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Smart grid utility management systems

SM Series
Spectrum management



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Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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REPORT ITU-R SM.2351-1

Smart grid utility management systems

(2015)

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1 Introduction

Smart grid is a term used for advanced delivery systems utility services (electricity, gas and water) from sources of generation and production to consumption points, and includes all the related management and back office systems, together with integrated modern digital information technologies. Ultimately, the improved reliability, security, and efficiency of the Smart grid distribution infrastructure is expected to result in lower costs for providing utility services to the user.

Communication technologies have fast become a fundamental tool with which many utilities are building out their smart grid infrastructure. Over recent years, for example, administrations and national commissions overseeing electric power generation distribution and consumption have made commitments to improve efficiency, conservation, security and reliability as part of their efforts to reduce the 40% of the world's greenhouse gases produced by electric power generation¹. Smart grid systems are a key enabling technology in this respect.

The key objectives of the Smart grid project are:

- to ensure secure supplies;
- to facilitate the move to a low-carbon economy;
- to maintain stable and affordable prices.

Secure communications form a key component of smart grid, and underpin some of the largest and most advanced smart grid deployments in development today. Moreover, with its overlay of information technologies, a smart grid has the ability to be predictive and self-healing, so that problems are automatically avoided. Fundamental to the smart grid project is effective smart metering in home and industry which allows for real time monitoring of consumption and communication with the grid control centres in a way that allows consumption and production to be matched and delivery to be made at the appropriate price level.

In ITU, the implementation of smart grid has become intrinsically linked to various wired and wireless technologies developed for a wide range of networking purposes². Smart grid services outside the home include advanced metering infrastructure (AMI), automated meter management (AMM), automated meter reading (AMR), and distribution automation. Inside the home, Smart grid applications will focus on providing metering, monitoring and control communications between the utility supplier, smart meters and smart appliances such as heaters, air conditioners, washers, and other appliances. A major application foreseen relates to the charging and pricing communications exchanged between electric vehicles (EV) and their charging stations. The smart grid services in the home will allow for granular control of smart appliances, the ability to remotely manage electrical devices, and the display of consumption data and associated costs to better inform consumers, and thus motivate them to conserve power.

2 Smart grid communications and features

The smart grid project envisages ubiquitous connectivity across all parts of utility network distribution grids from sources of supply grid, through network management centres and on to individual premises and appliances. Smart grid will require enormous 2-way data flows and

¹ The European Commission Smart Grid Vision and Strategy for Europe's Electricity Networks of the Future ("EC Smart Grid Vision Report" at 7 European Commission, 2006, available at <http://www.smartgrids.eu/documents/vision.pdf>).

² IEEE 802 has standards that have been developed specifically for smart grid and long range outdoor connectivity.

complex connectivity which will be on a par with the internet. More information on the communication flows envisaged over the electricity supply grid is available in the ITU Technical Paper “*Applications of ITU-T G.9960, ITU-T G.9961 transceivers for Smart Grid applications: Advanced metering infrastructure, energy management in the home and electric vehicles*”.³ In order to give a stronger focus in ITU-T on the smart grid project, the work involved on providing connectivity over power lines and the design of PLT modems specifically for smart grid applications has since been separated from the more general work on home networking under the G.9960 framework and now continues within the ITU-T G.990x (ex G.9955) family of Recommendations, i.e. G.9901, G.9902, G.9903, G.9904.

Smart grids will provide the information overlay and control infrastructure, creating an integrated communication and sensing network. The smart grid enabled distribution network provides both the utility and the customer with increased control over the use of electricity, water and gas. Furthermore, the network enables utility distribution grids to operate more efficiently than ever before.

The following countries, Research Institutes, Commissions, Industries and Standards Organizations have all identified features and characteristics of smart grid and smart metering:

- Recent United States legislation⁴
- Smart Grid Interoperability Panel (SGIP)⁵
- The Electric Power Research Institute (EPRI)⁶
- The Modern Grid Initiative sponsored by the U.S. Department of Energy (DOE)⁷
- The European Commission Strategic Research Agenda⁸
- Recent United Kingdom consultation on Smart Metering Implementation⁹
- Telecommunications Industry Association, Committee TR51, Smart Utility Networks¹⁰

³ <http://www.itu.int/publ/T-TUT-HOME-2010/en>.

⁴ The Energy Independence and Security Act of 2007 (Public Law 110-140) (TITLE XIII—SMART GRID). <http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf>.

⁵ NISTIR 7761v2 Priority Action Plan 2 Guidelines for assessing wireless standards for Smart Grid applications.

⁶ <http://my.epri.com/portal/server.pt>.

⁷ The DOE Sponsored Modern Grid Initiative identifies a Modern or Smart Grid is available at http://www.netl.doe.gov/smartgrid/referenceshelf/whitepapers/Integrated%20Communications_Final_v2_0.pdf.

⁸ EUR 22580 – Strategic Research Agenda for Europe’s Electricity Networks of the Future (EC Strategic Research Agenda) at 62, European Commission, 2007.
ftp://ftp.cordis.europa.eu/pub/fp7/energy/docs/smartgrids_agenda_en.pdf.

⁹ The United Kingdom Department of Energy and Climate Change organized a consultation on Smart Metering Implementation during 2010-2011 (ref: 10D/732 20/7/2010 – 30/03/2011); the results of which are now available here:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42742/1475-smart-metering-imp-response-overview.pdf.

¹⁰ <http://www.tiaonline.org/all-standards/committees/tr-51>.

3 Smart grid communication network technologies

Various types of communication networks may be used in smart grid implementation. Such communication networks, however, need to provide sufficient capacity for basic and advanced smart grid applications that exist today as well as those that will be available in the near future.

The electrical power grid is a commodity delivery system where the commodity (electric power) has a production-to-consumption cycle time of almost zero: generation, delivery and consumption happen “all” at nearly the same time. The challenge of balancing generation and demand will escalate with the integration of new technologies aimed at sustainably addressing energy independence and modernization of the aging power grid, e.g., renewable energy sources, distributed energy resources (DER), plug-in electric vehicles, demand-side management and response, storage, consumer participation, etc. Balancing generation and demand of a “perfect just-in-time system” requires the integration of additional protection and control technologies to ensure grid stability – not a trivial patch to the current grid and a true design challenge as both the generation and load become stochastic in nature.

For supporting the above technologies and applications, it is necessary to ensure the availability of a modern, flexible and scalable communications network that will tie together the functions of “monitoring” and “control.” Information and communication technologies will allow utilities to remotely locate, isolate and restore power outages more quickly, thus increasing the stability of the grid. Information and communication technologies will also facilitate the integration of time-varying renewable energy sources into the grid, enable better and more dynamic control of the load, and will also empower consumers with tools for optimizing their energy consumption.

These objectives have to be underpinned by standards that ensure that the various technologies and equipments supporting smart grid communications are fit for purpose and not conflict with each other or other telecommunication systems and elements operating at radio frequencies do not interfere with radiocommunication services.

3.1 The role of ITU and standards developing organizations

The telecommunication industry has a very important role in smart grid applications, for example broadband access can be used in demand side management and cloud-hosted energy service providers can also reach the home via existing broadband access technologies. Additionally, the consumer electronics industry will develop products on the basis of new energy efficiency standards and these products will also support smart grid applications. The convergence of telecom, power and consumer electronics industries for smart grid applications will drive a new eco-system of products. This convergence must happen under the auspices of international standard developing organizations.

The support of these applications and industry convergence will require the development of new Recommendations and enhancements to existing Recommendations covering all aspects of narrowband and broadband communications and their management across the power grid from generation to load. These studies will include communications issues from the physical layer to the transport or higher layer protocols over heterogeneous networks, as well as the definition of smart grid requirement and communication architecture.

Given the interdisciplinary nature of smart grid applications, a high degree of cooperation will be required between the ITU Sectors, involving Study Groups, Questions, Focus Groups (FGs), Joint Coordination Activities (JCAs), Global Strategic Initiatives (GSIs), as well with the international bodies, research institutes, industry consortia and other fora active in the smart grid project.

Global coordination on smart grid standards is taking place in IEC, which has developed strategic view and roadmap for smart grid activities¹¹, including standards gaps and recommendations.

ITU-T cooperates with the IEC contributing the communications-related aspects of smart grid. Collaboration with IEC TC 57 WG 20 is already well developed, and will be extended to other IEC Technical Committees and external organizations as appropriate. Without a strong coordination effort there is the danger of duplication of work as well as the development of incompatible and non-interoperable standards.

3.2 Coordination within ITU

Within ITU-T, the study and development of Recommendations related to transport in the access network is being carried out in several Study Groups (e.g., SGs 5, 9, 13, 15, 16 and 17). Coordination initiatives within ITU-T have built on a comprehensive informative previously being assembled through the ITU-T Focus Group on Smart Grid, which was established by the February 2010 meeting of the ITU-T Telecommunications Standardization Advisory Group (TSAG) in order to provide ITU-T Study Groups with a common forum for smart grid activities on standardization and to collaborate with smart grid communities worldwide (e.g. research institutes, forums, academia, SDOs and industry groups). The objectives identified were to:

- identify potential impacts on standards development;
- investigate future ITU-T study items and related actions;
- familiarize ITU-T and standardization communities with emerging attributes of smart grid;
- encourage collaboration between ITU-T and smart grid communities.

In a further initiative, a dedicated group called the Joint Coordination Activity on Smart Grid and Home Networking (JCA SG&HN) was established by TSAG at its meeting of January 2012 in order to coordinate activities within ITU-T. This replaced the former JCA on Home Networking (JCA-HN). The scope set for the JCA SG&HN was the coordination, both inside and outside of the ITU-T, of standardization work concerning all network aspects of smart grid and related communication as well as home networking. The JCA SG&HN successfully concluded in June 2013 and, since then, coordination on “smart grid and Home Networking” is being carried out by ITU-T SG 15, which will serve as the central point of coordination within ITU-T.

In addition, ITU-T SG 15 is presently participating in the following initiatives that address topics related to smart grid:

- [Joint Coordination Activity on Internet of Things \(JCA-IoT\)](#)
- [Joint Coordination Activity on ICT & Climate Change \(JCA-ICT&CC\)](#)
- [Focus Group on M2M \(FG-M2M\)](#)
- [Collaboration on Intelligent Transportation Systems \(ITS\) Communication Standard](#)

The role of ITU-R is to monitor activities and intervene where necessary in order to ensure that initiatives on frequency use and RF power for supporting smart grid communications disrupt or degrade the operation of radiocommunication services, noting that the power grid network closely matches the distribution of populations and the associated need for unhindered access radiocommunication services.

The parallel activities on smart grid communication technologies in the ITU-R Sector come under the ITU-R Study Group 1 Question ITU-R 236/1 – Impact on radiocommunication systems from

¹¹ See <http://www.iec.ch/smartgrid>.

wireless and wired data transmission technologies used for the support of power grid management systems.

4 Smart grid objectives and benefits

4.1 Reducing overall electricity demand through system optimization

Existing local electric distribution systems are designed to deliver energy and send it in one direction, but lack the intelligence to optimize the delivery. As a result, energy utilities must build enough generating capacity to meet peak energy demand, even though such peaks occur only on a few days per year and the average demand is much lower. Practically, this means that during days when demand is expected to be higher than average, the utility companies will restart occasionally used, less-efficient and more expensive generators.

The EU, the U.S. Congress¹², the International Energy Administration¹³ and many researchers and utilities believe that smart grid is an essential technology to improve the reliability and reduce the environmental impact of electric consumption. The EPRI has estimated that smart grid-enabled electrical distribution could reduce electrical energy consumption by 5% to 10% and carbon dioxide emissions by 13% to 25%¹⁴.

4.2 Integrating renewable and distributed energy resources

Smart grid connectivity and communications overcome the problem of handling self-generated electrical energy. With rising energy costs and ever-greater environmental sensitivity, more and more individuals and companies are taking it upon themselves to generate their own electricity from renewable energy sources, such as wind or solar. As a result it was often difficult, expensive, or even impossible to connect distributed renewable energy sources to the grid. Furthermore, even where renewable energy was fed back into the grid, the distribution grids around the world had no way of anticipating or reacting to this backflow of electricity. Techniques involving net metering will assist in the integration of disparate renewable energy sources in the grid. Decentralized generation and distribution of energy is one of the new capabilities enabled by the smart grid.

Smart grid offers the solution by communicating back to the control centre how much energy is required and how much is being input from the self-generator sources. The main generating capacity can then be balanced to take account of the additional inflow when meeting demand. Because smart grid enables this to happen in real time, utility companies can avoid problems arising from the unpredictability of renewable energy sources. The recent report for the California Energy Commission on the Value of Distribution Automation, prepared by Energy and Environmental Economics, Inc. (E3), and EPRI Solutions, Inc., stated that the value of such distributed electric

¹² For example, recent U.S. federal legislation, the Energy Independence and Security Act of 2007 (Public Law 110-140), sets out as the policy of the United States the implementation of smart grid systems to modernize the electric grid, and requires both the federal and state governments and regulators to take specific actions to support the implementation of a smart grid.

¹³ International Energy Agency, Energy Technology Prospectives, 2008 at 179.

¹⁴ See Electricity Sector Framework for the Future: Achieving the 21st Century Transformation at 42, Electric Power Research Institute (Aug. 2003) (“EPRI Report”), available at: http://www.globalregulatorynetwork.org/PDFs/ESFF_volume1.pdf.

storage capable of being managed in real time (such as a battery or plug-in vehicles) would be increased by nearly 90% over a similar asset that is not connected by a smart grid¹⁵.

4.3 Supporting smart metering

One application for Power Grid Management Systems is smart metering. Smart metering functions include:

- Advanced metering infrastructure (AMI),
- Automated meter management (AMM), and
- Automated meter reading (AMR).

The following is an example list of bands used for wireless Power Grid Management Systems in some parts of the world.

TABLE 1

Example of frequency bands used for wireless Power Grid Management Systems

Frequency (MHz)	Area/region	Comments related to the actual use
40-230 (part of), 470-694/698	North America, UK, Europe, Africa, and Japan	TV white space, rulemaking finished in USA and UK. Rulemaking is in process in Europe.
169.4-169.8125	Europe	Wireless MBus
220-222	Some parts of ITU Region 2	In ITU Region 1 + Iran, this range is part of the band used for terrestrial broadcasting according to the GE06 agreement, not used for AMR/AMI
223-235	China	Licensed band
410-430	Parts of Europe	
450-470	North America, parts of Europe	
470-510	China	Short range device (SRD) band
470-698	North America and Europe	In ITU Region 1 + Iran, this range is part of the band used for terrestrial broadcasting according to the GE06 agreement, not used for AMR/AMI
779-787	China	
868-870	Europe	European Radiocommunication Committee (ERC) Recommendation 70-03
873-876	Parts of Europe	ERC Recommendation 70-03
896-901	North America	Licensed band, Part 90 in the USA.
901-902	North America	Licensed band, Part 24 in the USA.
902-928	North America, South America, Australia	Licence exempt ISM. In Australia and some countries in South America, only the upper half of the band is allocated
915-921	Parts of Europe	ERC Recommendation 70-03
917-923.5	Korea	

¹⁵ California Energy Commission on the Value of Distribution Automation, [“California Energy Commission Public Interest Energy Research Final Project Report”](#), p. 95 (Apr. 2007) (CEC Report).

TABLE 1 (*end*)

Frequency (MHz)	Area/region	Comments related to the actual use
920-928	Japan	
928-960	North America	Licensed band, Part 22, 24, 90 and 101 in the USA.
950-958	Japan	Shared with passive RFID
1 427-1 518	United States of America and Canada	In parts of Region 1, namely in Europe: <ul style="list-style-type: none"> – The range 1 452-1 479.2 MHz is planned for use by terrestrial broadcasting according to the Ma02revCO07 agreement (registered in ITU as regional agreement) and by the Mobile service for supplemental downlink only according to relevant EC decision. – The range 1 492-1 518 MHz is used for wireless microphones according to ERC Recommendation 70-03, Annex 10. – Not used for AMR/AMI
2 400-2 483.5	Worldwide	
3 550-3 700	United States of America	Regionally licensed
5 250-5 350	North America, Europe, Japan	
5 470-5 725	North America Europe, Japan	
5 725-5 850	North America	Licence exempt, ISM band

The 3GPP2 cdma2000 Multi-Carrier family of technologies can also be used for power grid management applications. The applicable bands are defined in 3GPP2 C.S0057-E v1.0 Band Class Specification for cdma2000 Spread Spectrum Systems.

4.4 Providing a resilient network

Remote sensing technology along the electric distribution lines allows network operators to gather real-time intelligence on the status of their network. This enables providers of critical national infrastructure both to prevent outages before they occur and quickly pinpoint the site of an incident when one does occur. Smart grid does this by a series of software tools that gather and analyze data from sensors distributed throughout the electric distribution network to indicate where performance is suffering. Distribution companies can maximize their maintenance programs to prevent breakages, and quickly dispatch engineers to the scene of an incident, independent of consumer feedback. In recent years, highly publicized blackouts in North American and European networks have made electricity network security a political question, and with an aging network the number of outages, and associated disruptions to end users, are only going to increase. Smart grid will provide a real tool in this constant battle for control.

5 Smart grid reference architecture overview

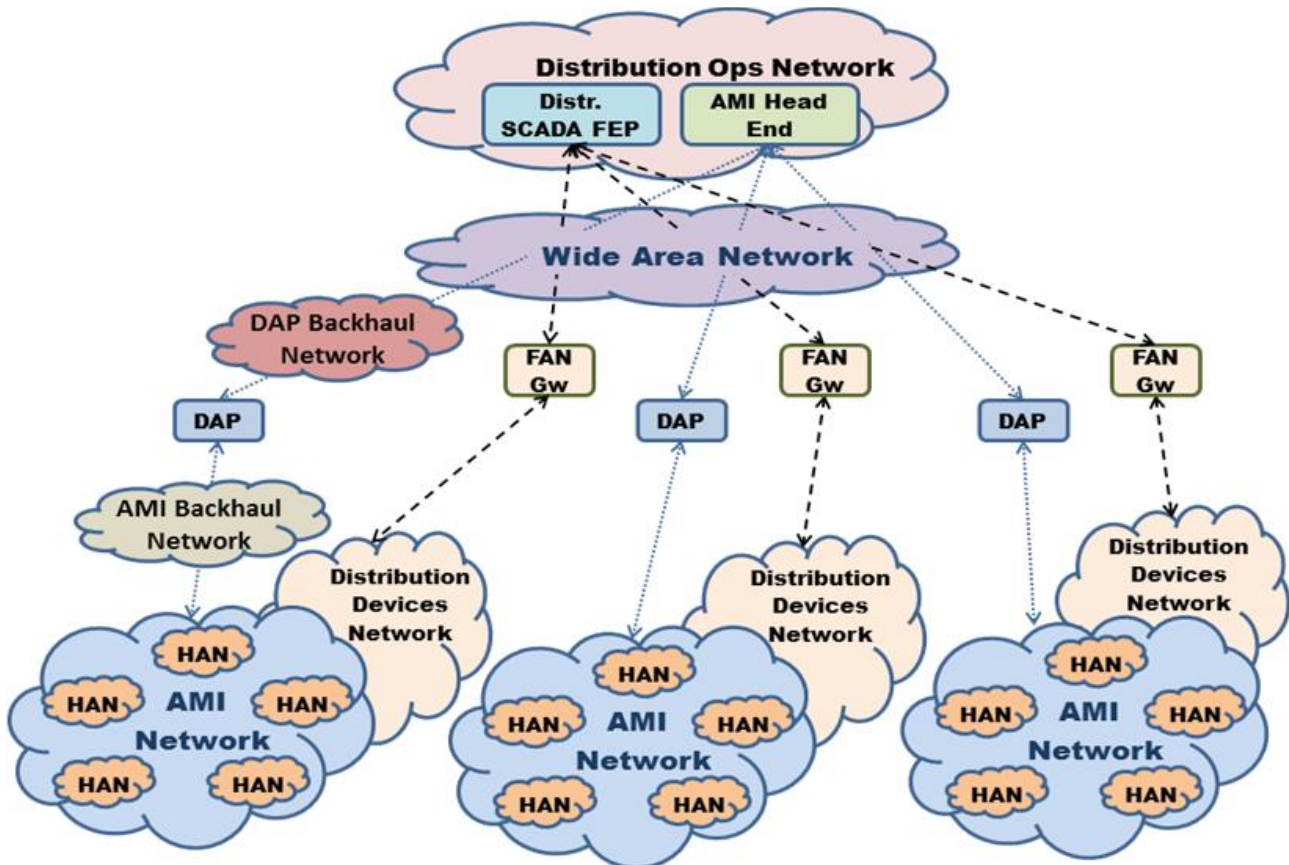
An example of a smart grid reference architecture is shown, in which the following elements are illustrated¹⁶:

¹⁶ The definitions and the Figure are from [NISTIR 7761 2013-07-12](#).

- Home area network (HAN) – A network of energy management devices, digital consumer electronics, signal-controlled or enabled appliances, and applications within a home environment that is on the home side of the electric meter.
- Field area network (FAN) – A network designed to provide connectivity to field DA devices. The FAN may provide a connectivity path back to the substation upstream of the field DA devices or connectivity that bypasses the substations and links the field DA devices into a centralized management and control system (commonly called a SCADA system).
- Neighborhood area network (NAN) – A network system intended to provide direct connectivity with smart grid end devices in a relatively small geographic area. In practice a NAN may encompass an area the size of a few blocks in an urban environment, or areas several miles across in a rural environment.
- Wide area network (WAN).
- Data aggregation point (DAP) – This device is a logical actor that represents a transition in most AMI networks between wide area networks and neighborhood area networks (e.g. collector, cell relay, base station, access point, etc.).
- Advanced metering infrastructure (AMI) – A network system specifically designed to support 2-way connectivity to electric, gas, and water meters or more specifically for AMI meters and potentially the energy service interface for the utility.
- Supervisory control and data acquisition (SCADA) – System used to routinely monitor electric distribution network operations and performs supervised control as needed.
- Front end processor (FEP) – This device serves as the primary conduit for issuing commands from DMS/SCADA and receiving information from field devices deployed with in the distribution network.

FIGURE 1

Example Smart grid network



A given wireless standard may find application in more than one of these areas. In addition, in some applications, a certain number of the links may be achieved with wired solutions.

Various views have been expressed (for example during consultations by the United Kingdom Department of Energy and Climate Change¹⁷) as to whether the frequencies used for the wireless components of smart grid communications should be from bands allocated and protected for such purposes, or in deregulated (e.g. bands exempt from individual licensing) bands. Note that billing and charging data is deemed to personal data in several countries and therefore subject to strict protection under data protection legislations.

Many wireless technologies provide strong security and privacy to protect user data in smart grid applications. For example: IEEE 802 standards provide robust, link-level privacy and security that is appropriate to protect personal data in cabled and wireless networks (both licensed and license exempt bands); also, 3GPP technologies provide means for network-wide authorization, authentication, privacy and security.

6 Power line and cabled standards for smart grid telecommunications

Smart grid will rely both on wired and wireless technologies in order to provide the connectivity and communication paths needed to handle the huge flows of data around utility distribution networks.

¹⁷ http://www.decc.gov.uk/en/content/cms/consultations/smart_mtr_imp/smart_mtr_imp.aspx.

6.1 Smart grid communications over power lines

An early candidate for consideration was power line communications/telecommunications (PLC) following on from the simplistic rationale that the electricity supply lines themselves provide ubiquitous connectivity across all parts of the electricity supply grid and that the necessary data signals could be sent end-to-end over the power lines themselves. This ignored some important points such as attenuation and noise along the power lines and how to route signals around the grid network, and crucially the integrity of the data.

The rationale for the ITU-T Sector to become involved with PLC was an appreciation that although increasing use was being made of mains electrical wiring for data transmission, the power lines were neither designed nor engineered for communications purposes. In particular, ITU-T had concerns with the unshielded and untwisted wires used for power transmission, which are subject to many types of strong interference¹⁸; many electrical devices are also sources of noise on the wire.

Because of the susceptibility of power line communication to incoming interference, advanced communications and noise mitigation technologies have been developed by ITU-T Study Group 15 for general purpose PLC applications within the Recommendation ITU-T G.9960 family of recommendations from 2010 onwards. More recently, ITU-T has developed a set of narrow band power line communications (NB-PLC) technologies in the ITU-T G.990x (G.9901, G.9902, G.9903, G.9904) family of Recommendations (ex G.9955) which have been designed specifically to support smart grid connectivity and communications. Two of these Recommendations (G.9903 and G.9904) have now been shown to be field-proven thanks to installations done in several countries located in Europe, Asia and Americas. The IEEE Standards Association has standards that leverage PLC for Smart grid applications, e.g. IEEE Std 1901.2-2013.

The frequency ranges defined for NB-PLC in the ITU-T G.990x (ex., G.9955) family of Recommendations (see Table 2 – G.9901, G.9902, G.9903, G.9904) are those already designated for use by PLT in Europe by CENELEC¹⁹ and CEPT²⁰, for the USA by the FCC, and for Japan by ARIB. Moreover, the limits on conducted and radiated interference set in the G.990x family of Recommendations comply with the IEC CISPR 22 standard, *“Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement”*, and also with CENELEC EN 50065-1 (2011) for frequencies below 148.5 kHz.

¹⁸ See section 5.1.2 of ITU-T Tutorial at <http://www.itu.int/pub/T-TUT-HOME-2010/en>.

¹⁹ [European Committee for Electrotechnical Standardization](#).

²⁰ [European Conference of Postal and Telecommunications Administrations](#).

TABLE 2

ITU-T Recommendations related to Smart Grid Communications

Recommendation No.	Recommendation title
G.9901	Narrow-band OFDM power line communication transceivers – Power spectral density specification
<u>G.9902</u>	Narrow-band OFDM power line communication transceivers for ITU-T G.hnem networks
<u>G.9903</u>	Narrow-band OFDM power line communication transceivers for G3-PLC networks
<u>G.9904</u>	Narrow-band OFDM power line communication transceivers for PRIME networks
<u>G.9905</u>	Centralized metric based source routing
<u>G.9959</u>	Short range narrowband digital radiocommunication transceivers – PHY & MAC layer specifications

The frequency ranges used in the ITU-T G.990x family of Recommendations for NB-PLC/smart grid therefore use best practice in avoiding incompatibilities with radiocommunication services that could arise with the ubiquitous deployment of PLT for smart grid communications. However, other standards developing organizations (SDOs) and industry groups outside ITU have taken an interest in developing PLT products for smart grid applications, which may need to give due consideration to compatibility requirements.

6.2 Smart grid communications over cable networks

In addition to Power Line Telecommunications, traditional cabled solutions such as optical fibre and copper are frequently used for wide area networks when right of way is available.

These links may be deployed directly by the utility on transmission and distribution assets, buried in trenches or conduits in the right-of-way, or leased from telecommunications carriers.

IEEE Std 802.3 Ethernet local area network operation is specified for selected speeds of operation from 1 Mb/s to 100 Gb/s over a variety of optical and dedicated separate-use copper media over a variety of distances.

- IEEE 802.3 EPON
- IEEE 802.3 Ethernet in the first mile

Wired Ethernet links are generally mandated to comply with applicable local and national codes for the limitation of electromagnetic interference for non-transmitting systems.

7 Wireless standards for smart grid telecommunications

7.1 Home area network

There are a variety of networking solutions using cable or wireless links that are already deployed for HANs, depending on the needs for energy, data rate, mobility and installation costs. The most common HANs using cable based solutions are IEEE 802.3 (Ethernet); for wireless solutions the IEEE 802.11 (WiFi), IEEE 802.15.4 (ZigBee, Thread, Wi-SUN EchoNet HAN), ITU-T G.9959 (Z-Wave) standards are widely deployed.

Wireless technologies can provide smart grid for all utilities and can easily connect directly into an IP based infrastructure when electrical safety or legal considerations prevent directly wired connections, which can be the case with gas or water meters.

Recommendation ITU-T G.9959, “*Short range narrow-band digital radiocommunication transceivers*”, was developed in ITU-T in order to provide for narrow band Wireless LAN functionality suitable for smart grid applications. During the early drafting stages of this work there had been some discussion between ITU-R and ITU-T concerning suitable frequency bands for such applications. At issue were the advantages and disadvantages of identifying frequencies within bands subject to some form of regulatory control by administrations or in bands designated for ISM use or otherwise designated at regional or national level for deregulated use, i.e. without a requirement for individual licensing. Much of the discussion was on security and reliability concerns, as smart grid communications may contain billing and personal data, with respect to bands that are freely available for a number of deregulated uses.

Several frequencies falling within bands around 900 MHz, according to national and regional designations for deregulated use, have now been advised as suitable for use under Recommendation ITU-T G.9959, of which only two, in Region 2, fall within a band designated for use by ISM applications. One of the design criteria for transceivers working to G.9959 is that they should support 1, 2 or 3 channels (each channel being associated with a centre frequency) depending on the availability of channels in the specific region/country concerned.

With regard to the choice and suitability of worldwide frequencies for G.9959, the basic requirement for G.9959 is to be backwards compatible with the Z-Wave²¹ technology which has been operating in the field for more than a decade. When considering assigning new frequencies for use by G.9959, it should be taken into account that this may render future products based on G.9959 incompatible with existing Z-Wave devices and thus, prevent new G.9959 devices from leveraging from the large interoperable ecosystem which already exists. The future spectrum needs for G.9959 and similar technologies for use with smart grid may become an issue at WRC-23 under agenda item 2.5.

It should also be noted that IEEE 802.11, and IEEE 802.15.4 are widely deployed for HAN applications and that both G.9959 and IEEE 802.15.4 based systems may employ frequency hopping and mesh routing in case direct range transmission is not possible because of long range, attenuation, distortion or temporary interference. This increases the robustness of the system when operating over unlicensed bands.

In addition to the spectrum management and compatibility considerations within the remit of ITU-R, there are also legal, privacy and security issues that will need to be considered in the appropriate fora on the integrity of wireless devices used in smart grid. Such considerations may have a bearing on the identification of frequencies for use in wireless smart grid communications – in particular the need to avoid interception, spoofing, data corruption, or loss in relation to charging and billing data.

All of the wireless standards mentioned in this section include encryption to provide privacy and security. The possibility of interference is an unavoidable result of operation in spectrum that is not subject to regulation, such as individual licensing. In general, HAN applications do not require high reliability. WAN and FAN applications using wireless connections that require high reliability and

²¹ Z-Wave is a low-power, low-cost wireless technology enabling consumer-grade products with networked features. Examples include remote controlled light dimmers, networked temperature sensors, electronic door locks and AV systems. A Z-Wave compliant node shall operate in the license free RF bands such as the ISM bands (http://www.z-wave.com/what_is_z-wave).

availability are best suited for operation in spectrum subject to individual licensing, mandatory standards or other forms of regulation.

7.2 WAN/NAN/FAN

The WAN/NAN/FAN communication networks share the need to carry data over relatively long distances (neighborhoods, cities) to operation centers. These networks can directly service the end node or serve as a backhaul. The type of solution that is selected depends on many considerations, some of which are:

- Link distance
- Availability of right of way (for cabled solutions)
- Link capacity
- Non-mains powered devices
- Availability
- Reliability
- Regulated (e.g. licensable) versus unregulated (e.g. license exempt) spectrum.

The IEEE 802 LAN/MAN standards committee has developed several wireless standards that are being used to support Smart Grid applications.

These solutions include:

- Wireless standards that support point-to-multipoint wireless
 - IEEE 802.11
 - IEEE 802.16
 - IEEE 802.20
 - IEEE 802.22
- Wireless standards that support wireless mesh
 - IEEE 802.15.4
 - IEEE 802.11

Other wireless communication technologies that can contribute to smart grid requirements include cellular technologies and sound broadcasting. Cellular networks under 3GPP responsibility (i.e. GSM/EDGE, WCDMA/HSPA and LTE) have evolved from providing telephony services to support a wide range of data applications, with in-built security and quality of service support. In recent 3GPP releases standardization enhancements for machine-type communication (MTC) have also been introduced, including support for congestion control, improved device battery lifetime and low complexity device support. Smart meters are available with individual monitoring and control functions provided using GSM technology. Also, inaudible subcarriers have been used for decades for simple wide area switching between metering tariffs using FM broadcasting networks in the USA and the LF 198 kHz national coverage broadcasting service in the United Kingdom. The IEEE 802 LAN/MAN standards committee has developed several standards that are being used to support smart grid applications.

8 Interference considerations associated with the implementation of wired and wireless data transmission technologies used in power grid management systems

The IEEE 802 LAN/MAN Standards Committee has developed many wireless technologies that have demonstrated interference resilient communications to enable power grid management without interference to others.

Typical features provided by the IEEE 802 family of standards are:

- For example, IEEE 802.11 (Wi-Fi™), and IEEE 802.15.1 (Bluetooth™) have demonstrated that they can co-exist while operating in the same band for many years.
- Although thousands of smart grid devices will be deployed, their data rate requirements may be low and it is very likely that all the devices will not be transmitting at the same time. Therefore, they can efficiently share the same spectrum.
- Regulators such as the Federal Communications Commission and UK Ofcom have proposed strict emission limits for various bands that strictly need to be adhered to in order to be able to use these bands.
- New cognitive radio sharing technologies developed within the IEEE 802 Standards (e.g. IEEE 802.22-2011™, also known as Wi-FAR™) can make efficient use of spectrum while doing no harm to other primary users operating in these bands or the adjacent bands.
- Features embedded within IEEE 802 standards such as spectrum sensing, spectrum etiquette, channel set management and co-existence will ensure minimal interference to themselves and others.

Cellular 3GPP technologies utilize licenced spectrum bands and therefore have controlled interference. Furthermore, advanced interference management techniques for multiple devices are in place such as enhanced interference cancellation.

3GPP solutions provide cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities – including work on codecs, security, quality of service – and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks.

The major focus for all 3GPP Releases is to:

- Make the system backwards and forwards compatible where-ever possible, to ensure that the operation of user equipment is un-interrupted.
- Perform extensive co-existence studies and develop specifications to ensure frequency band sharing of systems using different 3GPP access technologies with minimal impact on performance.
- Adhere to global regulatory emission requirements
- Provide and maintain access technologies supporting a wide range of data rates and capacity.

Furthermore, the 3GPP technologies can make use of diversity techniques, such as frequency hopping, to increase protection against interference and reduce interference towards other systems operating in the same band. The technologies also utilize interference planning and coordination techniques, such as system wide frequency planning, and inter-cell interference coordination to ensure efficient utilization of spectrum. Advanced interference suppression is also utilized at the receivers, increasing protection against interference.

3GPP2 has developed many wireless technologies that have demonstrated interference resilient communications to enable power grid management without interference to others. The 3GPP2 cdma2000 Multi-Carrier family of standards include:

- cdma2000 1x
- cdma2000 High Rate Packet Data (HRPD/EV-DO)
- Extended High Rate Packet Data (xHRPD).

3GPP2 cdma2000 Multi-Carrier family of standards is recognized by the ITU as an IMT technology as documented in Recommendation ITU-R M.1457. Typical features provided by the 3GPP2 cdma2000 Multi-Carrier family of standards are:

- A well proven technology with sophisticated access control to support a large number of users in both random access and traffic modes with minimum interference.
- Already globally deployed to provide connectivity to a wide spread geographic area.
- Each base station has a large coverage area by design.
- A complete set of specifications including network, security, test and performance specifications.

9 Impact of widespread deployment of wired and wireless networks used for power grid management systems on spectrum availability

One of the objectives of the 3GPP cellular wireless technologies and the IEEE 802 family of standards is that the spectrum availability will not be affected by interference associated with wide-spread deployment of such technologies and devices.

This is vital consideration given that:

- There are currently millions of installed wireless smart grid devices in a variety of countries and regions, e.g. Europe, Australia, North America, that are operating in shared spectrum. These deployments are growing and more are planned in these geographic regions because they have been successful and effective.
- Mobile consumer wireless devices are in wide use globally. Each device may transfer gigabytes of data per month. The data usage of wireless smart grid devices is orders of magnitude smaller. The licensed spectrum, which is managed by wireless carriers, can easily handle the incremental traffic.
- Existing regulations by regulators such as the Federal Communications Commission and UK Ofcom have successfully allowed for millions of wireless Smart grid devices to operate without harm to each other.
- IEEE 802 wireless standards use a variety of technologies, e.g. frequency hopping, mesh routing, fragmentation, coding, and high burst rate, which enable reliable wireless Smart Grid Networks. In addition, wireless Smart Grid networks are resilient to link breaks and power outages.
- Cellular wireless 3GPP technologies use a variety of techniques such as high level modulation and coding, resource block allocation, interference cancellation and mitigation, and MIMO to utilize the allocated spectrum efficiently. Additionally, Coordinated Multipoint provides additional robustness.
- New cognitive radio sharing technologies developed within the IEEE 802 Standards can make efficient use of spectrum while doing no harm to other primary users operating in these bands or the adjacent bands.
- Features embedded within IEEE 802 standards such as spectrum sensing, spectrum etiquette, channel set management and co-existence will ensure minimal interference to themselves and others.
- Cellular wireless 3GPP technologies are continuously evolving and new features relevant to smart grids will be introduced in 3GPP Release 13.

- Wired Ethernet links do not use wireless spectrum, and are generally mandated to comply with applicable local and national codes for the limitation of electromagnetic interference for non-transmitting systems. As such, there should be no additional interference considerations to radiocommunication associated with the use of Ethernet in the implementation of wireless and wired technologies and devices used in support of power grid management systems.

One of the objectives of the 3GPP family of standards is that the spectrum availability will not be affected by interference associated with wide-spread deployment of such technologies and devices considering

- widespread, global deployment of systems providing global roaming of millions of user equipment,
- reliable coverage of cellular network almost everywhere globally.

10 Conclusion

High-capacity, two-way communication networks employing wireless, PLT, or other telecommunications technologies that couple sensors and smart meters can transform existing distribution networks for utilities into smart grids.

Smart metering and communications via smart grid networks will in principle allow consumers to monitor and change their patterns of consumption to their best advantage. Utilities will also be able to introduce real time pricing measures in which charges can be adjusted continually to take account of considerations of total demand and the integrity of distribution grids. It will also be possible, in principle, to regulate the demand from particular classes of high usage domestic appliances and industrial equipment.

The overall objective is that these interactive smart grid networks can be monitored and controlled to enhance the efficiency, reliability, and security of the distribution networks for electricity, gas and water supplies, while assuring consumers of the continuity of supply.

Annex 1

Examples of existing standards related to power grid management systems

A1.1 IEEE Standards

IEEE 802 has a variety of wireless standards that are applicable to first mile applications for power grid management systems. A summary of the technical and operating features of the relevant IEEE 802 wireless standards are given in the tables below.

NOTE – See Recommendation ITU-R M.1450 Table 2, for technical parameters associated with IEEE Std 802.11.

TABLE A1.1

Technical and operating features of IEEE Std 802.11

Item	802.11	802.11ah ²²		802.11n	802.11ac
		Model 1 ²³	Model 2 ²⁴		
Supported frequency bands (licensed or unlicensed)	2.4 GHz	900 MHz	900 MHz	2.4 GHz	5 GHz
Nominal operating range	1.5 km	2 km	2 km	0.25 km	0.14 km
Mobility capabilities (nomadic/mobile)	Nomadic and mobile	Nomadic	Nomadic	Nomadic and mobile	Nomadic and mobile
Peak data rate (uplink/downlink if different)	2 Mb/s	156 Mb/s	1.3 Mb/s	600 Mb/s	6 934 Mb/s
Duplex method (FDD, TDD, etc.)	TDD				
Nominal RF bandwidth	20 MHz	1, 2, 4, 8, 16 MHz	2 MHz	20, 40 MHz	20, 40, 80, 160 MHz
Diversity techniques	Space time				
Support for MIMO (yes/no)	No	Yes	No	Yes	Yes
Beam steering/forming	No	Yes	Yes	Yes	Yes
Retransmission	Automatic repeat requested (ARQ)				
Forward error correction	Yes	Convolutional and LDPC	Convolutional and LDPC	Yes	Yes
Interference management	Listen before talk	Listen before talk and frequency channel selection	Listen before talk and frequency channel selection	Listen before talk	Listen before talk
Power management	Yes				
Connection topology	Point-to-point, multi-hop, star				
Medium access methods	CSMA/CA				
Multiple access methods	CSMA	CSMA/TDMA	CSMA/TDMA	CSMA	CSMA
Discovery and association method	Passive and active scanning				
QoS methods	Radio queue priority, pass-thru data tagging, and traffic priority				
Location awareness	Yes				
Ranging	Yes				
Encryption	AES-128, AES-256				
Authentication/replay protection	Yes				

²² IEEE P802.11ah is a project that has effectively been completed, but is awaiting the results of the approval process at the time of writing.

²³ Model 1 is family description + indoor model.

²⁴ Model 2 is specific operating model + outdoor model.

TABLE A1.1 (*end*)

Item	802.11	802.11ah ²⁵		802.11n	802.11ac
		Model 1 ²⁶	Model 2 ²⁷		
Key exchange		Yes			
Rogue node detection		Yes			
Unique device identification		48 bit unique identifier			

TABLE A1.2

Technical and operating features of IEEE Std 802.15.4

Item	Value
Supported frequency bands, licensed or unlicensed (MHz)	Unlicensed: 169, 450-510, 779-787, 863-870, 902-928, 950-958, 2 400-2 483.5 Licensed: 220, 400-1000, 1427
Nominal operating range	OFDM – 2 km MR-FSK – 5 km DSSS – 0.1 km
Mobility capabilities (nomadic/mobile)	Nomadic and mobile
Peak data rate (uplink/downlink if different)	OFDM – 860 kb/s MR-FSK – 400 kb/s DSSS – 250 kb/s
Duplex method (FDD, TDD, etc.)	TDD
Nominal RF bandwidth	OFDM – ranges from 200 kHz to 1.2 MHz MR-FSK – ranges from 12 kHz to 400 kHz DSSS – 5 MHz
Diversity techniques	Space and time
Support for MIMO (yes/no)	No
Beam steering/forming	No
Retransmission	ARQ
Forward error correction	Convolutional
Interference management	Listen before talk, frequency channel selection, frequency hopping spread spectrum, frequency agility.
Power management	Yes
Connection topology	Point-to-point, multi-hop, star
Medium access methods	CSMA/CA
Multiple access methods	CSMA/TDMA/FDMA (in hopping systems)
Discovery and association method	Active and passive scanning

²⁵ IEEE P802.11ah is a project that has effectively been completed, but is awaiting the results of the approval process at the time of writing.

²⁶ Model 1 is family description + indoor model.

²⁷ Model 2 is specific operating model + outdoor model.

TABLE A1.2 (*end*)

Item	Value
QoS methods	Pass-thru data tagging and traffic priority
Location awareness	Yes
Ranging	Yes
Encryption	AES-128
Authentication/replay protection	Yes
Key exchange	Yes
Rogue node detection	Yes
Unique device identification	64 bit unique identifier

TABLE A1.3

Characteristics of IEEE Std 802.16

Item	Value
Supported frequency bands (licensed or unlicensed)	Licensed frequency bands between 200 MHz and 6 GHz
Nominal operating range	Optimized for range up to 5 km in typical PMP environment, functional up to 100 km
Mobility capabilities (nomadic/mobile)	Nomadic and mobile
Peak data rate (uplink/downlink if different)	802.16-2012: 34.6UL / 60DL Mbit/s with 1 Tx BS Antenna (10 MHz BW). 69.2 UL / 120DL Mbit/s with 2 Tx BS Antennas (10 MHz BW) 802.16.1-2012: 66.7UL / 120DL Mbit/s with 2 Tx BS Antenna (10 MHz BW), 137UL / 240DL Mbit/s with 4 Tx BS Antennas (10 MHz BW)
Duplex method (FDD, TDD, etc.)	Both TDD and FDD defined, TDD most commonly used, Adaptive TDD for asymmetric traffic
Nominal RF bandwidth	Selectable: 1.25 MHz to 10 MHz
Diversity techniques	Space and time
Support for MIMO (yes/no)	Yes
Beam steering/forming	Yes
Retransmission	Yes (ARQ and hybrid ARQ (HARQ))
Forward error correction	Yes (convolutional coding)
Interference management	Yes (fractional frequency re-use)
Power management	Yes
Connection topology	Point-to-multipoint, point-to-point, multi-hop relaying
Medium access methods	Coordinated contention followed by connection oriented QoS is support through the use of 5 service disciplines
Multiple access methods	OFDMA
Discovery and association method	Autonomous discovery, association through CID/SFID
QoS methods	QoS differentiation (5 classes supported), and connection oriented QoS support

TABLE A1.3 (*end*)

Item	Value
Location awareness	Yes
Ranging	Optional
Encryption	AES128 – CCM and CTR
Authentication/replay protection	Yes
Key exchange	PKMv2 (Section 7.2.2)
Rogue nodes	Yes, cypher-based message authentication code (CMAC)/hashed message authentication code (HMAC) key derivation for integrity protection for control messages. Additionally ICV of AES-CCM for integrity protection of MPDUs.
Unique device identification	MAC Address, X.509 certificates, optional SIM Card

TABLE A1.4

Technical and operating features of IEEE Std 802.20 625k-MC mode

Item	Value
Supported frequency bands (licensed or unlicensed)	Licensed bands below 3.5 GHz
Nominal operating range	12.7 km (Max)
Mobility capabilities (nomadic/mobile)	Mobile
Peak data rate (uplink/downlink if different)	The peak downlink user data rates of 1 493 Mbit/s and peak uplink user data rates of 571 kbps in a carrier bandwidth of 625 kHz.
Duplex method (FDD, TDD, etc.)	TDD
Nominal RF bandwidth	2.5 MHz (accommodates Four 625 kHz spaced carriers), 5 MHz (accommodates Eight 625 kHz spaced carriers)
Modulation/coding rate – upstream and downstream	Adaptive modulation and coding, BPSK, QPSK, 8-PSK, 12-PSK, 16QAM, 24QAM, 32QAM and 64QAM
Diversity techniques	Spatial diversity
Support for MIMO (yes/no)	Yes
Beam steering/forming	Spatial channel selectivity and adaptive antenna array processing.
Retransmission	Fast ARQ
Forward error correction	Block and convolutional coding / Viterbi decoding
Interference management	Adaptive antenna signal processing
Power management	Adaptive power control (open as well as closed loop) scheme. The power control will improve network capacity and reduce power consumption on both uplink and downlink.
Connection topology	Point-to-multipoint
Medium access methods	Random access, TDMA-TDD
Multiple access methods	FDMA-TDMA-SDMA

TABLE A1.4 (*end*)

Item	Value
Discovery and association method	By BS-UT mutual authentication
QoS methods	The 625k-MC mode defines the three QoS classes. that implement IETF's Diffserv model: expedited forwarding (EF), assured forwarding (AF) and best effort (BE) Per hop behaviors based on the DiffServ code points (DSCP).
Location awareness	Yes
Ranging	Yes
Encryption	Stream ciphering RC4 and AES
Authentication/replay protection	BS authentication and UT authentication based on using digital certificates signed according to the ISO/IEC 9796 standard using the Rivest, Shamir and Adleman (RSA) algorithm
Key exchange	Elliptic curve cryptography (using curves K-163 and K-233 in FIPS-186-2 standard)
Rogue node detection	Protected from rogue nodes
Unique device identification	Yes

TABLE A1.5

Technical and operating features of IEEE Std 802.22

Item	Value
Supported frequency bands (licensed or unlicensed)	54-862 MHz
Nominal operating range	Optimized for range up to 30 km in typical point-to-multipoint (PMP) environment, functional up to 100 km
Mobility capabilities (nomadic/mobile)	Nomadic and mobile
Peak data rate (uplink/downlink if different)	22-29 Mb/s, greater than 40 Mb/s with MIMO
Duplex method (FDD, TDD, etc.)	TDD
Nominal RF bandwidth	6, 7 or 8 MHz
Diversity techniques	Space, time, block codes, spatial multiplexing
Support for MIMO (yes/no)	Yes
Beam steering/forming	Yes
Retransmission	ARQ, HARQ
Forward error correction	Convolutional, Turbo and LDPC
Interference management	Yes
Power management	Yes, variety of low power states
Connection topology	Point-to-multipoint
Medium access methods	TDMA/TDD OFDMA, reservation based MAC
Multiple access methods	OFDMA

TABLE A1.5 (*end*)

Item	Value
Discovery and association method	Yes, through device MAC ID, CID and SFID
QoS methods	QoS differentiation (5 classes supported), and connection oriented QoS support
Location awareness	Geolocation
Ranging	Yes
Encryption	AES128 – CCM, ECC and TLS
Authentication/replay protection	AES128 – CCM, ECC, EAP and TLS, replay protection through encryption, authentication as well as packet tagging.
Key exchange	Yes, PKMv2
Rogue node detection	Yes
Unique device identification	48 bit unique device identifier, X.509 certificate

A1.2 ITU-T Standards

The ITU-T G.990x (G.9901, G.9902, G.9903, G.9904) family of NB-PLC recommendations has been developed to support smart grid connectivity and communications. A summary of the technical and operating features are given in the tables below for the two field-proven NB-PLC technologies specified in ITU-T.

TABLE A1.6

Technical and operating features of Recommendations ITU-T G.9903 and G.9904

Item	G.9903 value	G.9904 value
Supported frequency bands	35-488 kHz	42-89 kHz
Peak data rate	42 kbps	128 kbps
Multiple access methods	OFDM	OFDM
Forward error correction	Reed Solomon, convolutional, scrambler, interleaver, repetition code	Convolutional, scrambler, interleaver
Network topology	Mesh	Tree
Retransmission	ARQ	ARQ
Medium access methods	CSMA and priority	CSMA and contention free or priority
Discovery and association method	6loWPAN and EAP-PSK based	Specific network registration procedure
QoS methods	QoS differentiation with 2 priorities	QoS differentiation with 4 priorities
Encryption	AES128 – CCM	AES128 – GCM
Authentication/replay protection	Authentication and anti-replay mechanism	Authentication and anti-replay mechanism
Key exchange	Yes	Yes
Unique device identification	64-bit unique device identifier	64-bit unique device identifier

A1.3 3GPP Standards

3GPP has a variety of wireless standards that are applicable to first mile applications for power grid management systems. A summary of the technical and operating features of the relevant 3GPP wireless standards are given in the table below.

TABLE A1.7

Technical and operating features of 3GPP Technologies

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Ability to reliably establish an appropriate device link	% of time	Depends on deployment (typical > 99%)	Depends on deployment (typical > 99%)	Depends on deployment (typical > 99%)	Depends on deployment (typical > 99%)
Ability to maintain an appropriate connection	failure rate per 1 000 sessions	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)
Voice		Yes	Yes	Yes	Yes
Data	Max user data rate per user in Mbit/s	Using 8 slots: 0.1856 Mbit/s (general packet radio service (GPRS) UL/DL) 0.5568 Mbit/s (enhanced GPRS (EGPRS) UL/DL) 0.928 Mbit/s (EGPRS2-A DL) 0.7424 Mbit/s (EGPRS2-A UL) Rel-7: Downlink dual carrier, 2x (EGPRS, EGPRS2-A) Rel-12: Downlink multi carrier, 2x – 16x (EGPRS, EGPRS2-A)	2.048 Mbit/s	346 Mbit/s DL; 34 Mbit/s UL for Rel 12	~4 Gbit/s DL; ~1.5 Gbit/s UL for Rel 12
Video	Max resolution in pixels @ x fps	Yes	Yes	Yes	Yes

TABLE A1.7 (continued)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Geographic coverage area	km ²	35 km radius with normal timing advance; 120 km radius with extended timing advance	120 km radius for extended range cells	120 km radius for extended range cells	100 km radius
Link budget	dB	146.36/133.39 dB (Veh A50) (EGPRS) With Rx diversity at BTS: 144 dB for GPRS/EGPRS /EGPRS2-A	Up to 147 dB	Up to 147 dB (additional coverage extension planned for Rel-13)	Up to 143 dB DL; Up to 133 dB UL (additional coverage extension planned for Rel-13)
Maximum relative movement rate	km/s	350 km/h	350 km/h	350 km/h	350 km/h
Maximum Doppler	Hz	1000 with channel tracking equalizer	648	648	648
Peak over the air uplink data rate	Mbit/s	0.271 Mbit/s (GPRS) 0.8125 Mbit/s (EGPRS) 1.0833 Mbit/s (EGPRS2-A)	1.024 Mbit/s	34 Mbit/s for Rel 12	~1.5 Gbit/s for Rel 12
Peak over the air downlink data rate	Mbit/s	0.271 Mbit/s (GPRS) 0.8125 Mbit/s (EGPRS) 1.3542 Mbit/s (EGPRS2-A) Rel-7: Downlink dual carrier, 2x (EGPRS, EGPRS2-A) Rel-12: Downlink multi carrier, 2x – 16x (EGPRS, EGPRS2-A)	2.048 Mbit/s	346 Mbit/s for Rel 12	~4 Gbit/s for Rel 12

TABLE A1.7 (continued)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Peak goodput uplink data rate	Mbit/s	Using 8 slots: 0.1856 Mbit/s (GPRS) 0.5568 Mbit/s (EGPRS) 0.7424 Mbit/s (EGPRS2-A)	0.960 Mbit/s	~29 Mbit/s (~15% overhead wrt PHY)	~1.275 Gbit/s (~15% overhead wrt PHY)
Peak goodput downlink data rate	Mbit/s	Using 8 slots: 0.1856 Mbit/s (GPRS) 0.5568 Mbit/s (EGPRS) 0.928 Mbit/s (EGPRS2-A) Rel-7: Downlink dual carrier, 2x (EGPRS, EGPRS2-A) Rel-12: Downlink multi carrier, 2x – 16x (EGPRS, EGPRS2-A)	1.920 Mbit/s	~294 Mbit/s (~15% overhead wrt PHY)	~3.4 Gbit/s (~15% overhead wrt PHY)
Public radio standard operating in unlicensed bands	GHz L/UL	Can be operated, but not currently specified.	Can be operated	Can be operated	Can be operated (Licensed-Assisted Access to unlicensed bands targeted for Rel-13)
Public radio standard operating in licensed bands	GHz L/UL	Multiple bands per 3GPP 45.005	Multiple bands as per 3GPP 25.101	Multiple bands as per 3GPP 25.101	Multiple bands as per 3GPP 36.101 and 36.104
Private radio standard operating in licensed bands	GHz L/UL	Can be operated, but not currently specified.	Can be operated, but not currently specified.	Can be operated, but not currently specified.	Yes, incl. push-to-talk and direct device-to-device technology
Duplex method	TDD/FDD	FDD	FDD and TDD	FDD and TDD	FDD and TDD, incl. half-duplex FDD

TABLE A1.7 (continued)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Carrier bandwidth	kHz	208 kHz @ 99%	5 MHz for FDD	5 MHz for FDD	1.4, 3, 5, 10, 15, 20 MHz Up to 100 MHz of aggregated bandwidth using Carrier Aggregation
Channel separation	kHz	200 kHz channel spacing	5 MHz for FDD	5 MHz for FDD	Nominal Channel spacing = $(BW_{Channel(1)} + BW_{Channel(2)})/2$, where $BW_{Channel(1)}$ and $BW_{Channel(2)}$ are the channel bandwidths of the two respective carriers
Number of non overlapping channels in band of operation		See 3GPP 45.005	See 3GPP 25.101	See 3GPP 25.101	See 3GPP 36.101 and 36.104
Spectral Efficiency	bits/s/Hz	270.8/200=1.354 (GPRS) 812.5/200 = 4.0625 (EGPRS) 1354.2/200=6.771 (EGPRS2-A)	0.2048 bit/s/Hz UL; 0.4096 bit/s/Hz DL	2.2 bit/s/Hz UL; 5.6 bit/s/Hz DL	15 bit/s/Hz UL; 40 bit/s/Hz DL
Average Cell Spectral Efficiency	bits/s/Hz/cell	1.1760 Mbit/s/MHz/cell (Veh A50) (EGPRS)	0.67 DL (with Diversity); 0.47 UL (Pedestrian A)	Depending on deployment scenario, example value ranges are 1.1-1.6 DL; 0.7-2.3 UL	Depending on deployment scenario, example value ranges for Rel-8 are 1.8 – 3.2 DL; 0.7-1.05 UL
Frame duration	Ms	120/26 ms	10 ms (2 ms TTI)	10 ms (2 ms TTI)	10 ms (1 ms TTI)

TABLE A1.7 (continued)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Maximum packet size	Bytes	1 560 bytes at RLC interface	No fixed size for FDD (depends on modulation level and number of channelization codes); TDD (3.84 Mbit/s) = 12750 bytes (see 3GPP 25.321)	42 192 bits per stream on DL; 22996 bits for UL	8 188 bytes for DL/UL
Segmentation support	Yes/No	Yes	Yes	Yes	Yes
Diversity technique	Antenna, polarization, space, time	Yes	Yes	Yes	Yes
Beam steering	Yes/No	No	No (<i>for Rel 5</i>)	Yes	Yes
Retransmission	ARQ/HARQ/-	Yes, e.g. ARQ, HARQ –incremental redundancy	Yes, e.g. ARQ/HARQ	Yes, e.g. ARQ/HARQ	Yes, e.g. ARQ/HARQ
Error correction technique		Punctured convolutional coding Turbo added in EGPRS2-A per Rel 7	Convolutional and Turbo	Convolutional and Turbo	Turbo; Tail Biting Convolution on BCH
Interference cancellation		Yes, e.g. Single antenna interference cancellation (SAIC) DL IRC DL and UL	No (<i>for Rel 5</i>)	Yes for both DL and UL	Yes
RF frequency of operation		Multiple bands per 3GPP 45.005	Specified in 3GPP 25.101	Specified in 3GPP 25.101	Specified in 3GPP 36.101
Retries		Configurable	Configurable	Configurable	Configurable

TABLE A1.7 (continued)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Receive signal strength indication (RSSI)		Yes; 64 levels between -110 dBm + scale and -48 dBm+scale	Yes; 77 levels between -100 dBm and -25 dBm	Yes; 77 levels between -100 dBm and -25 dBm	LTE reports Reference signal received power (RSRP) for LTE neighbor cells and RSSI (77 levels between -100 dBm and -25 dBm) for HSPA and EDGE neighbor cells. See 3GPP TS 36.133.
Lost packets		Residual block error ratio (BLER) = 1% after HARQ	Residual BLER = 1% after HARQ	Depends on operating point but typically 1% residual BLER after HARQ	Depends on operating point but typically 1% residual BLER after HARQ
Mechanisms to reduce power consumption		Yes, e.g. DTX, DRX and power control	Yes, e.g. DTX, DRX	Yes, e.g. DTX, DRX	Yes, e.g. DTX, DRX
Low power state support		Yes	Yes	Yes, e.g. Longer DTX/DRX cycles in all states	Yes
Point to point		Yes	Yes	Yes	Yes
Point to Multipoint		Yes	Yes	Yes	Yes
Broadcast		Yes	Yes	Yes	Yes
Handover		Yes	Yes	Yes	Yes
Media access method		Circuit-switched TDMA	Circuit-switched CDMA	Scheduled packet based CDMA	Scheduled packet based OFDMA
Discovery		Sync and Broadcast channel	Sync and Broadcast channel	Sync and Broadcast channel	Sync and Broadcast channel
Association		Temporary block flow (TBF)	Through various RNTIs	Through HRNTI and ERNTI assigned to UEs	Through CRNTI
Traffic priority	diffserv, resserv	3GPP-defined priorities	3GPP-defined priorities	3GPP-defined priorities	3GPP-defined priorities

TABLE A1.7 (continued)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Radio queue priority		Scheduler in base station	Yes at the Node B scheduler	Yes at the Node B scheduler	Yes at the eNode B scheduler
Location awareness (x,y,z coordinates)		aGPS and UTDOA methods as per 3GPP spec	aGPS and OTDOA methods as per 3GPP spec	aGPS and OTDOA methods as per 3GPP spec	A-GNSS, OTDOA, E-CID, UTDOA methods as per 3GPP spec
Ranging (distance reporting)					
Encryption	Algorithms supported	A5/3, A5/4, GEA3	KASUMI	KASUMI and SNOW 3G	SNOW 3G/AES
Authentication		Yes	Yes, mutual	Yes, mutual	Yes, mutual
Replay protection		Yes	Yes	Yes	Yes
Key exchange	Protocols supported	MILENAGE	MILENAGE	AKA	AKA
Interference sources		Other users, cells and networks	Other users, cells and networks	Other users, cells and networks	Other users, cells and networks
Co-channel interference		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation
Adjacent channel interference		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation
Alternate channel interference		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation
Collision avoidance		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation
Protection mechanisms		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation

TABLE A1.7 (continued)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Sensitivity to other interfering radio technologies		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation
Degree of interference caused to other radio technologies		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation
Sensitivity to power line RF emissions		Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation	Managed as per 3GPP specs and implementation
MAC address			Yes	Yes	Yes
SIM card		Yes	Yes	Yes	Yes
Other identity		IMEI	IMEI	IMEI	IMEI
Rogue detection		Yes	Yes	Yes	Yes
Base standard, Standards Development Organization (SDO)	SDO name	ATIS (3GPP Organizational Partner)	ATIS (3GPP Organizational Partner)	ATIS (3GPP Organizational Partner)	ATIS (3GPP Organizational Partner)
Profiling and application organizations	Association/ Forum name				
Temperature range		As per 3GPP 45.005	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 & 25.102	As per 3GPP 36.101 & 36.104
RF noise sources – other radios		As per 3GPP 45.005 & 45.050	As per 3GPP 25.942	As per 3GPP 25.942	As per 3GPP 36.101 & 36.104
RF noise sources – other electrical equipment		As per 3GPP 45.005 & 45.050	As per 3GPP 25.943	As per 3GPP 25.943	As per 3GPP 36.101 & 36.104
Rx sensitivity	dBm	As per 3GPP 45.005 –100 dBm (Veh A120) @ 10% BLER	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 & 25.102	As per 3GPP 36.101 & 36.104
Tx power peak	dBm	As per 3GPP 45.005	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 & 25.102	As per 3GPP 36.101 & 36.104

TABLE A1.7 (*end*)

Functionality characteristic	Measurement unit	GSM/EDGE	UMTS	HSPA+	LTE
Tx power steps	dB	As per 3GPP 45.005	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 & 25.102	As per 3GPP 36.101 & 36.104
Antenna gain	dBi	As per 3GPP 45.005	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 & 25.102	As per 3GPP 36.101 & 36.104
Noise floor	dBm	As per 3GPP 45.050	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 & 25.102	As per 3GPP 36.101 & 36.104
Modulation	GFSK, OFDM, BPSK, GMSK	GMSK, 8-PSK, 16QAM/32QAM added in EGPRS2-A per Rel 7	BPSK/QPSK	QPSK, 16QAM/64QAM	QPSK, 16QAM/64QAM/256QAM
Forward error coding		Punctured convolutional code	Convolutional and Turbo	Convolutional and Turbo	Turbo; Tail Biting Convolution on BCH

Recent releases of the 3GPP standards have introduced enhancements for machine type communications (MTC), e.g.

- Delay tolerant access establishment in Rel 10 (UMTS, HSPA+, LTE)
- Extended access barring in Rel 11 (GSM/EDGE, UMTS, HSPA+, LTE)
- UE power saving mode in Rel 12 (GSM/EDGE, UMTS, HSPA+, LTE)
- Low complexity UE category in Rel 12 (LTE)
- 3GPP has started work on further enhancements for machine type communications in Rel 13, targeting e.g. lower complexity devices, improved coverage, and increased battery life.

A1.4 3GPP2 Standards

3GPP2 has a variety of wireless standards that are applicable to power grid management systems. A summary of the technical and operating features of the relevant 3GPP2 wireless standards are given in the table below.

TABLE A1.8

Technical and operating features of 3GPP2 cdma2000 Multi-Carrier family of standards

Item	Value		
	cdma2000 1x	cdma2000 high rate packet data (HRPD/EV-DO)	Extended high rate packet data (xHRPD)
Supported frequency bands (licensed or unlicensed)	Licensed, multiple bands possible (see 3GPP2 C.S0057-E)	Licensed, multiple bands possible (see 3GPP2 C.S0057-E)	Licensed, multiple bands possible (see 3GPP2 C.S0057-E)
Nominal operating range	160 dB pathloss (For urban deployment, a typical max range is 5.7 km at 2 GHz following 3GPP2 C.R.1002-B Evaluation Methodology. For special deployments, range as large as 144 km can be achieved with optimized parameter settings.)	160 dB pathloss (For urban deployment, a typical max range is 5.7 km at 2 GHz following 3GPP2 C.R.1002-B Evaluation Methodology. For special deployments, range as large as 144 km can be achieved with optimized parameter settings.)	North America covered under the geosatellite deployment case; 11.4 km in terrestrial deployment; 2 GHz
Mobility capabilities (nomadic/mobile)	Nomadic and mobile	Nomadic and mobile	Nomadic and mobile
Peak data rate (uplink/downlink if different)	3.1 Mbit/s (1.23 MHz carrier) on downlink 1.8 Mbit/s (1.23 MHz carrier) on uplink;	4.9 Mbit/s per 1.23 MHz carrier, with up to 16 carriers possible on downlink; 1.84 Mbit/s per 1.23 MHz carrier, with up to 16 carriers possible on uplink;	3.072 Mbit/s per 1.23 MHz carrier on downlink; 0.0384 Mbit/s per 12.8 kHz channel, up to 96 12.8 kHz channels supported in 1.23 MHz on uplink
Duplex method (FDD, TDD, etc.)	FDD	FDD	FDD
Nominal RF bandwidth	1.25 MHz	1.25 to 20 MHz (1 to 16 carriers)	1.25 MHz
Diversity techniques	Antenna, polarization, space, time	Antenna, polarization, space, time	Antenna, polarization, space, time
Support for MIMO (yes/no)	No	Yes	No
Beam steering/forming	Yes	No	No
Retransmission	HARQ	HARQ	HARQ
Forward error correction	Convolutional and Turbo	Convolutional and Turbo	Convolutional and Turbo
Interference management	Yes, Multiple techniques such as receiver interference cancellation, power control, etc.	Yes, Multiple techniques such as receiver interference cancellation, power control, etc.	Yes, Multiple techniques such as receiver interference cancellation, power control, etc.
Power management	Yes, variety of low power states	Yes, variety of low power states	Yes, variety of low power states

TABLE A1.8 (end)

Item	Value		
	cdma2000 1x	cdma2000 high rate packet data (HRPD/EV-DO)	Extended high rate packet data (xHRPD)
Connection topology	Point-to-multipoint	Point-to-multipoint	Point-to-multipoint
Medium access methods	CDMA	CDMA (RL)/TDMA (FL)	FDMA (RL)/TDMA (FL)
Discovery and association method	Yes, mobile continuously searches for the strongest base station. Mobile registers with a group of base stations, and associates with the strongest base station when transmitting/receiving data. Mobile registers and potentially receives a MAC ID.	Yes, mobile continuously searches for the strongest base station. Mobile registers with a group of base stations, and associates with the strongest base station when transmitting/receiving data. Mobile registers and receives a MAC ID.	Yes, mobile continuously searches for the strongest base station. Mobile registers with a group of base stations, and associates with the strongest base station when transmitting/receiving data
QoS methods	Yes, 3GPP2-defined priorities	Yes, 3GPP2-defined priorities	Yes, 3GPP2-defined priorities
Location awareness	Yes, GNSS and AFLT	Yes, GNSS and AFLT	No
Ranging	Yes, based on round trip delay measurement	Yes, based on round trip delay measurement	Not specified
Encryption	Cellular Message Encryption Algorithm (CMEA); AES	AES	AES
Authentication/replay protection	Yes; CAVE & AKA	Yes; CHAP & AKA	Yes; CHAP & AKA
Key exchange	CAVE, SHA-1 & SHA-2 for AKA	SHA-1, SHA-2 & MILENAGE	SHA-1, SHA-2 & MILENAGE
Rogue node detection	Yes, base station can be authenticated	Yes, base station can be authenticated	Yes, base station can be authenticated
Unique device identification	Uses 60 bits MEID and SimCard (optional)	Uses 60 bits MEID and SimCard (optional)	Uses 60 bits MEID and SimCard (optional)

Annex 2

Smart grid in North America

A2.1 Introduction

In the United States of America and Canada, government agencies have recognized the real-time, high-capacity capabilities of a smart grid will enable utilities and end users to access the full economic and environmental benefits from renewable, especially distributed renewable, resources²⁸. Similarly, these capabilities are expected to unleash the potential benefits of dynamic rate structures and demand response applications that require the ability to interact with many thousands of devices in real time²⁹.

A2.2 Rationale for Smart grid deployment

U.S. and Canadian authorities already acknowledge a fully integrated communication network as an integral part of a smart grid. For instance, the U.S. Department of Energy-sponsored modern grid initiative identified that *“the implementation of integrated communications is a foundational need [of a smart grid], required by the other key technologies and essential to the modern power grid ...”*³⁰

The Department goes on to say that *“[h]igh-speed, fully integrated, two-way communications technologies will allow much-needed real-time information and power exchange”*³¹.

²⁸ In late 2008, the California Air Resources Board (CARB) stated that “a ‘smart’ and interactive grid and communication infrastructure would allow the two-way flow of energy and data needed for widespread deployment of distributed renewable generation resources, plug-in hybrids or electric vehicles, and end-use efficiency devices. Smart grids can accommodate increasing amounts of distributed generation resources located near points of consumption, which reduce overall electricity system losses and corresponding GHG emissions. Such a system would allow distributed generation to become mainstream, ... would support the use of plug-in electric vehicles as an energy storage device ... [and] would in turn allow grid operators more flexibility in responding to fluctuations on the generation side, which can help alleviate the current difficulties with integrating intermittent resources such as wind.” California Air Resources Board Scoping Plan, Appendix Vol. I at C-96, 97, CARB (Dec. 2008).

²⁹ See e.g. Enabling Tomorrow’s Electricity System – Report of the Ontario Smart Grid Forum, Ontario Smart Grid Forum (February, 2009) which cautions “initiatives on conservation, renewable generation and smart meters begin the move towards a new electricity system, but their full promise will not be realized without the advanced technologies that make the smart grid possible.”

³⁰ See A Systems View of the Modern Grid at B1-2 and B1-11, Integrated Communications, conducted by the National Energy Technology Laboratory for the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability (Feb. 2007). Such integrated communications will “[connect] components to open architecture for real-time information and control, allowing every part of the grid to both “talk” and “listen”. The smart grid: An Introduction at 29, U.S. Department of Energy (2008).

³¹ *Id.*

Similar emphasis on advanced communications functionality has been put forth by state authorities³² and other industry stakeholders. For example, the Ontario Smart Grid Forum recently stated that “communications technology is at the core of the smart grid. [Such technology] brings the data generated by meters, sensors, voltage controllers, mobile work units and a host of other devices on the grid to the computer systems and other equipment necessary to turn this data into actionable information”³³.

Annex 3

Smart grid in Europe

A3.1 Introduction

Extensive European expertise and resources have been devoted to understanding and promoting smart grids as a solution to the challenges that Europe faces in terms of climate change and energy efficiency, including all of the following initiatives:

- **January 2008, Fiona Hall MEP Report “Action plan for energy efficiency: realizing the potential”**³⁴ Report recognizes the importance of information and communication technologies to help generate additional productivity gains beyond the EU’s 20% target and considers that “*certain technologies such as smart grid technology ... should ... be the subject of effective policy recommendations*”.
- **June 2008, European Parliament (first reading) on the Directive on common rules for the internal market in electricity**³⁵ advocates that “*pricing formulas, combined with the introduction of smart metres and grids, shall promote energy efficiency behaviour and the lowest possible costs for household customers, in particular households suffering energy poverty.*”

³² “Modernizing the electric grid with additional two-way communications, sensors and control technologies, key components of a smart grid, can lead to substantial benefits for consumers.” California PUC Decision Establishing Commission Processes for Review of Projects and Investments by Investor-Owned Utilities Seeking Recovery Act Funding at 3 (10 Sept. 2009), available at: http://docs.cpuc.ca.gov/word_pdf/FINAL_DECISION/106992.pdf. See also, California Energy Commission on the Value of Distribution Automation, California Energy Commission Public Interest Energy Research Final Project Report at 51 (Apr. 2007), available at: <http://www.energy.ca.gov/2007publications/CEC-100-2007-008/CEC-100-2007-008-CTF.PDF>. “[C]ommunications is a foundation for virtually all the applications and consists of high speed two-way communications throughout the distribution system and to individual customers.”)

³³ See *Enabling Tomorrow’s Electricity System – Report of the Ontario Smart Grid Forum* at 34, Ontario Smart Grid Forum (Feb. 2009). The Report also states that “the communication systems that the utilities are developing for smart meters will not be adequate to support full smart grid development. The communications needs associated with the collection of meter data are different from those of grid operations. Additional bandwidth and redundant service will be needed for grid operations because of the quantity of operational data, the speed required to use it and its criticality. *Id.* at 35.

³⁴ <http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+REPORT+A6-2008-0003+0+DOC+PDF+V0//EN&language=EN>.

³⁵ <http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P6-TA-2008-0294>.

- The **Smart Grid European Technology Platform**³⁶ works to “formulate and promote a vision for the development of European electricity networks looking towards 2020”, and in particular looks at how advanced ICT can help electricity networks become flexible, accessible, reliable and economic in line with changing European needs.
- The **Address project**³⁷ (Active distribution networks with full integration of demand and distributed energy resources) is an EU-funded project which aims to deliver a comprehensive commercial and technical framework for the development of “active demand” in the smart grids of the future. ADDRESS combines 25 partners from 11 European countries spanning the entire electricity supply chain. PLT is a significant component of the projects underway pursuant to Address³⁸.

A3.2 European activities in some Member States³⁹

A3.2.1 The European Industrial Initiative on electricity grids

The European Industrial Initiative on electricity grids⁴⁰ is launched by the European Commission within the European Strategic Energy Technology (SET) Plan.

The SET-Plan was proposed by the European Commission’s General Directorates for Energy and for Research on 22 November 2007 with the aim to accelerate the availability of new energy technologies and to create a long term EU framework for energy technology development. The SET-Plan brings together the coordination of the European Commission, the research capacities of the major European institutes and universities, the engagement of European industry and the commitment of the Member States. One of two challenges addressed by the SET-Plan is mobilizing additional financial resources, for research and related infrastructures, industrial-scale demonstration and market replication projects. In the SET-Plan communication, the Commission informed about the increased budgets of the Seventh Framework Programme of the European Communities (2007-2013), as well as the Intelligent Energy Europe Programme.

³⁶ <http://www.smartgrids.eu/>.

³⁷

http://cordis.europa.eu/fetch?CALLER=ENERGY_NEWS&ACTION=D&DOC=1&CAT=NEWS&QUERY=011bae3744bf:2435:2d5957f8&RCN=29756.

³⁸ See “Iberdrola, EDP Announce Big Smart Grid Expansions at EUTC Event,” Smart Grid Today, 9 November 2009 (“Iberdrola is using PLC to connect its smart meters while EDP is using a mix of PLC and wireless”).

³⁹ Source for whole paragraph: European Regulators’ Group for Electricity and Gas Position Paper on Smart Grids – Ref: E09-EQS-30-04, Annex III
http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_CONSULT/CLOSED_PUBLIC_CONSULTATIONS/ELECTRICITY/Smart_Grids/CDhttp://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_CONSULT/CLOSED%20PUBLIC%20CONSULTATIONS/ELECTRICITY/Smart%20Grids/CD.

⁴⁰ References: European Commission, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions “A European strategic energy technology plan (SET-Plan) - Towards a low carbon future”, COM(2007) 723 final, 22 November 2007 European Commission, “Energy for the Future of Europe: The Strategic Energy Technology (SET) Plan”, MEMO/08/657, 28 October 2008.

The average annual budget dedicated to energy research (EC and Euratom) will be €886 million, compared to €574 million in the previous programmes⁴¹. The average annual budget dedicated to the Intelligent Energy Europe Programme will be €100 million, doubling previous values.

To engage the European industry, the European Commission proposed to launch in spring 2009 six European Industrial Initiatives (EII) in the areas of wind; solar; bio-energy; CO₂ capture, transport and storage; electricity grids and nuclear fission. EIIs are devoted to strengthen energy research and innovation, to accelerate deployment of technologies and to progress beyond business-as-usual approach. EIIs bring together appropriate resources and actors in industrial sectors, in which sharing of risks, public-private partnerships and financing at European level gives additional value.

The EII on electricity grids is expected to focus on the development of the smart electricity system, including storage, and on the creation of a European Centre to implement a research programme for the European transmission network⁴², with the final objective to enable a single, smart European electricity grid able to accommodate the massive integration of renewable and decentralized energy sources⁴³. As for other European Industrial Initiatives, EII on electricity grids shall have measurable objectives in terms of cost reduction or improved performance.

A3.2.2 National technology platform – smart grids Germany

“E-Energy: ICT-based Energy System of the Future⁴⁴ “is a new support and funding priority and part of the technology policy of the Federal Government. Just like the terms “E-Commerce” or “E-Government”, the abbreviation “E-Energy” stands for the comprehensive digital interconnection and computer-based control and monitoring of the entire energy supply system.

It was decided that the electricity sector would be the first area addressed by the project, as the challenges with regard to real-time interaction and computer intelligence are particularly high due to electricity's limited ability to be stored. The primary goal of E-Energy is to create E-Energy model regions that demonstrate how the tremendous potential for optimization presented by information and communication technologies (ICT) can best be tapped to achieve greater efficiency, supply security and environmental compatibility (cornerstones of energy and climate policy) in power supply, and how, in turn, new jobs and markets can be developed. What is particularly innovative about this project is that integrative ICT system concepts, which optimize the efficiency, supply security and environmental compatibility of the entire electricity supply system all along the chain – from generation and transport to distribution and consumption – are developed and tested in real-time in regional E-Energy model projects.

To force the pace on the innovative development needed and to broaden the impact of the results, the E-Energy programme focused on the following three aspects:

- 1) creation of an E-Energy marketplace that facilitates electronic legal transactions and business dealings between all market participants;

⁴¹ European Commission, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions “A European strategic energy technology plan (SET-Plan) - Towards a low carbon future”, COM(2007) 723 final, 22 November 2007.

⁴² The proposal to constitute a European Centre for Electricity Networks came from the 6FP RELIANCE project, in which eight European transmission system operators participated.

⁴³ European Commission, “Energy for the Future of Europe: The Strategic Energy. Technology (SET) Plan”, MEMO/08/657, 28 October 2008.

⁴⁴ <http://www.e-energy.de/en/>.

- 2) digital interconnection and computerization of the technical systems and components, and the process control and maintenance activities based on these systems and components, such that the largely independent monitoring, analysis, control and regulation of the overall technical system is ensured;
- 3) online linking of the electronic energy marketplace and overall technical system so that real-time digital interaction of business and technology operations is guaranteed.

An E-Energy technology competition was held and six model projects were declared the winners. They each pursue an integral system approach, covering all energy-relevant economic activities both at market and technical operating levels.

The programme will run for a 4-year term and mobilizes, together with the equity capital of the participating companies, some €140 million for the development of six E-Energy model regions:

- eTelligence, model region of Cuxhaven
Subject: Intelligence for energy, markets and power grids
- E-DeMa, Ruhr area model region
Subject: Decentralized integrated energy systems on the way towards the E-Energy marketplace of the future
- MeRegio
Subject: Minimum Emission Region
- Mannheim model city
Subject: Model city of Mannheim in the model region of Rhein-Neckar
- RegModHarz
Subject: Regenerative model region of Harz
- Smart Watts, model region Aachen
Subject: Greater efficiency and consumer benefit with the Internet of Energy

Besides the project coordinators, others like vendors of electrical equipment, system integrators, service providers, research institutes and universities are involved.

By 2012, the selected model regions are to develop their promising proposals up to the stage at which they are ready for market launching and to test their marketability in everyday application.

Annex 4

Smart grid in Brazil

A4.1 Introduction

The Ministry of Mines and Energy has promoted studies on technologies that could be used for the Smart Grid concept. These studies were motivated by the necessity to reduce the technical and non-technical losses and to improve the performance of the whole system in order to provide more reliability, resilience, security, etc. Recently, a study group supported by the Brazilian Ministry raised problems of the current power system and presented technologies and solutions that may reduce the losses and improve the performance of these power systems. These studies took into

account the economic aspects as well, mainly the cost that would be acceptable for the installation over 45 million meters in the country.

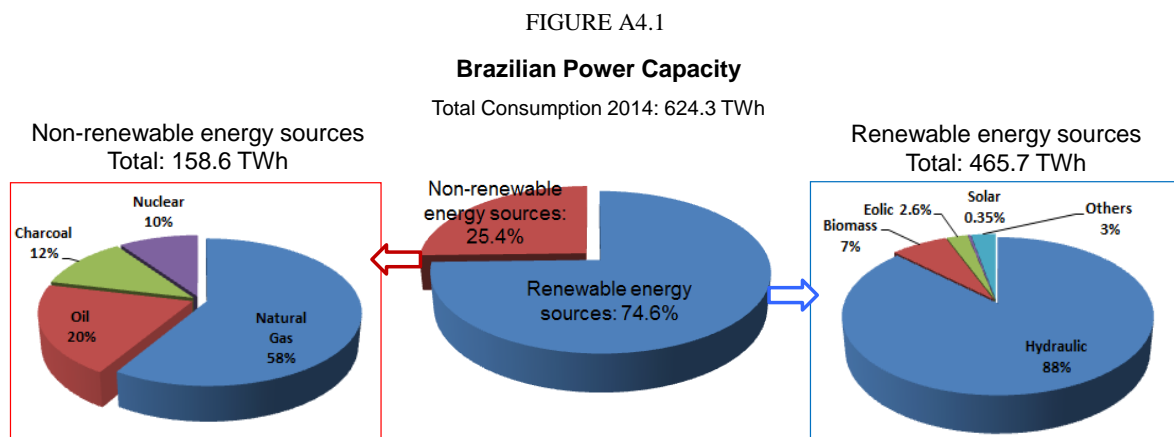
Additionally, other studies have been carried out by private institutions with public funding as the one led by ABRADDEE and APTEL, nonprofit associations related with the electric sector.

- APTEL – Association of Private Companies Proprietary of Infrastructure and Telecommunications Systems, created on 7 April 1999.
- ABRADDEE – Brazilian Association of Distributors of Electric Power, established in August 1975.

A4.2 Brazilian power sector

Currently Brazil has over 142 GW of power capacity and over 75 million of customer use. As shown in Fig. A4.1 [1], it can be seen that the energy consumption in Brazil (2014) is about 624.3 TWh.

The percentage of renewable energy produced is 74.6% while the non-renewable sources reach 25.4%.



The average consumption in Brazil is 68 GW with peaks over 80 GW. Recently, the electric sector informed that it is foreseen that the consumption will increase around 44%, what demands energy efficiency for the electric system.

As a first step of this process, the Ministry considers as priority the reduction of technical and non-technical losses of power systems. The technical losses in transmission system and distribution system are 5% and 7%, respectively. Additionally, the non-technical losses, such as non-authorized energy taps in distribution systems add up to 7%.

With these numbers, one can foresee huge challenges for Brazil in developing a power system that would increase efficiency and reduce losses.

A4.3 Brazilian smart grid study group

In order to understand the smart grid concept, in May 2010 the Ministry of Mines and Energy created a study group composed of members of the electric and telecommunications sectors. One of the aims of this group is to evaluate the applicability of this concept in the Brazilian Power Grid in order to increase the efficiency of the system.

In mid-March 2011, a report was presented to the Minister of Mines and Energy on the state of art of this technology. This report contains information on the concepts of the Smart Grid, as well as technical information on economic, billing and telecommunication issues.

In the part on telecommunications, the study took into account the technologies and resources available in Brazil and what kind of technologies used in other countries could be applied in Brazil. As an initial strategy, the Brazilian Government has special interest in Advanced Metering Infrastructure deployment.

As part of this study, in October 2010, a technical group visited the United States of America to gather information on smart grid issues. In general, it was detected that almost all telecommunication technologies deployed as support for Smart Grid functionalities could be applied for Brazil's purposes.

The ABRADDEE/APTEL study group presented its study report in December 2011 to ANEEL, the national power regulator – Agência Nacional de Energia Elétrica. The study has focused in projecting the roll out of the Smart Grid functionalities over the entire Brazilian electric sector in a ten year period and forecasting the investments and benefits associated with these projections. The study used the database of more than 50 distributions utilities that are associated of the project leaders and the projections are based on the real conditions of the Brazilian companies.

A4.4 Telecommunication issues

It was seen that several kinds of telecommunication technologies can be applied for the same purpose. For example, both Zig-Bee and Mesh Grid can be used for reading end-users' energy consumption meters. For Backhaul, WiMax, GPRS, 3G, 4G etc. may all be used. Each solution depends on technical aspects like available spectrum, propagation, throughput etc.

Currently there is uncertainty about the backhaul throughput needed by the Smart Grid applications. Certainly, this information is strategic for Smart grid projects in order to choose the proper solution and requirements for spectrum resources like bandwidth, limits of harmful interference to other services, power limits and propagation aspects. So far, there have not been any studies on system requirements for telecommunication system that could be applied for Smart grid.

We are concerned of electric field measurement techniques in the use of Power Line Carrier (PLC) in LF band in smart grid applications. Recently, some companies in Brazil have demonstrated interest on certification of PLC equipment with carriers around 80 kHz with 20 kHz of band for Smart Metering. The emissions around this frequency are limited by regulation and the electric field limit is presented for measures taken at 300 m from the source.

The ABRADDEE/APTEL study has realized the needs of investments around 19 billion of "Reais" in telecommunications assets and 3 billions of "Reais" in Information technologies assets to deploy the basic smart grid functionalities like smart metering, distribution grid automation, self-healing, distributed renewable generations sources and electric cars.

The reference model for the communication architecture used was the one proposed by IEEE P2030. The suggested architecture defines a logical hierarchy and a standard interface for interoperable interconnections that can be deployed by several communication network technologies like the ones that were used in the study: wireless (Wi-Fi 802.11, WIMAX 802.16), GPRS, 3G, MPLS, VPN and optical fiber and radio links for the field area network (FAN) and for the Backhaul.

A research about the existent telecom networks in the Brazilian utilities realized that optical fibers are used in 69% of the Backhaul systems, GPRS is the dominant technology for the last mile access and microwave links (400 MHz and 900 MHz) are used in 44% companies mainly to connect data equipment installed in the poles. Around 50% of the utilities use dedicated lines from the public telecom operators.

A4.5 Technical data

It is essential to raise data about backhaul throughput, latency, resilience, reliability etc., which would be considered suitable for Smart grid in order to plan the necessary resources of infrastructure and spectrum and to avoid obsolescence and waste of resources.

Using the Common Information Model – CIM adopted by the IEC and defined by IEC 61970, the ABRADDEE/APTEL study, highlighted the need to develop a specific strategy related with cyber security in the smart grids considering the following potential risks:

- High complexity of the electric network.
- New vulnerabilities form the interconnected networks.
- Leverage of the number of access points.
- Protection of the consumers' privacy.

A4.6 LF measurements

Additionally, for enforcement purposes, in order to avoid the cumbersome procedures for electric field measurements in urban areas, taking into account rigorous regulation, it is recognized that other procedures such as power measurement would be less cumbersome than spectrum analyzer connected to LF antenna.

A4.7 Conclusion

Due to the strategic nature of Smart Grid implementation in developing countries, we request contributions from other administrations on technical data and LF measurements as discussed above.

Regarding the size and complexity of the telecom network needed to support the deployment of the smart grid concept over the Brazilian electric grid, the ABRADDEE/APTEL study recommended, among others actions, a deep analysis of the spectrum using the objective to identify and reserve specific frequency bands dedicated for applications in the field and metropolitan areas.

References

- [1] Presentation: Distributed Generation by Rodrigo Campos de Souza – APTEL Seminar of Mini and Micro Power Generation – Rio de Janeiro – RJ – 8 December 2015.

Annex 5

Smart grid in the Republic of Korea

A5.1 Korea's Smart grid roadmap

To address climate change, Korea has recognized the need of rolling out a Smart grid as infrastructure for the low carbon, green industry in preparation for its binding reductions of greenhouse gas emissions. With this in mind, the Korean government is pursuing the Smart grid initiative as a national policy to achieve the vision of “Low carbon, Green growth.”

In 2009, Korea's Green Growth Committee presented "Building an Advanced Green Country" as its vision, and outlined the contents of the Smart grid roadmap⁴⁵. Views and comments of experts from the industry, academia, and research institutes had been collected since November 2009 and were reflected into the final roadmap announced in January 2010. According to the national roadmap, the Smart grid project has been implemented in the following five areas with the goal to build a nationwide Smart grid by 2030:

- 1) Smart power grid
- 2) Smart place
- 3) Smart transportation
- 4) Smart renewable
- 5) Smart electricity service.

Korea's Smart grid project will be implemented by three stages; the first stage aims at the construction and operation of the Smart grid Test-bed to test relevant technologies. The second stage is to expand the test-bed into metropolitan areas while adding intelligence on the part of consumers. The last stage is for the completion of a nationwide Smart grid enabling all of the intelligent grid networks.

FIGURE A5.1

Korea's Smart grid roadmap

Implementation Directions by Phase	First Stage (2010~2012)	Second Stage (2012~2020)	Third Stage (2021~2030)
	'Construction and operation of the Smart Grid Test-bed' (Technical validation)	'Expansion into metropolitan areas' (Intelligent consumers)	'Completion of a nationwide power grid' (Intelligent power grid)
Smart Power Grid	<ul style="list-style-type: none"> - Real-time power grid monitoring - Digital power transmission - Operate optimal distribution system 	<ul style="list-style-type: none"> - Predict possible failures in power grids - Connect the power system with that of other countries - Connect the power delivery system with distributed generation and power storage devices 	<ul style="list-style-type: none"> - Self-recovery of power grids - Operate an integrated energy Smart Grid
Smart Consumer	<ul style="list-style-type: none"> - Power management of intelligent homes - Various choices for consumers including rates 	<ul style="list-style-type: none"> - Smart power management of buildings/factories - Encourage consumers' power production 	<ul style="list-style-type: none"> - Zero energy homes/buildings
Smart Transportation	<ul style="list-style-type: none"> - Build & test electric vehicle charging facilities - Operate electric vehicles as a pilot project 	<ul style="list-style-type: none"> - Expand electric vehicle charging facilities across the nation - Effective maintenance and management of electric vehicles 	<ul style="list-style-type: none"> - Make the presence of charging facilities commonly available - Diversify charging methods - Utilize portable power storage devices
Smart Renewable	<ul style="list-style-type: none"> - Operate microgrids by connecting distributed generation, power storage devices and electric vehicles - Expanded utilization of power storage devices and distributed generation 	<ul style="list-style-type: none"> - Optimal operation of the power system with microgrids - Expand the application of power storage devices 	<ul style="list-style-type: none"> - Make renewable energy universally available
Smart Electricity Service	<ul style="list-style-type: none"> - Consumers' choice of electricity rates - Consumers' selling of renewable energy 	<ul style="list-style-type: none"> - Promote transactions of electrical power derivatives - Implement real-time pricing system nationwide - Emergence of voluntary market participants 	<ul style="list-style-type: none"> - Promote various types of electrical power transactions - Promote convergence for the market of electricity-based sectors - Lead the power market in Northeast Asia

Upon completion to the third stage, the outcome and benefit of Smart grid will be noteworthy; through Smart grid, Korea plans to reduce national electricity consumption by 6% while facilitating a wider use of new and renewable energy such as wind and solar power. In addition, Korea will

⁴⁵ <http://www.ksmartgrid.org/eng/>.

reduce 230 million tons of GHG emissions and annually create 50 000 jobs with the scale of 68 billion won domestic market by year 2030. The accumulated know-how's will work as a bridge for Korea to advance into the international market. Korea's green growth will greatly contribute to preventing global warming in future.

From the national standpoint, Smart grid project aims to raise energy efficiency and implement green-energy infrastructure by building eco-friendly infrastructure that reduces CO₂ emissions. From the industrial standpoint, this project seeks to secure a new growth engine that will drive Korea in the age of green growth. From an individual standpoint, it is headed for low carbon and green life by enhancing quality of life through experiences of and participation in a low carbon, green life.

A5.2 Technology development

A town with 3 000 households is to be established as the Smart grid Test-bed (10MW), where there will be a total of two sub-stations with at least 2 BANKs and, for each BANK, there will be two distribution lines. The Smart grid Test-bed will be the site for the results of research programs on 'power transmission using IT' and new renewable energy resources.

About 10 consortiums in five areas have participated in testing technologies and developing business models, implementing this project by two phases as shown in Table A5.1.

TABLE A5.1

Jeju Test-bed implementation plan by phase

Phase	Period	Key focus areas	Key contents
Basic stage (Infrastructure building)	2010 ~ 2011	Smart Power Grid Smart Place Smart Transportation	Linking grid networks and consumers, grid networks and electric vehicles
Expansion stage (Integrated operation)	2012 ~ 2013	Smart Renewable Smart Electricity Service	<ul style="list-style-type: none"> – Provide new power services – Accommodate renewable energy sources to the power grid

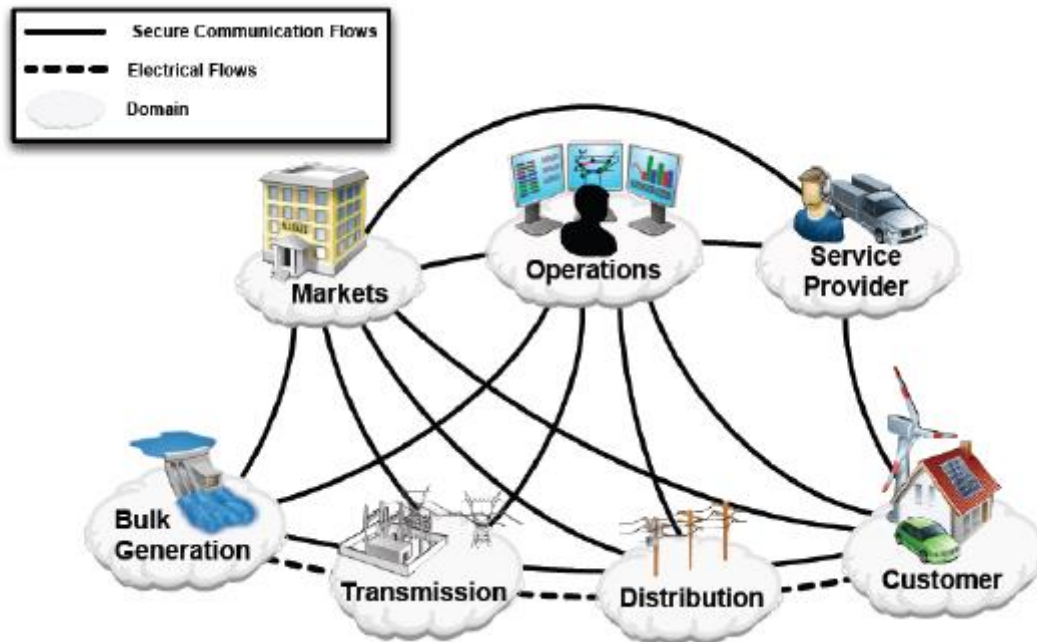
Annex 6

Smart grid in Indonesia

A6.1 Introduction

Smart grid implementation engaged technology equipment that changes service flow from power plant to customer which consist of 7 important domain: bulk generation, transmission, distribution, customers, operation, market, and service provider. Each domain itself consists of smart grid elements which connected each other through two-ways communication using analog or digital communication to gather and act as information and electricity lane. Connection is basic of smart grid to enhance efficiency, reliability, security, economy and sustainable of electricity production and distribution.

FIGURE A6.1
Interactions of Smart grid actors



Smart grid as system to system, which has three main layer: power and energy layer, communication layer, and IT layer. Those layers are key element in electrical and communications flows.

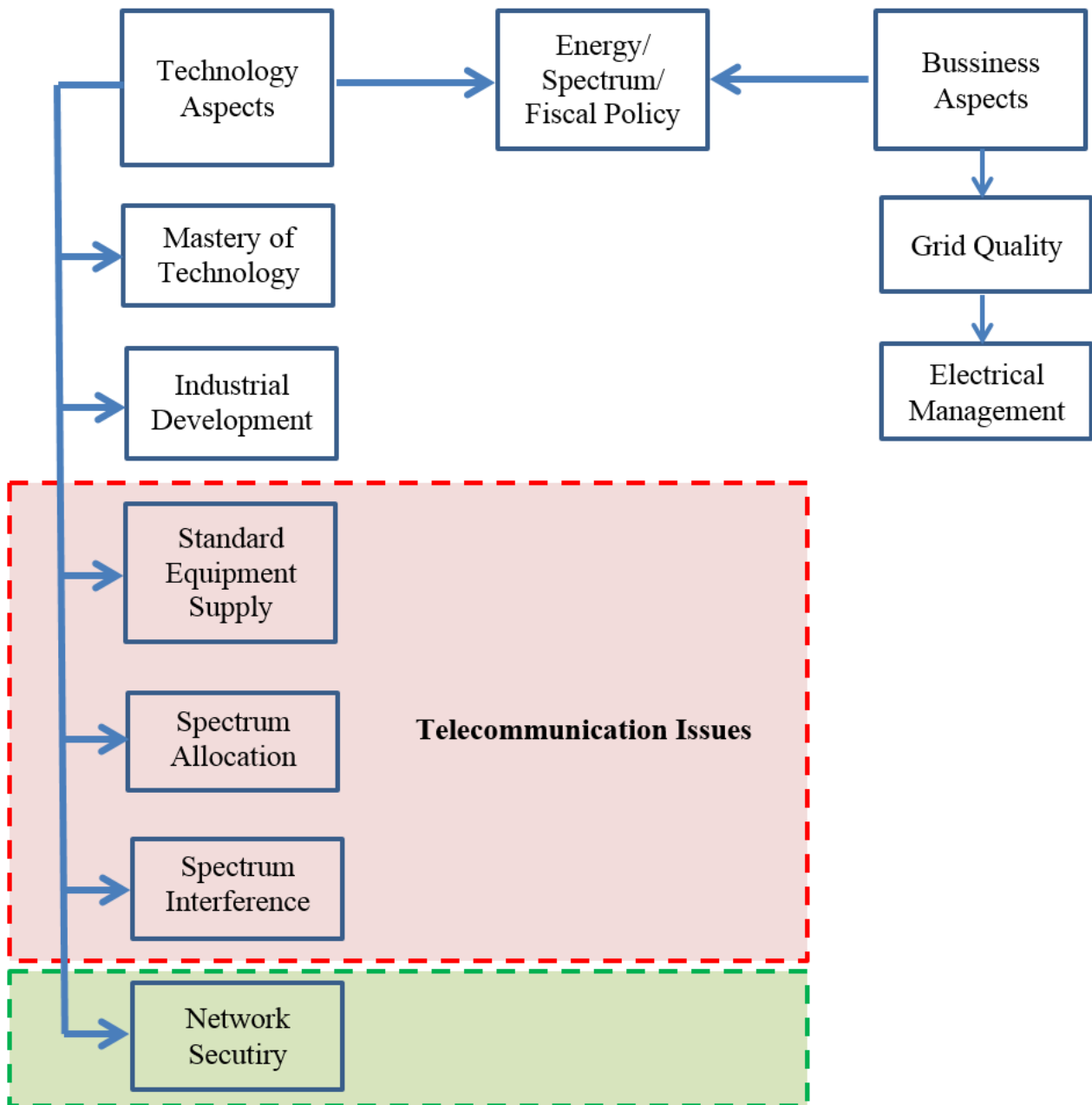
In power/energy consumption, the trend of consumption and energy price is increasing. This condition is in line with the mobile service subscribers.

A6.2 Smart grid development and challenging issues

The Indonesian government is aware that smart grid could be an alternative solution for efficiency for the electricity usage. Due to that, the government agency has built pilot project regarding smart grid implementation in Eastern part of Indonesia. This pilot project was conducted by Agency for Assessment and Application Technology in cooperation with PLN (National Electricity Company).

There are several challenging issues for smart grid development. Technology and business aspects which could be used as fundamental reference in developing policy and regulation.

FIGURE A6.2
Challenging issues



Referring to Fig. A6.2, those two main issues that influence the development of smart grid, we are concerned on several issues in telecommunication and IT aspect, i.e.:

- a) Standard equipment and supply:
To provide brief description on equipment technical specification in order to check the compatibility.
- b) Spectrum resources:
To have strategic plan on spectrum allocation, required bandwidth for this application. This issue is important in order to use scarce resources efficiently.
- c) Spectrum Interference:
To make sure that this technology implementation does not cause interference to other services.

d) Network Security:

To make sure the security of data flow.

Since this application could be laid in various mobile (broadband) services, it is proposed to the Study Group to discuss further on telecommunication requirements in order to assist developing countries to establish a strategic plan as a guidance in addressing proper policy and regulation related the implementation of smart grid.

Annex 7

Researches on wireless access technologies for Smart grid in China

A7.1 Introduction

Wireless technology is an important part of power management system, by which various management and control information be transmitted in real time bidirectional interaction. Early on, the communication capacity required by power distribution and utilization communication network is generally small. The traditional narrowband wireless communication devices which use fixed frequencies, are mainly used as the private wireless communication means in power management systems. With the development of smart grid, electric energy data acquisition, load demand management, on-site video monitoring services required by power distribution and utilization communication network put forward higher requirements on communication bandwidth, transmission delay and reliability. To this end, China carries out researches and construction of a new generation of power communication network in smart grid construction. Up to the present, the new wireless communication system has large-scale pilot applications for smart grid in China.

A7.2 A wireless access technology for Smart grid in China

A7.2.1 Introduction

The Smart and Wide-Coverage Industry-Oriented Wireless Network (SWIN) is designed to take full account of the service demands of smart grid. It is based on 4G technology and licensed frequency band 223-235 MHz for Smart grid. The system has many advantages comparing to narrowband wireless communication systems, such as wide coverage, massive subscriber accesses, high spectral efficiency, real-time, high safety and reliability, powerful network management capabilities and so on.

A7.2.2 Key technical features

The band 223-235 MHz was allocated in 25 kHz as a unit by China National Radio Administration Bureau. For the spectrum characteristics, SWIN can aggregate multiple discrete narrowband frequencies to provide broadband data transmission. Meanwhile spectrum sensing technology by which inter-RAT interference in adjacent band can be detected to improve coexistence capability is one of the key technologies of SWIN. It can ensure coexistence with existing narrowband systems at the same frequency band 223-235 MHz.

TABLE A7.1

Technical and operation features of SWIN

Item	Value
Supported frequency bands, licensed or unlicensed (MHz)	Licensed frequency bands: 223-235 MHz
Nominal operating range	3~30 km
Mobility capabilities (nomadic/mobile)	Mobile
Peak data rate (uplink/downlink if different)	1.5 UL/0.5 DL Mbit/s (1 M BW) 13 UL/5 DL Mbit/s (8.5 M BW)
Duplex method (FDD, TDD, etc.)	TDD
Nominal RF bandwidth	Selectable: 25 kHz – 12 MHz
Support for MIMO	No
Retransmission	HARQ
Forward error correction	Convolutional, Turbo
Interference management	Fractional frequency re-use, spectrum sensing
Power management	Yes
Connection topology	point-to-multipoint
Medium access methods	Random Access (Contention based and non-contention based)
Multiple access methods	SC-FDMA (uplink) and OFDMA (downlink)
Discovery and association method	Autonomous discovery, association through Bearer
QoS methods	QoS differentiation (5 classes supported, scalable)
Location awareness	Yes
Encryption	ZUC
Authentication/replay protection	Yes
Key exchange	Yes
Rogue node detection	Yes
Unique device identification	15 digit (IMEI)

A7.2.3 Industrialization and Application

At present, the SWIN system consists of baseband chips, terminals, base stations, core network, and network management equipment. SWIN has deployed in power distribution and utilization communication networks. Up to now, SWIN trial networks have been deployed in 13 provinces of China, serving smart grid services of electricity information acquisition, load control, distribution automation and so on. After a period of running test, it is proved that SWIN can satisfy service requires of smart metering and distribution automation.

A7.2.4 Standardization

At present, China smart grid operating company (State Grid Corporation of China) has already begun to develop standards of SWIN. The State Radio_monitoring_center Testing Center (The national radio spectrum management organization) and China Communications Standards Association (CCSA) are making SWIN RF standard, in order to ensure coexistence between

systems operating in the same band. Meanwhile, the national standardization of SWIN is going to be carried out.

A7.3 Conclusion

China's researches on wireless access technologies for Smart grid are introduced. SWIN can provide satisfied wireless communication for Smart grid, by which the cost of construction and operation of smart grid can be reduced.
