributed system with multiple networks, energy sources and loads, there is a need to have an effective communication and coordination to monitor, analyse and stabilize the grid at various hierarchical levels, [2].

1.2 Topologies of Metering

In this chapter there are evaluated two topologies of metering, the systems based on automatic meter reading devices and the smart metering systems.

A substantial part of an AMR based system is based on a unidirectional communication connecting the meter to the data concentrator. For AMR communication networks, four important technologies are considered: first, Power Line Communications (PLC) allows communication over the existing energy line, in second, telephone/Internet lines that uses the telephone infrastructure for a wired connection, in third, the cellular network that allows wireless communication over a long distance and finally, short range radio frequency for low distances, [3].

Smart Metering Systems use some of the same means of communication of AMR. However the bidirectional communication is inherent to Smart Metering Systems. Even if there are considered a wide range of topologies and architectures to be used in Smart Grids, the most common is a topology where the Smart Meter collects data from several devices, in a Home Area Network (HAN), mostly in the wireless domain, and sends the collected energy data to a data concentrator that connects several Smart Meters in a distributed Metropolitan Area Network (MAN). A central command center receives the data from all data concentrators and in this command center resides the data storing, the servers and the processing facilities, including the management and billing applications, [4].

1.3 Requirements of Communication

1.3.1 AMR technical requirements and performance metrics

Certain quality requirements should be met by an AMR network. In a new design of a AMR network, those quality requirements are given by the following quality metrics, [3].

Reliability: A major requirement of the AMR network is the insurance and guarantee that all meter readings are received as well as all utility server control packets. A fair assessment of the given network is made by performance metrics such as the success rate and the loss rate.

Scalability: It is mandatory to made the assessment of a designed network focusing on the ability of providing support to several meters that ate placed in a large geographical area. Moreover, this scalability metrics is also related to the frequency of the readings.

Real time communication: The data transfer between the energy meter and the data storage unit is required to arrive within a given amount of time. Therefore, a performance metric evaluating the end-to-end delay is required.

Order: Each packed received is required to be identified with the time of the measurement, to ensure that, at the receiving station, the packet ordering is guaranteed.

Security: The security in communication is required to be guaranteed. Having this on mind, the level of the security implemented in a meter-station communication is expressed in terms of the implemented cryptographic tools used in the different protocol stack layers and the number of the bits used. Usually, at lower layers the implemented security is hop-to-hop and between both ends of the AMR application is implemented a end-to-end security.

On the field of Data Collection Mechanism, to accomplish large varieties of data with a high bandwidth, the devices must support three modes of communication: fixed scheduling (where the acquired data is reported at fixed intervals), event-driven (where the data are generated and transmitted due to events on meters) and demand-driven (where the data packets are transmitted upon a request made by the data collection center), [3].

1.3.2 Smart Metering Systems requirements

A bidirectional communication is essential for Smart Metering Systems. The ability of sending the acquired data to the analyzing computer as well as receiving service commands from operation center is a major requirement. A standard communication is a necessary part of the AMI and a highly reliable communication network is mandatory for communicating with high volume of data, [4]. The following requirements are essential to design and select an appropriate communication network, [5]:

- Large quantity of information transferred;
- Implementation of restrictions to access the data;
- Ensuring the confidentiality of critical data;
- The complete information of customer's consumption has to be represented;
- Displaying of the relevant information on the status of grid;
- Ensure the authenticity and the precision of information in the communications with final device;
- Promotion of cost effective solutions;
- Have the potentiality of hosting advanced features beyond AMI requirements.
- Support a possible future expansion.

1.4 Communication Systems in AMR

In this section is covered the communication in AMR based systems. Unidirectional communication devices are extremely cost effective and simple to use. The usage of such devices in a metering infrastructure allows the consumption measurement in order to implement Demand Response (DR) programs. Those communication devices allow utilities to alert program applicants and/or the appliance directly about a DR event, [6].

Considering a meter device functionality as a sensor node providing energy consumption measures, the number of metering devices can increase up to thousands, [3].

Starting from the wired technologies and then covering the wireless ones, the communication technologies in AMR are the following:

- Power Line Communication - Narrowband;
- Power Line Communication - Broadband;
- Telephone lines;
- Messaging over GSM network;
- Short Range RF communication.

1.4.1 Power Line Communication

Transmitting the data over the voltage distribution lines (electrical power), Power Line Communication is a communication technique to transmit data signals from one device to another, [3; 2].

Similarly to wireless communication in a certain way, it has the advantage of not requiring extra cabling. However, this technology depends on several factors (such as the speed of propagation, the chosen frequency, the voltage level carried, the distance that separates two communicating devices and the presence of transformers), affecting the PLC propertiessuch as limited bandwidth, [3].

PLC Narrowband Topology

The PLC Narrowband topology has a limited bandwidth at low frequency with low attenuation (very few dB per kilometer), limited bitrate and long packet dimension. It has an operating range of 3–500 kHz including CENELEC, ARIB and FCC specified bands, [6; 1]. It is distinguished between High and Low data rate narrowband PLC, depending if it uses a single carrier or multi-carrier.

In most recent advances of this technology using multi-carrier based technology and mainly based on orthogonal frequency division multiplexing (OFDM), This technology can achieve data rates up to 1Mbps. However, in order to guarantee a quality of service (QoS) level that is suitable for SG control, robust coding techniques are required and consequently the available rate, at the physical layer, should not exceed 50 kbps, [6; 1].

PLC Broadband Topology

The Broadband PLC technology operates in a range between 2 MHz and 250 MHz having data rates achieving several hundred Mbps. This technology is suitable for in-home communications, where the low coverage is only up to few hundreds of meters (due to the high attenuation), [6; 1].

Despite the coverage area limit on this technology, applying this technology to SG is possible, by limiting the available bitrate (to 3.8 Mbps, by setting modulation parameters to robust mode choices). This technology allows short packet durations (much less shorter than the 20 ms electrical cycle), which are well suitable to guarantee optimal operation of real-time algorithms, [6].

Comparison of topologies: PLC Broadband vs PLC Narrowband

Both technologies are of extreme importance on the development of smart grid solutions, due to its advantages. The PLC Narrowband is more appropriate to the data acquisition and communication objectives in Smart Grid. The additions to Smart Grid Applications on the field of End User Internet applications are one field where PLC Broadband is more suitable, [1].

1.4.2 Telephone Lines

Invented by Alexander Graham Bell in 1876, the telephone has been an important mean of communication. In 1958 data transfer was added over telephone lines to fulfill the desire of transferring data between remote machines, [7].

With the increase of bandwidth needs, Asymmetric Digital Subscriber Line (ADSL) technologies extended the signaling to upper frequencies (up to 1.1 MHz in ADSL1 and ADSL2, and up to 2.2 MHz in ADSL2plus). Standardized in 2003, ADSL2plus is one of the most widely used broadband technologies that are currently available, [7].

Telephone lines are preferable and they offer high reliability with relative lower costs, and its operation is straightforward. An AMR system can achieve the inbound, outbound, or bidirectional communication functionality using telephone lines, [3].

However, the availability of having telephone lines covering each automatic meter is a constraint since it is not always satisfied, [3].

1.4.3 Messaging over GSM Network

On the wireless side, the communication technologies used in AMR are Messaging over GSM Network and Short range RF communication. Starting with Messaging over GSM Network, one important service is the Short Message Service (SMS) that has turned into a communication protocol that allows devices to transfer delay-tolerant messages, [3].

Different standards supports SMS technology, namely Global System for Mobile communications (GSM), Digital Advanced Mobile Phone Service (D-AMPS) and Code-Division Multiple Access (CDMA2000). Researchers has been attracted to use SMS service due to his recognition and broad coverage of GSM networks. However, latency increases starting on several minutes to hours and failure rate is considerable, [3].

1.4.4 Short Range Radio Frequency

The second wireless technology considered in AMR systems is the Short range Radio Frequency (RF). This technology deals with low-power RF equipments at the customer site and several solutions are classified covered by RF: Bluetooth, WiFi, Zigbee, where they are dependent of the frequency bandwidth and the signal power, [3].

A few solutions presented in [3] propose the usage of short range RF as a part of data communication between AMR and a data concentrator. In next section some of the technologies used in the past to collect data from AMR's has been intensively used in smart metering systems.

1.5 Communications in Smart Metering Systems

It is considered that smart meters acts as the access points. The data collected is transmitted from smart meters to aggregation points. By having short distances between nodes, technological solutions having low power consumption and transmission based on wireless are preferable and the dominant solutions for the lower level networks. These wireless networks includes HomePlug, 2.4GHz Wifi, ZigBee and 802.11 wireless networking protocol, [4; 8].

At the aggregation points, backup power is required since it is considered a critical level subsystem. on the lower level, considering the smart meters as a non-critical device, backup power is not needed, [4].

1.5.1 PLC in Smart Metering Systems

Similarly to the AMR communications, The PLC is an available technology for in-home communication and it's advantages are the low cost and easy access to expand and penetrate in the utility provider's territory. However, their disadvantages includes their reduced bandwidth (maximum of 20 Kbps) and decrease of reliability near the transformers due to the data distortion. In remote locations PLC is valuable duo to the lack of coverage of wireless networks to cover a low number of nodes, [4].

1.5.2 Wireless in Smart Metering Systems

The following sections will cover the wireless communications in smart metering systems, starting with the low-rate and low-power communications applied around the smart meters and ending with the high-rate communications (and consequently higher costs and power than low rate communications). With the increasing on demand for higher bandwidth, broadband technologies such as mobile WiMAX, IEEE 802.16e and broadband PLC are expected to be considered and used in newer installations, [4].

IEEE 802.15.4 (ZigBee)

The standard IEEE 802.15.4 imposes conditions in the physical layer and media access control focusing on low-rate (up to 300 kHz) wireless personal area networks. Developed by the Zigbee Alliance and covering the specifications of the IEEE 802.15.4 on the physical layer and the medium access control, Zigbee is a commonly used for low power wireless communication technology. It operates on the ISM bands of 868 MHz, 915 MHz and 2.4 GHz adopting direct sequence spread spectrum (DSSS), [1].

DASH7

On the low-rate field of research, an alternative to Zigbee is the DASH7. Using the ISO/IEC 18000-7 standard to support this wireless sensor network technology, DASH7 is developed to reach active Radio Frequency Identification Devices (RFIDs) and operates at 433MHz band. The advantage is the typical range of 250m (could achieve 5 km) and has a typical and maximum data rates of 28 kbps and 200 kbps, being in this specifically designed for Smart Grid and for applications in Smart Energy.

IEEE 802.11 (Wireless LAN (WLAN) or Wi-Fi)

IEEE 802.11 is the standard for the information exchange between systems and for the telecommunications. The coverage area of this technology is on local and metropolitan area networks (LANs and MANs). The specific requirements are on the Medium Access Control and on Physical Layer. The most popular versions of this standard is the IEEE 802.11b and IEEE 802.11g, that differs in the modulation technique (Direct Sequence Spread Spectrum (DSSS) technique versus Orthogonal Frequency Division Multiplexing (OFDM) modulation technique). The data rates are, respectively, 11 Mbps and 54 Mbps, [1; 9].

IEEE 802.16 (WiMAX)

On the field of the broadband wireless communication there is the Worldwide Interoperability for Microwave Access (WiMAX) under the IEEE 802.16 standard. It is specifically developed aiming the point-to-multipoint communications being applied in fixed and mobile applications and it has data rates up to 70 Mbps over a distance of 50 km. Framed into the smart grid systems, this communication technology is considered as a solution for high data rate communication link to be applied at the backbone of the utilities, [1].

GSM and GPRS

Operating at 900 MHz and 1800 MHz, the Global System for Mobile communications (GSM) is the most used cellular network all over the world. The modulation technique is the Gaussian Minimum Shift Keying (GMSK) and it achieves transfer rates up to 270 kbps. Its architecture consists of four components: the Operation Support Substation, the Network Switching Substation, the Base Station Subsystem and the Mobile handset. Due to its level of development around the world being present in remote locations, this advantage makes this an interesting technology to be applied in Smart Grid applications, [1].

LTE/LTE-Advanced

Long Term Evolution (LTE) is a recent standard for wireless technology that allows high data rates with high capacity and low latency and with a good Quality of Service (QoS). The improved version of this technology, the LTE-Advanced, admit higher capacity with expanded peak data rate of 1 Gbps for the downlink and 500 Mbps for the uplink, obtained on the increase of the spectral efficiency, higher number of active subscribers connected at the same time, and better performance at cell edges, [4]. This technology, for the Smart Metering environment where the high bandwidth and good QoS are mandatory at some communication points.

1.6 Smart Metering Standards

This section will cover the standardization process that has been done in the field of communications in smart metering systems. Several work has been done to gather all players together in order to reach the requirement for communication within a network (the usage of agreed standards and a universal language). On the field of

AMR the following protocols has been proposed: ZigBee, Modbus, M-Bus, DLMS/IEC62056, IEC61107 and ANSI C.12.18, [4].

1.6.1 Smart Metering Standardization Activities in Europe

Framed in 2009/72/EC Directive, to accomplish the vision of smart grid being supported by the technologies referred above, it is mandatory to follow industrial standards in order to ensure reliability and interoperability, [10].

The benefits of Smart Meters are well known and presented previously in this article. Despite there is an interest to implement those technologies across the world, the adopted communications, regulation, standardization and technologies may vary depending on economical, political, geographical, and social factors. These systems are, therefore, highly complex due to the large number of stakeholders involved with direct interest in the process, [10].

The harmonize process of smart metering/grid standards has been done. Besides this clear effort within Europe of harmonization, there is also an effort to have a single establishment of European standards that will be widely used. The focus of this harmonization in on communications, architectures and solutions, [10].

1.6.2 Communication Standardization in Europe

Having standards on metering systems is an activity established either in international and European levels of standardization CENELEC/CEN and ETSI). Starting from the European level, three bodies has a prime objective issued by the Mandate M/441 EN "...to create European standards that will enable interoperability of utility meters which can then improve the means by which customers' awareness of actual consumption can be raised in order to allow timely adaptation to their demands (commonly referred to as smart metering)", [11].

This way five Standardization Technical Committees has been created for the aforementioned purposes.

Smart Meters Coordination Group (SM-CG)

This Technical Committee was setup as a Joint Advisory Group between CENELEC, CEN and ETSI for the establishment of European standards focusing an open architecture to be implemented in utility meters that enables interoperability and improvement of customer awareness on their energy consumption. It target three specific standardization: the electricity meters, the non-electricity meters (gas, water and heat) and the home automation. On the field of functionalities, it has the following points, [10]:

- Promote the remote reading of all metrological data and ensure the provision of these measurements to appropriate market organizations,
- Bidirectional communication between the metering system and designated market organizations,
- The support of advanced billing and tariffying systems,
- The meter is allowed to disable and enable loads or power sources,
- The communication between meters and individual devices within the home/building,
- The meter provides the information via a portal/gateway to an in-home/building display or to other auxiliary equipment.

CENELEC TC 13

Another technical committee is the CENELEC TC 13 with the scope of preparing European Standards (without discarding the utilization of IEC standards) for the measurement of electrical energy and for the controlling of the load on electrical equipments. The activities of TC 13 are related to the development of a common language in AMR/AMI for participating partners, being defined in the IEC 62056 DLMS/COSEM, [10].

Device Language Message Specification (DLMS) is the specification of an application layer, being a widely used concept for the abstract modelling of communication entities. Companion Specification for Energy Metering (COSEM) is a specification applying object oriented models of meters. COSEM provides a view of their functions being based on the available standards for exchanging data between energy meters. A list of roles and functionalities of DLMS/COSEM are presented in , [4; 3].

The role and function of DLMS/COSEM can be defined as, [4]:

- An object model specification of the functionality of the meter as seen from its interface(s).
- An identification system to be applied on every measured data.
- A messaging method that communicates with the model and to converts the data to a frame (a series of bytes).
- A message transport method to exchange the information from the metering device to the data collection system.

CEN TC 294

CEN TC 294 focus his work on the standardization procedures of communication systems to be applied on meters and on their remote reading functionality. The activities of this technical committee arte in the development of the EN13757, covering the standards for all the Meter-bus (M-BUS) and wireless M-BUS, [10].

CENELEC TC 205

This TC focus his work on preparing the standards to cover home and building electronic systems, using Information and Communication Technology. It has also to guarantee the integration of several control and management applications used in homes and buildings. The activities of this TC are the coverage of the deployment of the EN50090 and the EN50491 standards, creating regulations in Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS), [10].

ETSI M2M

The purpose of this TC is to develop standards to be applied in Machine-to-Machine (M2M) communications. The activities of this group are on Next Generation Networks as well as on the 3GPP standards initiative for mobile communication technologies, [10].

1.6.3 World wide standardization

Similarly, the same standardization approach has been applied all over the world. In USA, there is the IEEE P2030, the ANSI, the US NIST and the future Internet Protocol for smart grids in the IETF. Furthermore, the standardization in China is driven by the State Grid Corporation of China (SGCC). Moreover, in India the IEEE Standards Association (IEEE-SA) brought in two new standards, IEEE 1701 and IEEE 1702, focusing on the creation of a multi-source plug-and-play communications environment to be applied in varied smart metering devices, [10].

1.7 Research opportunities and challenges

In this section, a small overview on research opportunities and challenges is presented. This is of particular importance in a primordial research stage. It is divided in four parts: the interoperability of multiple communication technologies, the scalability of solutions, a self-organizing network on existent infrastructure and the approach used in home networking research to smart metering systems.

Interoperability

A relevant feature of smart grids is the interconnection of several energy distribution networks as well as several power generating sources and consumers. This interconnection depends on a communication network that is not influenced by the physical medium used does not depend of the manufacturers and the type of devices. It is suggested generic application interfaces (APIs) and middlware as a interesting improvement for the devices used in smart metering, the systems and the communication networks that contributes for the implementation of smart grids, [10].

Inserted in the railway smart metering environment and framed in the Shift2Rail European Commission program, [12], this research trend has an added value on achieving the goals of interconnecting several devices (independent of the manufacturers and type of devices).

Scalable internetworking solutions

In the field of Wireless Sensor Networks (WSN), the research has the possibility to be extended to smart grid and smart metering systems. Therefore, the global M2M communication infrastructure topology, the service requirements and the device functionalities has the opportunity to be detailed. As previously refered, ETSI has a technical committee towards solving the M2M issues, [10]. On the railway environment, due to the dispersion of the railway system across a large area, the usage of WSN on Smart Metering technical demonstrators is desirable, [12].

Self-organizing overlay networks

With the scale of smart grids and their deployment complexity, telecommunication network systems that supports smart grids are pushed to rely and depend on the existing public networks. A self-organizing network that is upon an existing infrastructure is an approach to contribute to the science on smart grid systems, [10].

Home networking challenges

Framed on the paradigm of the research on home networking, where the developed systems are focused on providing multimedia applications having increased Quality of Service (QoS), as well as zero-configuration of the devices and uninterrupted connectivity to home users, the smart metering systems has an interesting possibility of inheriting these features, [10].

1.8 Synthesis

Several authors cover the communication in smart and non-smart metering systems as a part of the whole infrastructure. Event if it was not followed a specific structure observed in the literature review, the structure of this chapter was based on the work of [4], [3] and [2] where they propose similar coverages to review this thematic.

Based on their work, a literature review was made divided in three stages. In first stage, the requirements of communications in smart and non-smart metering systems was covered as a starting point to have a good overview of the features that communications has to be according with.

In second stage the past, current (and future) technologies in communication are presented, describing theirs benefits and drawbacks and, if possible, the possible integration of those technologies in smart (and non-smart) metering infrastructure.

In the third stage, the standards and directives that regulates those technologies are presented following the work on literature review made by [10].

This three-stage structure (requirements - presentation of technologies - standards) was followed either for smart and non-smart metering systems. Despite the several approaches in the literature to present this thematic, the followed structure presents in advance what is the goal of the communication on those systems before presenting the communication technologies itself and their own standards and regulations around the world.

The last part of this chapter present a brief work of [10] on evaluating the current research opportunities on this field of science. On smart grid systems there is several work that can be performed to contribute to this field. However, the most of those research opportunities on the usage of new communication technologies that are inserted on the development of standards.

For the future work, this following on studying the research opportunities should be continued, not only on the railway environment - where it will be the focus of the future work - but in the smart grid development.

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