Chapter 5
Smart Meter

M. Rahman and Amanullah M. T. Oo

Abstract Utility meters are being changed from simple measurement devices to multi-dimensional technical devices and also enhanced by the addition of new informational and communication capacities like smarter metering systems [1]. Smart meters enable automatic, bi-directional communication between the consumers and the utility. Compared to traditional energy, meters display only the amount of energy consumed, but smart meters can directly send usage data back to the utility. The information of electricity consumption could be collected in real time with accuracy from smart meter [2]. Modern distribution companies are required to adopt smart meters in their network to improve the efficiency of the networks and to be in par with the smart grid environment. This chapter has conducted a rigorous review that outlines the existing distribution network, deployment of smart meter in distribution network, and possible difficulties to deploy smart meter network in distribution system. The purpose of this chapter is to provide the necessary background to understand the concepts related to smart meter, smart meter network, and relevant research carried out in this area. A concise review of importance of implementing smart meter in distribution network, bandwidth requirement for smart meter network, bandwidth and latency barrier in smart meter network, and communication coverage of smart meter network is presented.

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5.1 Details Description of Smart Meter

Smart meters are placed in consumer's premises that exchange information between consumers and control center. A smart meter has the following capabilities [3]:

- Real-time data of electricity use and electricity generated locally;
- Offering the possibility to read the meter readings both locally and remotely;
- Offering the interconnection between premise-based networks and devices such as DG.

Usually, a smart meter is considered for registry of electricity use. The intelligence of the meter is incorporated in the smart meter. It has several basic functions, namely measuring the electricity consumed or generated, remotely switching the customer and remotely controlling the maximum electricity used as shown in Fig. 5.1, [3]. Furthermore, the design processes of smart meter create many opportunities across smarter metering technologies [4].

Smart meters refer to systems in which information flows in both directions. These systems open up a wide range of opportunities for utilities through up-to-date information and innovative products. There is a growing interest to know how the new information and communication technologies (ICT) can change the conventional meter into a smart meter for energy saving and energy security purposes [1]. The functionalities of new metering technologies are brought together in distinct packages in this smart metering system.

Direct energy consumption monitoring and improving energy efficiency are the main purpose of smart metering on distribution networks. Smart meters encourage consumers to change behavior by turning down the electrical appliances during peak demand period. These effects are fostered either by exposing consumers to their general consumption patterns or by financial incentives. Energy efficiency can be improved as consumer regulates power consumption based on their needs. The data generated and transmitted by smart meters open up a range of operational

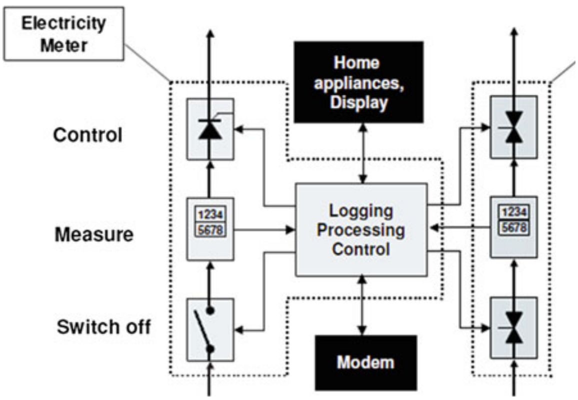

Fig. 5.1 Schematic diagram of a typical smart meter configuration [3]

improvements including monitoring and controlling energy usages. This detailed network information improves the network operations and facilitates more renewable energy generation and integration. The broad range of energy saving opportunities allows smart meter an attractive option for distribution network. Benefits of smart meter in distribution network, investigation of the requirements of smart meter in distribution, technological configurations of smart meter, smart meter monitoring program, and impact of smart meter in distribution system are discussed in the following few subsections.

5.1.1 Benefits of Smart Meter

Smart distribution network is required to maintain and enhance energy security. Globally, the indigenous energy resources to secure energy supplies have driven the development and deployment of new and renewable technologies including advancing ways in which energy is delivered by smart meter. The implementation of a smart meter in distribution system can facilitate a step transformation in the way energy is produced and consumed. Smart meter with high-tech communication capabilities monitor energy usage and allow consumers to make informed choices about how much energy to be used and when to consume it [5].

5.1.2 Requirement of Smart Meter in Smart Distribution Network

Smart meter provides consumers with the ability to use electricity more effectively and provides utilities with the ability to operate them more efficiently. Adoption of smart meter in smart distribution network will enhance the electric delivery system including generation, transmission, distribution, and consumption. It allows the possibilities of DG bringing generation closer to the consumers [5]. This shorter distance from generation to consumption empowers consumers to be active participants in their energy choices.

Furthermore, the significance of smart metering also rises from eliminating the need for more energy generation which reduces the requirement of electricity grid expansion to overcome the electricity congestion problem. This is possible by means of distributed generation and demand response [6]. Energy consumption levels are substantially reduced, and peak load generation is lessened as loads are being shifted from peak to off-peak [7]. Smart meters act as the intelligent nodes on smart distribution network. The increasing importance on energy from renewable energy sources puts a further strain on the current distribution network, which is currently “one way” only—it cannot accept from micro-generated electricity. From the operational point of view, the use of smart metering system allows for improved management and control over the electricity distribution system [8]. The smart distribution system should be more reliable, reducing significantly the staggering cost of power outages for consumers and businesses. Today, the tools for improving real-time monitoring and controlling the distribution system with advanced information technology are available. The deployment of smart meter in distribution system with advanced information technology can manage these increasingly complicated networks. An integrated, information technology (IT)-enabled, electric distribution system is required for improving reliability of distribution system, but it is really critical for bringing higher percentages of renewable electricity energy into our energy mix due to the variable nature of many of these resources. By introducing a large number of IEDs (like smart monitors and control points) in the distribution network, the smart distribution network enables more precise management, which can increase effective capacity [8].

5.1.3 Technical Configurations of Smart Meter

Rapid changes in ICT have dramatically changed the potential of utility meters and the new system to measure the energy consumption was known as "smart meter" as a reflection of their increased functionalities and communication capacities compared to the "simpler" predecessors which mainly measure the energy consumption by manual reading [1]. Electric meter manufacturers and information communications providers have been competing to provide utilities with their new smart metering systems.

Current distribution networks are old and were not designed to cope with future electricity demand. Smart meter is also a key element for providing advanced home appliances and end-use technologies on line to capture new efficiencies [8]. From the operational point of view, the use of smart metering system allows for improved management and control over the electricity distribution system. Moreover, the future demand distribution network made available by using smart metering facilitates for further grid planning.

Meter manufacturers and communications providers have been competing to provide utilities with their new smart metering systems. Siemens Limited is one of the smart meter provider organizations, and their devices are high-performance power monitoring devices [3]. The devices are used to detect the power values for electrical feeders or individual consumers. Furthermore, the devices provide important measured values for assessing the system state and the power quality. The devices provide accurate knowledge of your systems characteristics and offers more than 50 basic values regarding the power quality as shown in the Table 5.1.

Table 5.1 Smart meter parameters settings [4]

Function	Parameters/infrastructure performance
Basic measuring values	Voltage, current, active power, reactive power, power factor, frequency
Extended measuring values	Phase displacement angle, Phase angle, harmonics voltage, harmonics current, distortion current, maximum values/date and time, asymmetry voltage
Power detection/counters	Apparent energy, active energy, reactive energy, power demand of last measuring period, measuring period, operating hours counter
Interfaces	Ethernet, simultaneous connection, protocol, gateway
Input/outputs	Digital input, digital output, operating voltage
Clock/calendar	Real-time clock, calendar function, summer time/winter time switchover
Display/operation	Display, indication, operation, language

5.1.4 Smart Meter Monitoring Program

Smart meter is a two-way information communication system. The basic elements of a smart meter monitoring program are shown in Fig. 5.2. It includes smart meters, a means of communication, and a power quality data warehouse. The means of communication could include fixed twisted pair cable, telephone lines, mobile phones, power line carrier, radio, fiber optic, or a combination of these [9].

The chosen meters must be capable of recording the parameters. The data warehouse must be an effective and secure means of storing data from all meters in the monitoring period. The quantity of data stored will be dependent upon the transmitted data [9]. Present smart meters that capture power quality data have concentrated on transmitting all data such as 10 min data for voltage, current, power factor as well as others data. The data must first be sent from the smart meter to the power quality data warehouse. A more sensible and realistic option is for each smart meter to report by exception in real time or using power quality indices for each site. However, adoption of smart meter that faces several challenges in smart distribution network can be described in the following sub-section.

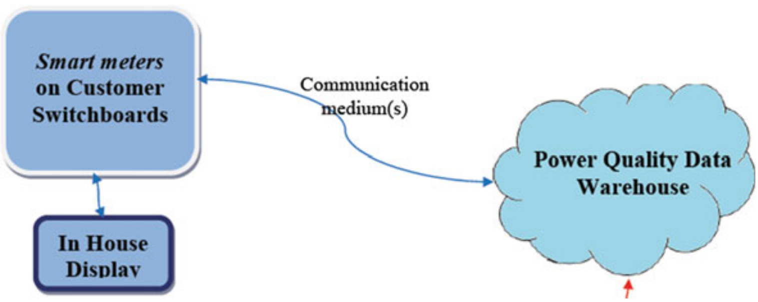

Fig. 5.2 Smart meter monitoring program [9]

5.1.5 Impact of Smart Meter in Distribution System

Despite a number of benefits from the widespread application of smart metering technology, the adoption of this new technology faces technical challenges. The smart meter network faces new challenges and stresses which may put at risk its ability to reliably deliver power. The challenges include the following:

Communication network challenges: Smart meters offer better interface technologies. As smart meters enable bi-directional communication between the customer and the utility, these devices provide access to more information than traditional meter. To facilitate a robust communication between smart meter devices and centralized control system, a high bandwidth communication channel is required to allow digital data move throughout the network efficiently and effectively.

Standard communication protocol: Lack of standardization of smart metering technology means that large number of smart meters of different types has been deployed for collecting and dispatching data and instructions, transforming the data and storing data under different communication protocols [10]. If same communication protocol is used, the problem may be minimized. Otherwise, international standards covering automatic meter data exchange can also overcome this technical barrier [11]. The strategies outlined above provide a bridge to the implementation of future smart technologies where real-time data will be the best practice network. They will provide a basis for implementing smart meter network in distribution system which provides a range of security, quality, and reliability.

5.2 Smart Meter in Distribution Network

Smart meter in distribution network covers modernization of distribution system. This system is directed at several disparate set of goals including facilitating competition between providers, enabling a large-scale use of variable energy sources, establishing the automation, and monitoring capabilities in distribution system [10]. The smart meter network is used to describe the integration of the elements connected to the electrical grid with an information infrastructure to offer numerous benefits for both the providers and consumers of electricity. It is an intelligent future electricity system that demands two-way information systems through an intelligent communication system.

The technologies, devices, and systems that make up a smart distribution network will vary across electricity distribution systems, like as the existing electricity networks vary according to the geographic, climatic, ownership, and business parameters.

5.2.1 Components of Smart Meter Network in Distribution System

The smart meter network components include [11]:

- integrated communications infrastructure that enables near real-time, two-way exchanges of information and power;
- smarter measurement devices (including advanced metering infrastructure) that record and communicate more detailed information about energy usage;
- sensors and monitoring systems throughout the network that keep a check on the flow of energy in the system and the performance of the network's assets;
- automatic controls that detect and repair network problems and provide self-healing solutions;
- advanced switches and cables that improve network performance; and
- IT systems with integrated applications and data analysis.

Figure 5.3 describes new opportunities that are enabled by smart distribution networks, rather than being a component part of smart networks. There are a range of other technologies, devices, and applications that are often associated with smart meter in distribution networks, such as customers' energy management systems, renewable energy supplies, and energy storage technologies [11].

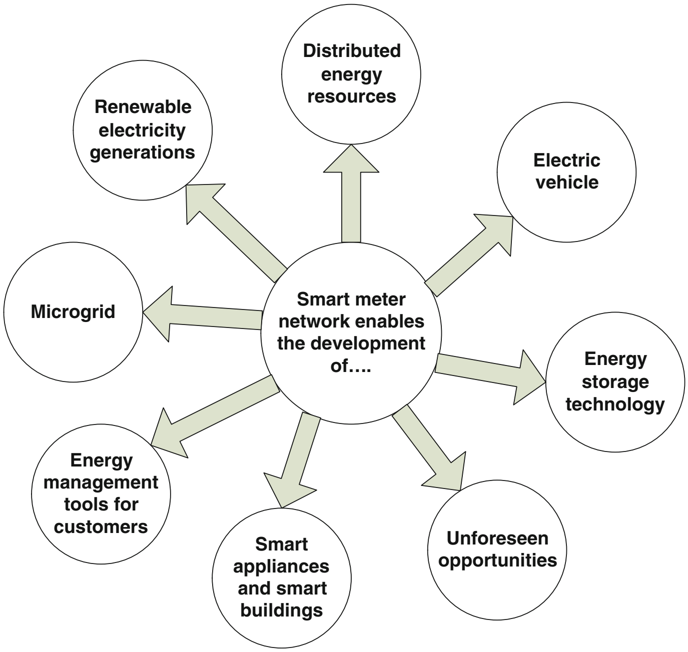

Fig. 5.3 Smart meter network components and opportunities [11]

5.2.2 Characteristics of Smart Meter in Distribution Network

The following provides additional attributes on the smart distribution network characteristics [11–13]:

- active participation of consumers occurs through the provision of two-way communications and information that gives the consumer the ability to consume and provide energy;
- achieve self-healing (i.e., automatic fault response), the integration of devices and sensors with a secure communications network will automatically recover unaffected sections of the network and isolate those elements in need of repair. Resistance to security attack is enhanced as end-to-end cyber-security is enforced across the network with smart network security protocols;
- enable generation and storage options at the macro and micro level by way of participatory networks established at all levels of the network, allowing individual and industrial customers;
- optimize assets and efficient operation and reduce operating and maintenance costs, harnessing the information provided by sensing and monitoring devices and automatic switching capability;
- enable distribution network is flexible to natural disasters with rapid restoration capabilities.

Therefore, it clearly indicates that smart distribution network is a vital need today for a sustainable, secured power system for the future. However, development of smart meter network introduces potential difficulties includes communication network challenges which are discussed in the next section.

5.3 Roles of Communication Protocol or Standard in Smart Meter Network

A communications protocol or standard is a system that has rules for exchanging information between nodes or stations. In smart meter network, this communication facilitates the communication between smart meter to central server and vice versa. Communication system uses defined formats for exchange messages, and each message has an exact significance intend to provoke a defined response of the receiver.

The architecture of monitoring, control, and communications of the smart meter in distribution network predates the many advances made in the last 30 years in the fields of computing, networking, and telecommunications [10]. It has been observed that the speed of development and widespread adoption of smart meter networks will depend on same communication protocol or national standards that are applicable in a number of major areas [11, 14] which are as follows:

End-to-end cyber-security for smart meter networks: The broad communications infrastructure deployed for smart network applications may increase the potential number of attack points on the electricity network increasing the risk posed from cyber-security on energy supply. The importance of end-to-end cyber-security protection has been established to address the security concerns of smart networks. The technology choices deployed for smart networks will heavily depend on the setting of cyber-security policies.

Interconnection and interoperability standards for energy connection: The connection of widespread micro-generation solutions is anticipated to increase significantly with the adoption of smart networks. These new energy sources are predominantly focused on renewable technologies and low carbon emitting alternative fuel sources. While there are existing standards already available for connecting new loads, it is suggested that these standards need to be reviewed and modified to cater for interconnection of devices onto the network and this interoperability standards should be developed to use in the broader smart meter network rollout in any region of Australia.

Application-level data communications standards Application-level data communications standards are required to establish in distribution system that will enable interoperability and technology advancement to facilitate the national smart networking. These standards will be needed to enable a device in the field to converse with back-office systems using a common protocol that is interoperable. It is suggested that these standards should be leveraged from existing local and international communications standards.

5.3.1 Communication Protocols

Information has become a vital factor to the efficient operation and expansion of a reformation electric utility industry. Efficient communication with redundancy is a vital issue in any network that communicates information among nodes or stations [15]. For efficient and effective power system communication, TCP/IP, DNP3 protocol for data transmission is used widely. These protocols plays significant role in reliably transmitting data from different IEDs to main control center or server. Some of the most common protocols that are directly related to smart meter network are discussed in the following sections.

TCP/IP Internet Protocol Suite

TCP/IP provides connectivity between equipment from many vendors over a wide variety of networking technologies. It consists of a well-defined set of communication protocols and a several standardized application supports. TCP/IP communication protocols were originally developed for the Department of Defence (DoD) advanced research project agency's network (ARPANET), in the early 1970s. In the early 1980s, TCP/IP was included as an integral part of Berkeley's UNIX version 4.2. As a result, the protocol suit gained wide-spread network use. In 1983, TCP/IP become the military's protocol standard for networking and internetworking [16]. It is the protocol in use on both ARPANET and MILNET (a spin–off of ARPANET). The Internet Protocol (IP) is a network layer protocol which provides the routing function across multiple networks [16]. IP uses datagram to communicate over a packet-switched network [17, 18]. It also provides datagram services for Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). This protocol comprises four layers:

Network Interface Layer: This layer is the lowest level of the TCP/IP stack. It is responsible for transmitting datagram's over the physical medium to their final destination.

Internet Layer: This layer is responsible for providing host to host communication. It is here that packet is encapsulated into an Internet diagram, the routing algorithm is run, and the datagram is passed to the Network Interface Layer for transmission on the attached network.

Transport Layer: This layer is responsible for providing communication between applications residing in different hosts. By placing identifying information in the datagram (such as socket information), the transport layer allows process-to-process communication. Depending on the needs of the requesting application, the Transport layer of the TCP/IP stack may provide either a reliable service (TCP) or an unreliable service (UDP). In a reliable delivery service, the receipt of a datagram is acknowledged by the destination station.

Application Layer: This layer is the highest level of the Internet model. A few of the applications include Telnet, File Transfer Protocol, and Simple Mail Transfer Protocol. Functional layers of TCP/IP and Open System Interconnection (OSI) layer are given below as shown in Fig. 5.4.

The IP forms a computer network by linking computers assigning each one a single IP address [19]. Each IP packet carries an IP address [20], which consists of destination address and host address. The host address is the IP address of the

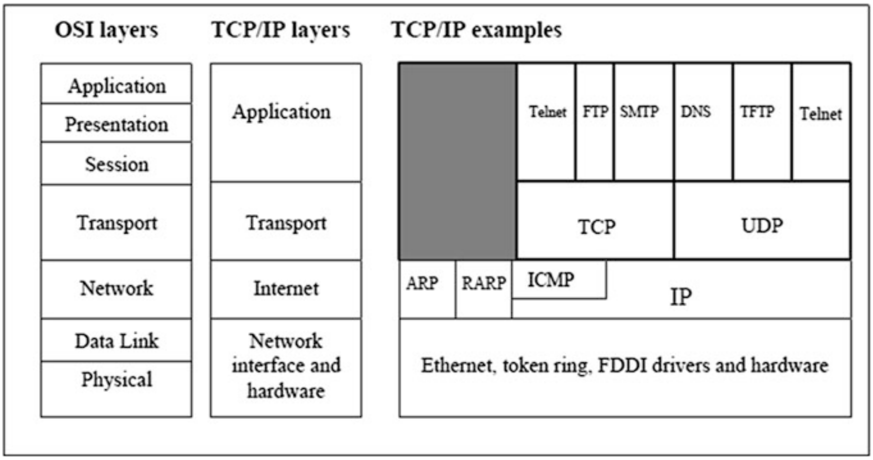

Fig. 5.4 TCP/IP protocols and functional layers [45]

sending computer, and the destination address is the address of the recipient or recipients of the packet. This protocol has also routing facility which route data from one network to another network from source to the destination address.

The major concern with IP is that it makes no attempts to decide if packets get to their destination or to obtain corrective action if they do not. Therefore, IP does not present guaranteed delivery. This difficulty can be avoided in some applications where a transport protocol that carries out such a function is utilized. The best example for the later is TCP [21], which makes up for IP's deficiencies by offering reliable, stream-oriented connections that are independent of the nature of the applications. However, other applications requiring best-effort services (faster transmission times) usually use UDP [22], which is a simple connection less transport layer protocol without guaranteed for reliable delivery. UDP packets are delivered the same as the IP packets and may even be discarded before reaching their destinations. Although the transmission of data requires the best-effort service in distribution network applications, reliability is also a major concern. The best-effort service requires the use of IP alongside TCP, which is the reliable transmission for distribution network. The highest level protocols within the TCP/IP protocol stack are application protocols. They communicate with applications on other hosts and are the client-visible interface to the TCP/IP protocol suite [23]. The TCP/IP protocol suite includes application protocols, namely:

- File Transfer Protocol (FTP);
- Simple Mail Transfer Protocol (SMTP) as an Internet mailing system.

These are a number of the most broadly implemented application protocols, but many others exist. Each particular TCP/IP implementation will contain a lesser or greater set of application protocols. It is often easier to make applications on top of TCP because it is a reliable stream, connection-oriented, congestion-friendly, and flow control-enabled protocol. As a result, most application protocols will use TCP and most applications utilize the client/server model of interface as well [23]. TCP is a peer-to-peer, connection-oriented protocol. The applications typically use a client/server model for communications as demonstrated in Fig. 5.5.

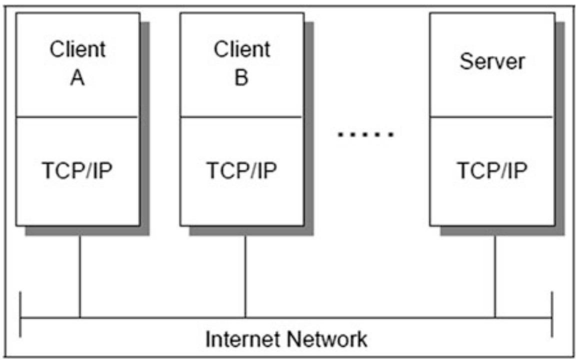

Fig. 5.5 The client/server model of applications [23]

The server offers a service to clients when a client requests a service. The applications consist of both server and client, which can run on the same or on different systems. Users usually invoke the client part of the application, which builds a request for a particular service and sends it to the server part of the application using TCP/IP as shown in Fig. 5.6. The server receives a request, performs the service, and sends back the result in a reply. A server can usually manage multiple requests and multiple requesting clients at the same time [23].

If two hosts on different networks wish to communicate, the source host sends the packets to the right router. The router then routes each packet through the system of routers and networks until it reaches a router linked to the network as the destination host. Routing architecture is given in Fig. 5.7. This final router forwards the packet to the physical address of the destination host. Each network acts as a link between a router and all the hosts residing on it.

A router looks like a typical host to any of its connected networks. Routers forwards packets based on the destination network number rather than the physical address of the destination host. Since routing is based on numbers of network, the amount of information a router requirements is proportional to the number of networks that make up the Internet, not the number of machines.

In this study, TCP/IP is used in the OPNET simulation software environment as a communication protocol to develop the smart meter network in distribution system. In this model of smart meter network, latency or propagation delay is measured by selecting different bandwidth to evaluate the performances of smart meter distribution network.

Distributed Network Protocol (DNP3)

DNP3 [24] is a supervisory control and data acquisition (SCADA) protocol that permits information to be sent between a slave device (such as IED or smart meter) and a master device (such as control center or server). The slave device will

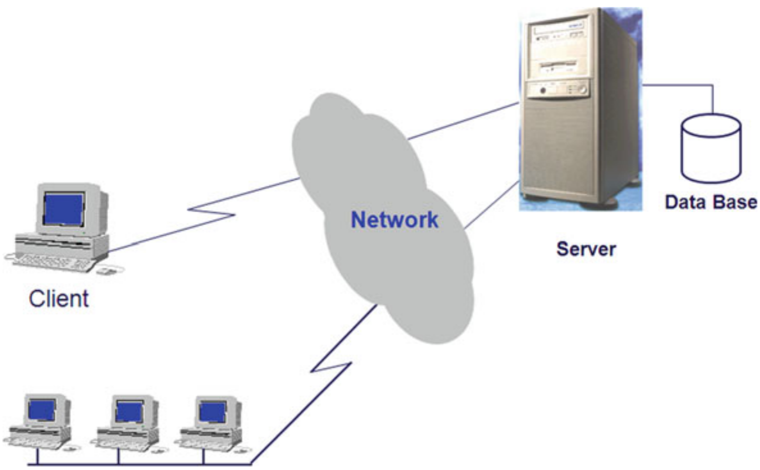

Fig. 5.6 Client–server network architecture [23]

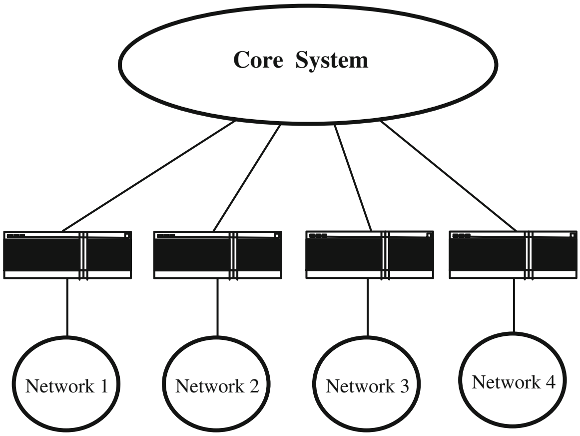

Fig. 5.7 Routing architecture [46]

respond to requests for data that are issued by the master, but may also be configured to send data in respond to a field event without that data having been requested by the master. It has been used primarily by electric utilities like the electric companies, but it operates suitably in other areas.

Figure 5.8 shows common system architecture utilize today. At the top row of the figure is a simple one-to-one system having one master station and one slave. The second type of system is known as a multi-drop design. One master station communicates with couple of slave devices. The master desires data from the first slave, then moves onto the next slave for its data and repeatedly interrogates each slave in a round-robin order. The middle row illustrates hierarchical type system where the device in the middle is a server to the client at the left and is a client with respect to the server on the right.

Both lines at the bottom of Fig. 5.8 illustrate that data concentrator applications and protocol converters. A device may collect data from multiple servers on the right side of the figure and store this data in its database where it is recoverable by a master station client on the left side of the figure. This design is often shown in substations where the data concentrator gathers information from local intelligent devices for transmission to the master station. In current years, some vendors have utilized TCP/IP to convey DNP3 messages. This approach has allowed DNP3 to acquire advantage of Internet Technology and allowed economical data collection and control between widely separated devices.

The DNP3 software is layered to give reliable data communication, and also, this layering gives an organized approach to the communication of data and commands. Figure 5.9 shows the layering.

The link layer is responsible for making the physical link reliability. It performs this by providing error detection and duplicate frame detection. The link layer sends and receives packets, and the packets are called frames in DNP3 terminology. Sometimes transmission of more than one frame is essential to transport all of the information from one device to another. It is the task of the transport layer to break long messages into smaller frames sized for the link layer to transmit

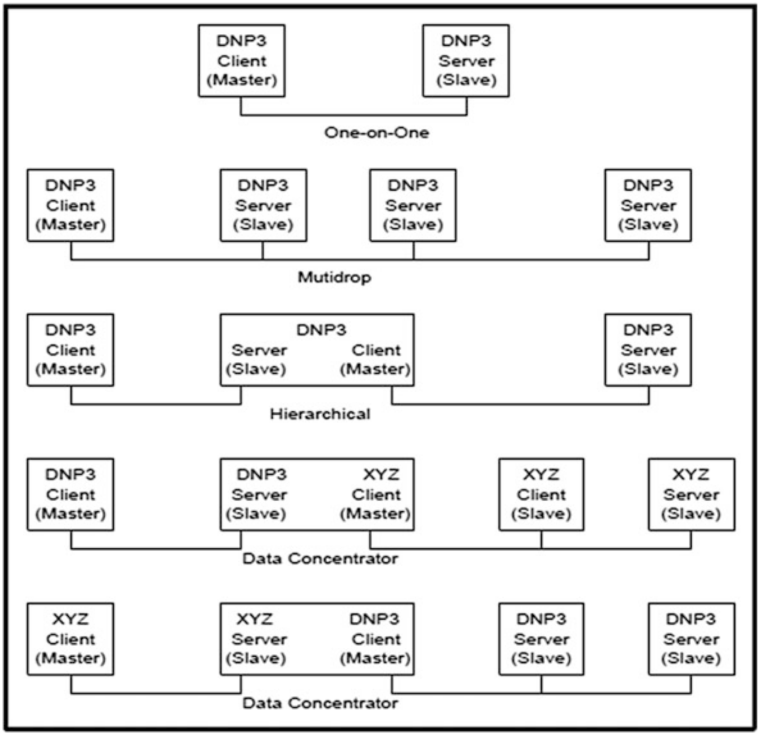

Fig. 5.8 DNP3 common system architecture [24]

or when receiving to reassemble frames into longer messages. In DNP3, the transport layer is incorporated into the application layer.

Application layer messages are broken into fragments. Fragment size is established by the size of the receiving device's buffer. It normally ranges from 2,048 to 4,096 bytes. If a message is larger than one fragment, it requires multiple fragments. Fragmenting messages has the responsibility of the application layer.

The application layer works together with the transport and link layers in order to allow reliable communications that offers standardized functions and data formatting. DNP3 goes a step further by classifying events into three classes. When DNP3 was conceived, class 1 events were regarded as having higher priority than class 2 events, and class 2 were higher than class 3 events. The user layer can request the application layer to poll for class 1, class 2 or class 3 events, or any combination of them.

The most attractive reasons for choosing the Internet protocol suite as a transport mechanism for DNP3 are as follows:

- Seamless integration of the substation LAN to the corporate WAN utility
- Leverage existing equipment and standard.

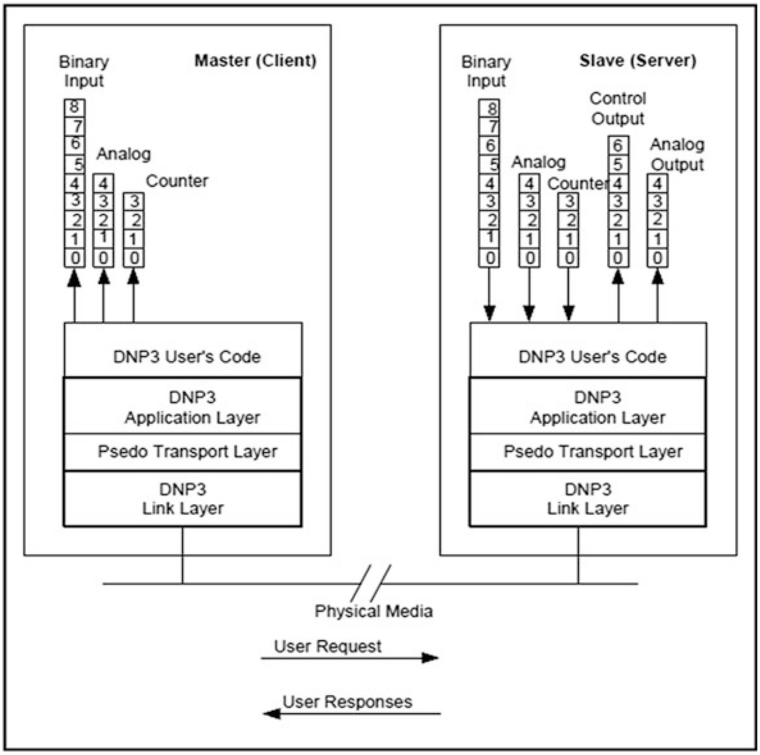

Fig. 5.9 Client and server relationship [24]

The Internet protocol suite and DNP use the OSI layering paradigm; each piece of the protocol stack in one station logically communicates with the corresponding piece in the other station(s). It is therefore easy to build DNP on top of the Internet protocol suite since the Internet layers appear transparent to the DNP layers as shown in Fig. 5.10.

5.3.2 Communication Standard

The increased expansion of the Internet and networked communications and the large-scale installation of wide-area networking technology facilitate the use of smart meter in distribution network [25]. A potential barrier is the threat related to installation of those new technologies without agreed standards. Lack of standards increase the threat of stranded assets; for example; utility deploying a tools is not supported by the industry and necessitating further setting up of some applications prior to the end of their expected lifetime. Standards can also assist to decrease setting up complication, make possible interoperability, and address security.

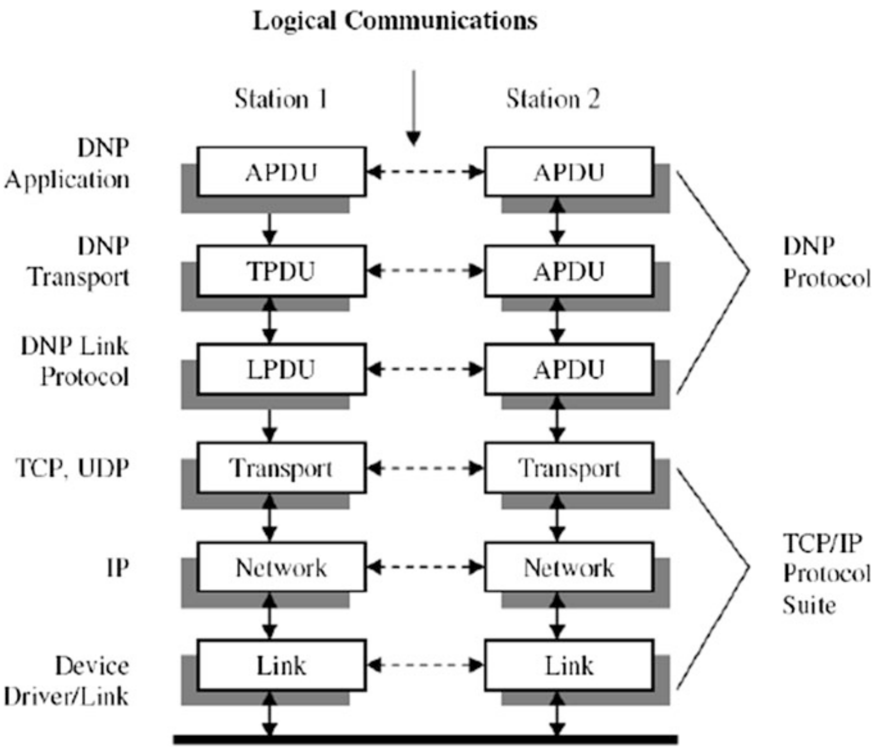

Fig. 5.10 DNP3 protocol stack [24]

Interoperability can offer appliance producers with the confidence and inspiration to install smart meter network in the products [26].

The necessity of smart meter system interoperability for the customer is already well recognized within the industry. Along with the challenge of developing the three different sets of standards (substation, feeders, and customer devices), comes the coordination between the different standards. The development of the smart meter network interoperability standards is a dynamic process which will have to adapt to the new type of loads and generation systems (DER and DG) to be connected to the distribution system [27].

Figure 5.11 shows an integrated distribution system based on interoperability standards such as the International Electro Technical Commission (IEC) 61850 series leading to a "plug and play" concept for the distribution equipment to be connected with the future Smart Grid. The illustrated new communications infrastructure (based on interoperability standards such as the IEC 61850 series) must have sufficient bandwidth to support the traditional distribution network as well as bulk data download to support advanced waveform and sequence of events analysis. The new infrastructure must be robust enough to support increased bandwidth requirements of IEC 61850 without degrading the existing communications with the automated distribution network [27]. Details of IEC 61850 and its use in smart meter network are discussed in the following sections.

IEC 61850

Development of IEC 61850 is based on the standard communication protocols to allow interoperability of IEDs from different manufacturers. IEC 61850 describes utilizing of existing standards and commonly accepted communication principles, which permits for the free exchange of information between IEDs. It allows applications to be designed independent from the communication theory enabling them to communicate using different communication protocols. Therefore, it provides a neutral interface between application objects and their related application services as shown in Fig. 5.12.

One of the most important features of IEC 61850 is that it covers qualitative properties of engineering tools, measures for quality management and configuration management. This is needed when utilities are planning to build a substation automation system (SAS) with the intention of merging IEDs from different manufacturers; they expect not only interoperability of functions and devices, but also a homogenous system handling [28]. Hence, IEC 61850 offers a neutral interface between application objects and the related application services allowing a compatible exchange of data among the components of a SAS [29, 30]. The IEC61850 abstract communication service interface (ACSI) models are conceptual

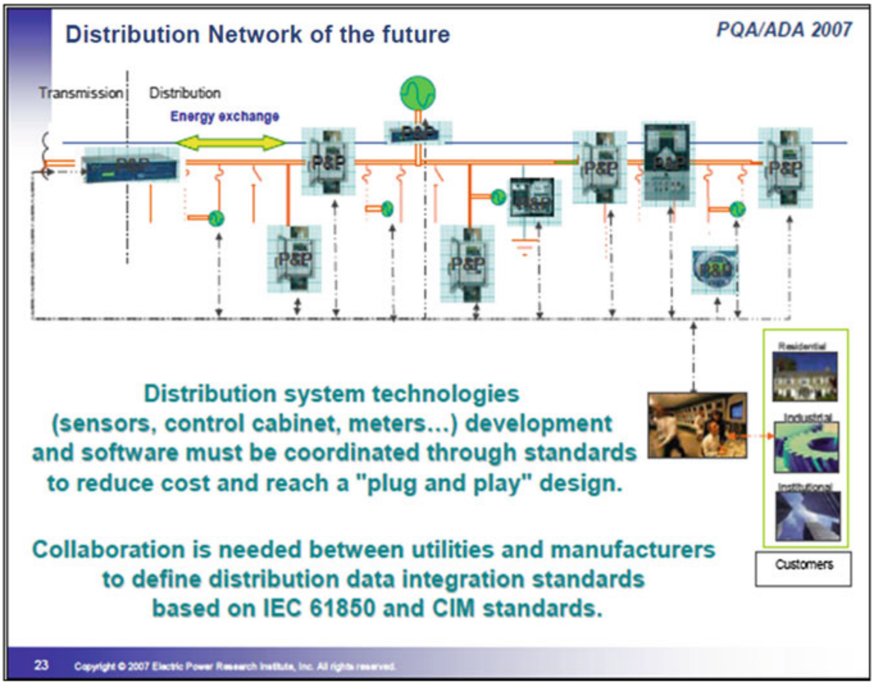

Fig. 5.11 Distribution network with interoperability standards [27]

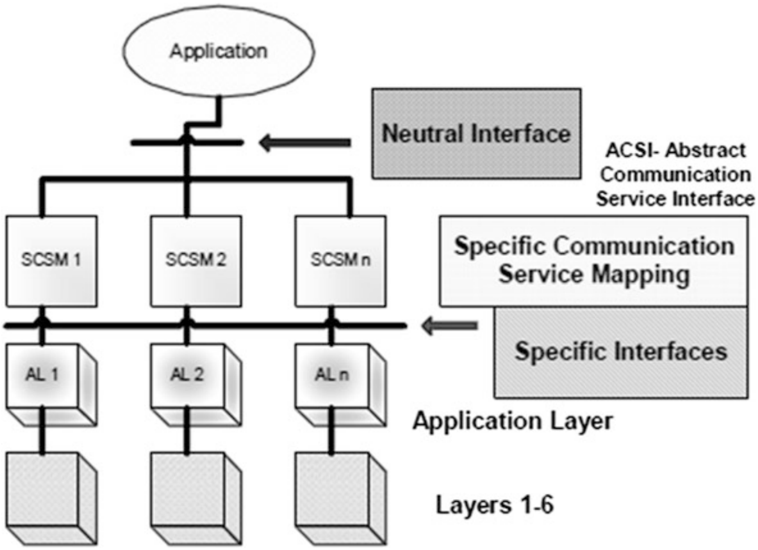

Fig. 5.12 The basic reference model [28]

definitions of common utility communication functions in field devices mainly describing communications between clients and remote servers. Some of the interfaces depict communications between a client and a remote server, while other interfaces are offered for communication between an application in one device and remote application in another device. The communications between a client and a remote server could be device control, reporting of events and setting control [31]. It aims for common utility functions to be performed consistently across all field devices provided [32]. Accordingly, ACSI defines substation-specific information models such as common DATA classes and substation-specific information exchange service models. ACSI specifies the basic layout for the information models and the information exchange service models as shown in Fig. 5.13. Nevertheless, the implementation of the objects and the modelling issues are left to the user.

A representation of physical object can be referred to as an object model. For instance, the measurements of voltage, current and power consumption, and power factor in a relay can easily be grouped together to form the "measurement model". Once standardized, it will be achievable to send information from devices without having to recognize any information about the manufacturer of the device. The Logical Node is primarily a composition of data and data set plus some additional services. This data consists of a composition of data attribute type (DAType), functional components (FC), and trigger conditions. The smallest entities for information exchange are the Logical Nodes such as XCBR. The Logical Nodes are then used to build the Logical Devices. In turn, several Logical Devices are then used to build up the IEDs [33].

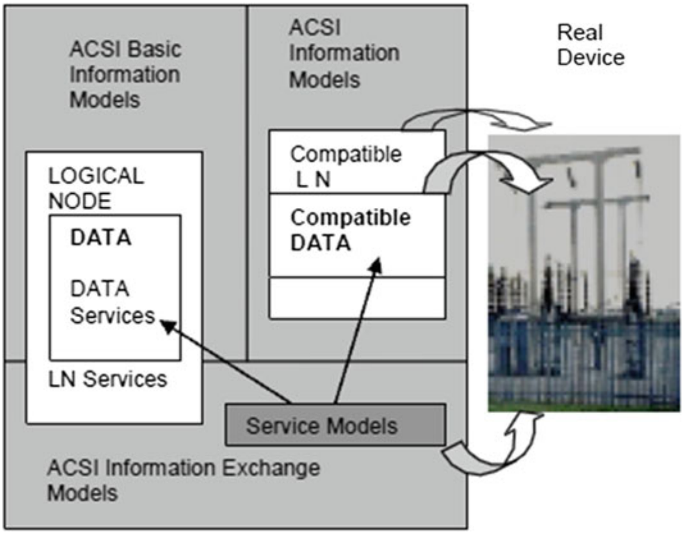

Fig. 5.13 ACSI conceptual model [32]

Each of the classes comprising the Logical Node consists of a number of building blocks. Even though ACSI permits separate devices to share data and services, it is only an abstract application layer protocol without any real procedure for sending and receiving data. It can only be serviceable when it is plotted to a definite communication service such as Manufacturing Message Specification (MMS) protocol, Distributed Component Object Model (DCOM) or Common Object Request Broker Architecture (CORBA). The specific communication service mapping (SCSM) explains the execution details of services and models using a specific communication stack [34]. The new communications infrastructure (based on interoperability standards such as the IEC 61850 series) must have sufficient bandwidth to support the traditional distribution network as well as bulk data download to support advanced waveform and sequence of events analysis. The new infrastructure must be robust enough to support increased bandwidth requirements of IEC 61850 without degrading the existing communications with the automated distribution network [35].

Integration of large-scale smart meter in distribution network introduces new challenges in the network as considerable amount of bandwidth is required for data communication between smart meter and central station. For the distribution network, it is an essential need to consider propagation delay and latency. In the next few sections, major criteria for a robust smart meter network are discussed.

5.4 Bandwidth Requirement for Smart Meter Distribution Network

In the digital age, literally thousands of digital data are available in a single IED in smart meter network, and communication bandwidth should not be a limiting factor. A broadband communications network is a need to enable comprehensive system-wide monitoring and coordination to facilitate applications such as distribution automation, demand response, and power quality monitoring. The present SCADA systems do not sense or control nearly enough of the components of the modern distribution system, and therefore, reliable, up-to-date information embedded power system is required [36].

Smart meter network needs an intelligent communications infrastructure facilitating timely and secure information flow, and this network in distribution system is needed to provide power to the evolving digital economy. It must offer robust, reliable, and secure communication since IEDs and smart meter make the necessary system assessments for distribution network when needed. Over the past 35 years, there has been a substantial increase of communication speeds from 300 bps (bits per second) to digital relays that today operate at 100 Mbps. Not only have the communication speeds changed, but the communication protocols have migrated from register-based solutions to text-based data object requests. In addition, the physical interfaces have transitioned from RS-232 serial over copper to Ethernet over fiber—both local and wide-area network. Interoperability has become a reality, and today's devices are self-describing and programmable [37]. In this digital distribution system, a utility pole hooked up to high-speed Internet. Hundreds of IEDs attached to the lines monitor how power flows through the consumer's house and that information is then sent back to the utility company. The process allows a utility to more efficiently handle the distribution of electricity by allowing two-way communications between consumers and energy suppliers via the broadband network [38]. Smart meter network also requires a far greater degree of visibility and control devices as data collection and real-time analysis become a more fundamental part. However, real-time measurements with communication channels are very limited in current distribution networks. Moreover, distribution network is enhanced by large-scale application of smart meters [39, 40]. Smart meter network allows easy broadcast of network applications from center controller to many connected smart meters but only slow communications back from the connected devices to the central controller [41].

An inspection of the Victorian automated metering infrastructure (AMI) functionality specification [42] shows a system that reveals a change in capability relative to the pre-existing meter infrastructure. This functionality of AMI is designed to deliver specific outcomes. Some more advanced smart grid concepts will lay beyond the capabilities of an AMI with a reasonable level of sophistication. Key restrictions are the asymmetric bandwidth of the communications

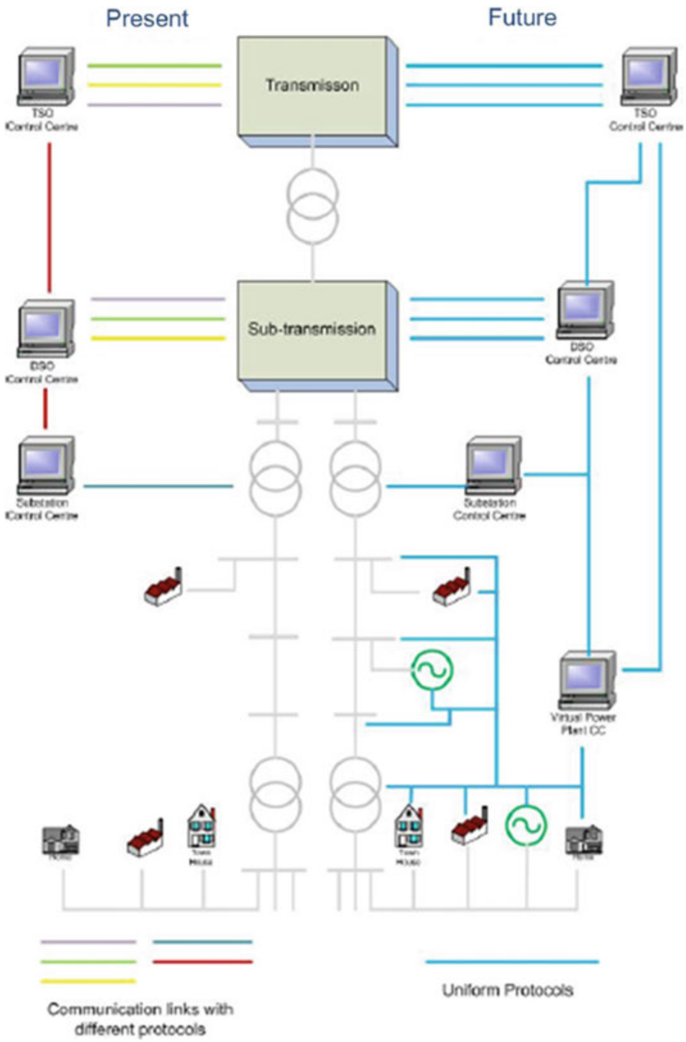

Fig. 5.14 Smart grid rollout of communications coverage to the distribution level [42]

channel and latency. Load control is one of the faster AMI commands. The Victorian functional specification [42] requires 99 % of meters respond in 1 min to group commands but for individual meter commands only 90 % need respond in 30 min. Only 2 % of meters may be switched individually within a 24 h period. Distributed generation, storage, and load control would be unable to operate within the limitations of an AMI. Any communications to individual devices are potentially subject to very long delays [41].

5.5 Communication Coverage of Smart Meter Distribution Network

The management of the previously identified AMI functions will require the use of a highly capable communications network that can provide guaranteed levels of performance with regard to bandwidth and latency. Figure 5.14 provides the extension of a communications and control infrastructure that currently include the existing distribution system [43]. An extension of communications coverage to the distribution network can support a variety of distribution automation functions.

Each Australian distributor faces challenge in developing a coherent communications solution that will support their smart meter network aspirations. Many distributors have current programs in place to increase the level of automation, and monitoring of distribution assets primarily for reliability improvement purposes. For example, Energex is currently deploying a distribution level SCADA network [41]. The recently announced federal broadband network will provide speeds in the 100 Mb/s range. It may present a possible communications solution [41]. National Energy Efficiency Initiative within the Department of the Environment, Water, Heritage and the Arts announced Smart Grid demonstration projects links broadband with intelligent grid technology and smart meters [44]. This announcement marks a turning point in supporting a robust communications layer in smart meter network.

5.6 Conclusions

This chapter presents an extensive description on the smart meter and its requirement for the development of a smart meter network. Initially, necessity of smart meter in distribution network with their technical requirements was discussed. Later, components of smart meter in distribution network with characteristics are discussed to make a foundation for the smart grid. Various communication protocols and communication standard were also investigated to choose suitable communication protocols or communication standard in smart distribution network.

It is to note that for an energy-efficient, secured, and robust distribution network, integration of smart meter with distribution network is essential. As discussed, communication protocols and communication standard and bandwidth are vital factors for an effective smart meter network.

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