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Smart grid utility management systems

SM Series

Spectrum management

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REPORT ITU-R SM.2351-3

Smart grid utility management systems

(2015-2016-2017-2021)

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Scope

This Report provides an overview of Smart Grid systems and details of the wide array of technologies that are available for the monitoring and control of Smart Grid networks and Smart Meter networks. These technologies include wired, e.g. power line telecommunications (PLT), and wireless communications, e.g. 6.25 / 12.5 / 25 kHz narrow band technologies up to multiple-MHz broadband technologies.

As examples there are applications involved from customer meter reading through to the critical control of multiple high-power electricity generating stations attached directly to the high voltage distribution system at the Gigawatt level.

The Annexes also include details of narrow-band, wideband, and broadband standards available for Smart Grid and Smart Meter technologies.

The main text includes an overview of the spectrum available in various countries for Smart Grids and Smart Meter systems. The Annexes include more details of that use.

This Report focuses principally on the electricity industry where the changes are most rapid and extensive, but similar developments are taking place in gas and water infrastructure (including clean water, waste water and sewerage, and hot water).

Acronyms and Abbreviations

A list of acronyms and abbreviations used in this Report is provided in the final Attachment.

1 Introduction

The "Smart Grid" is a two-way electric power delivery network connected to an information and control network through sensors and control devices. This supports the intelligent and efficient operation/optimization of the power network including the generation, transmission, distribution, and end user networks.

The overall system has two basic components (outside the home versus inside the home). The first is the information gathering from all consumers in the many millions. The second is to use the consumer gathered information to provide an input to the control network that manages the generation, transmission and distribution of energy across the supply system. These two components have different operational requirements but need to work together in a cooperative manner with safety as a built-in necessity.

A smart meter is an electronic device that records consumption of electric energy in periodic intervals of an hour (or less) and reports this information to the electric utility for monitoring and billing. A smart meter enables two-way communication between the meter and the utility company. In addition to the function of automated meter reading it also can receive and handle control information regarding energy management from the utility, and report power quality monitoring information. The smart meter does not provide open access to its functionality to the users, regardless of its physical installation location (outdoor plant, in-building, in-home etc.).

The key objectives of the Smart grid are:

–   to ensure secure supplies of electricity, gas, and water;

–   to facilitate the move to a low-carbon economy;

–   to maintain stable and affordable prices.

Communication technologies are a fundamental tool with which many utilities are building out their smart grid infrastructure. 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. In many cases, effective smart metering allows for near real time monitoring of consumption and reporting, is integrated with the grid control centres in a way that, in line with other power usage balancing methods, 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 linked to various wired and wireless technologies developed for a wide range of networking purposes. Smart grid services outside the home include advanced metering infrastructure (AMI), automated meter management (AMM), automated meter reading (AMR), Supervisory Control and Data Acquisition (SCADA), teleprotection, synchrophasors, and distribution automation.

Inside the home, Smart grid applications will focus on providing metering, monitoring and control communications between the utility supplier, smart metres 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 envisages ubiquitous connectivity across all parts of utility network transmission and distribution grids from sources of supply grid, through network management centres and, where applicable, on to individual premises and appliances. Smart grid will require two-way data flows and complex connectivity. The data flow rates will vary from kbit/s for narrow band systems up to multiple Mbit/s wideband / broadband systems. More information on the communication flows envisaged over the electricity supply grid using the grid itself as the communication medium is available in the ITU-T 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".[1] Further work in ITU-T on using home networking technology (the G.hn project)

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[1] https://www.itu.int/pub/T-TUT-HOME-2010.

to support smart grid communications is set out in the ITU-T Technical paper on the use of G.hn technology for smart grid.[2]

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

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 allow utilities to remotely locate, isolate and restore power outages more quickly, thus increasing the stability of the grid. Information and communication technologies 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 equipment supporting smart grid communications are fit for purpose and do not conflict with each other or other telecommunication systems and ensure that those elements operating at radio frequencies do not interfere with other radiocommunication services.

The ITU and standards development organisations work cooperatively to achieve these objectives.

4   Smart grid objectives and benefits

4.1   Reducing overall electricity demand through system optimization

Traditional electric transmission and distribution systems were designed to deliver energy in one direction only but lacked the intelligence to optimize the delivery. During the on-going transition to smart grids, energy utilities must continue to include enough generating capacity to meet peak energy demand, even though such peaks occur only at isolated times 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

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[2]   GSTP-HNSG - Technical paper on the use of G.hn technology for smart grid (itu.int).

than average, the utility companies will restart occasionally used, less efficient but quick starting on demand and usually more expensive generators.

Smart grids are an essential requirement to improve the reliability and reduce the environmental impact of electric consumption.

4.2   Integrating renewable and distributed energy resources

Smart grid connectivity and communications overcome the problem of integrating consumer generated and multiple diverse sources of generation, e.g. windfarms, into the main central power distribution systems. 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 of the unpredictability of renewable energy sources it is often difficult, expensive, or even impossible to rely on their energy generation into the grid. Furthermore, even where renewable energy is fed back into the grid, the distribution grids around the world have difficulty 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 balance supply discrepancies arising from the unpredictability of renewable energy sources.

The 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 distributed electric 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 grid[3].

4.3   Supporting smart grids using smart metering

One application which supports power network balancing is smart metering. Smart metering functions include:

–   Advanced metering infrastructure (AMI),

–   Automated meter management (AMM), and

–   Automated meter reading (AMR).

Annex 9 contains an example list of frequency bands used for wireless Smart Metering and Smart Grid Systems in some parts of the world.

4.4   Providing a resilient Smart Grid network

A major consideration in designing Smart Grid networks is to ensure that the network can withstand and recover from disruption. The following definitions are commonly applied to achieve the required objectives at the design stage:

–   Best Practice is defined as those measures that can be taken to guarantee resilience, irrespective of cost.

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[3]   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).

– Good Practice is defined as those measures which can be taken to provide a degree of resilience commensurate with the Corporate risk strategy. It is important for an organisation to understand when Best Practice is necessary, and when Good Practice is more appropriate.

Electricity utilities often employ dedicated telecommunications systems to enable diverse, intelligent, applications within their networks. Including:

– Teleprotection to isolate part of the network when a fault or an abnormal system condition is detected, whilst at the same time avoiding interruptions to other users of the network. These systems minimise disruption to supplies and reduce the risk of damage to infrastructure through excessive current flows.

– Supervisory Control and Data Acquisition (SCADA) systems are used to initiate controls and monitor voltage, current, temperature levels and switch positions throughout the network, with the opportunity to reconfigure the network remotely in response to changing demand, faults in the network, and various operating conditions.

– Monitoring and control functions can be embedded in the network to remotely control equipment and reconfigure the network automatically without operator intervention, and reporting the actions of the Distribution Automation system to the control room.

– Dynamic Asset Management (DAM) applications continuously monitor the condition and loading of assets on a dynamic basis to increase capacity, avoiding the need to re-enforce networks. Real-time measurements can also help to predict failures, avoiding breakdowns and interruptions to customer supplies.

– Resilient mobile voice communications enable communications between the control room and field staff for routine operations, safety and emergency restoration of supplies, especially during severe weather and electricity supply outages when commercial networks may not be available. (More details of these systems can be found in Annex 8).

– Closed-Circuit TeleVision (CCTV) is used to monitor remote sites for security, safety and remote monitoring of assets.

Although recent developments in commercial telecoms networks facilitate the carriage of some critical communications capability, mission critical utilities retain a number of uniquely demanding requirements:

– Utility telecommunications growth comes from increasing the geographic coverage of the monitoring networks, numbers of connection points, and speed of response, rather than necessarily increased data rates.

– Geographic coverage availability requirements (e.g. up to 99.999% for power line protection and 99.9% for scanning telemetry systems) within the defined service area including, in some cases, remote and unpopulated areas. For example, power lines traverse remote regions where there is little population. Renewable energy and water resources are also often in remote locations. These remote and unpopulated areas may not attract commercial telecom operator services.

– Enhanced resilience to enable networks to operate in the absence of main electric power for an extended period, which may extend from a few minutes to 72 hours, and even beyond.

– Network hardened to ensure resilience against severe weather, including high winds, flooding, snow, icing, extreme temperatures, and electromagnetic disturbances such as lightning strikes.

– System reliability needs to be designed to meet exact technical requirements rather than for economic gain, e.g. for *best practice* resilience operation.

–   Separate, independent and diverse redundant routing. Note: when the primary route is interrupted, it is essential that the diverse route works immediately and correctly. This is especially true when instant access to radio spectrum is required.

–   Access to suitable allocated spectrum is preferred so that expansions and enhancements grid control network may be planned with confidence and incorporated speedily.

–   Utilities need high levels of security for their telecom networks, and infrastructure sites, not only in terms of integrity to prevent malicious disruption of utility operations; but also guaranteed access where denial of service occurs either from network congestion or malicious intent, denying the utility visibility of its network.

–   Consumer telecom product cycles are decreasing so that products can be obsolete within a year, whereas utility physical infrastructure has a typical life of 50 years. Telecoms equipment embedded in large plant operates continuously such that replacing obsolete telecoms equipment is a major exercise. The standard longevity of network communications equipment life and support may need to be 10 to 20 years.

–   Telecom signal latency and asymmetry requirements in the electricity industry are linked to voltage / power levels, requiring latencies as low as 6 ms with associated asymmetry of less than 300 us if protection systems are to function correctly. These requirements emerge from the need to compare 'in cycle' values across an electricity network in real time where the duration of a half-cycle is needed to maintain stability and accurately identify faults.

–   Whereas commercial networks are inherently download-centric, utility networks are upload-centric with a small number of control rooms remotely monitoring a large number of assets across wide geographic areas.

Remote sensing technology along the electric transmission and 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 analyse data from sensors distributed throughout the electricity network to indicate where performance is degraded. Transmission and distribution companies can maximize their maintenance programs to prevent failures, and quickly dispatch engineers to the scene of an incident, independent of consumer feedback. Teleprotection schemes, synchrophasors, SCADA systems and Automation units are designed to detect problems in transmission and distribution networks, ideally identifying the fault and dynamically reconfiguring the network without interrupting supplies to customers; or at least minimising the period of interruption. 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 likely to increase. Smart grids provide a real tool in this constant battle for control.[4]

5   Smart grid reference architecture overview (outside the home)

An example of a smart grid reference architecture is shown, in which the following elements are illustrated[5]:

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[4] Report provides examples of where smart grid technology has reduced network outages. http://www.jrc.co.uk/sites/default/files/JRC-EUTC%20Report%20on%20socio-economic%20value%20of%20spectrum-Jan2014-issue1.pdf.

[5] The definitions and the Figure are from NISTIR 7761 Rev. 1 (June 2014).

– 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 Distributed Automation (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).

– Neighbourhood area network (NAN) (described as a 'Distribution Devices Network' in the diagram below) – 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) – A highly resilient, highly available and secure network designed to backhaul data from DAP and FAN into the Network control centre, and convey control commands from the network control to field devices. The WAN may also directly interconnect to critical network elements such as teleprotection schemes and synchrophasors. The WAN may be copper or fibre based fixed links, microwave fixed links, and occasionally satellite.

– Data aggregation point (DAP) – This device is a logical actor that represents a transition in most AMI networks between wide area networks and neighbourhood area networks (e.g. collector, cell relay, base station, access point, etc.).

– Advanced metering infrastructure (AMI) – A network system specifically designed to support two-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

Report SM.2351-01
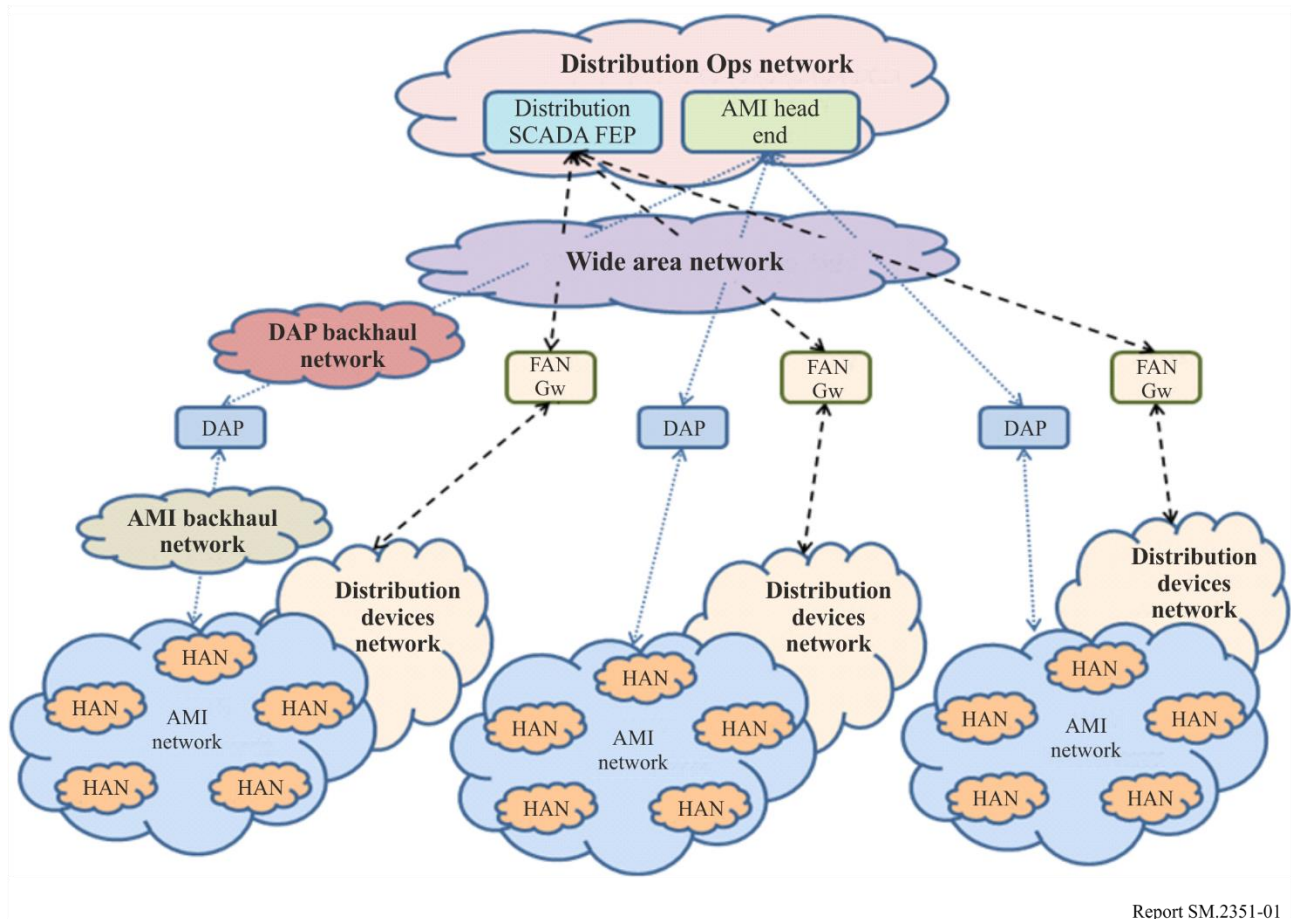
A given wireless standard may find application in more than one of these areas. In addition, in some applications, a certain number of the links may be achieved with wired solutions.

Various views have been expressed (for example during consultations by the United Kingdom Department of Energy and Climate Change[6]) as to whether the frequencies used for the wireless components of smart grid communications should be from frequency bands allocated and protected for such purposes, or in bands exempt from individual licensing. Note that billing and charging data is deemed as personal data in several countries and therefore subject to strict protection under privacy data protection legislations.

Many wireless technologies provide strong security and privacy to protect user data in smart metering networks and monitoring and control information 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.

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6   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 for smart grids 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. It should be noted that in the event of any system fault where the physical supply connection is open that this link becomes unavailable at what may be a critical time requiring a report to be sent.

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, although it is cost prohibitive to install dedicated fixed wires or fibre to every individual 'end of network' device unless these connections already exist for other purposes.

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.

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 grids 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 use 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 frequency bands that are freely available for a number of deregulated uses.

Some frequencies falling within bands around 900 MHz, subject to national and regional designations for licence exempt use, have now been advised as suitable for use under Recommendation ITU-T G.9959. One of the design criteria for transceivers working to G.9959 is that they should support one, two or three 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-Wave[7] 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.

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 individual licensing. In general, HAN applications do not require high reliability. WAN and FAN applications using wireless connections that require high reliability and availability are best suited for operation in spectrum subject to individual licensing, mandatory standards or other forms of regulation.

7.2   WAN/NAN/FAN/WASN

The WAN/NAN/FAN/WASN 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, e.g. lower frequency bands used for longer distances;

–   Availability of right of way (for cabled solutions);

–   Link capacity;

–   Non-mains powered devices;

–   Radio link availability, e.g. up to 99.999%;

–   Reliability, e.g. *Best Practice*, or *Good Practice*, resilience operation;

–   Power backup requirements, e.g. up to 96 hours;

–   Licensable versus license exempt spectrum.

–   Separate, independent, and diverse redundant routing requirements;

–   Longevity of equipment life and support, e.g. up to 20 years; and

–   Security of infrastructure and sites.

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[7] 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).

ITU-R has developed Recommendation ITU-R M.2002 – Objectives, characteristics and functional requirements of wide-area sensor and/or actuator network (WASN) systems, and Report ITU-R M.2224 – System design guidelines for wide area sensor and/or actuator network (WASN) systems.

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

See § A1.2 for further information on these IEEE standards.

Other wireless communication technologies that can contribute to smart grid requirements include cellular technologies, sound broadcasting, and satellite. 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, ultra-low complexity devices, increasing numbers of devices, and improved indoor coverage as elaborated up in § 9. Smart meters are available with individual monitoring and control functions provided using 3GPP technologies.

See § A1.4 for further information on 3GPP standards.

3GPP2 has a variety of wireless standards that are applicable to power grid management systems; see § A1.5.

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.

In addition, VHF and UHF narrow band technologies are used to monitor and control intelligent electricity, gas, and water grids These technologies are currently based mainly on 12.5 kHz and 25 kHz bandwidth systems in point-to-multipoint and mobile like configurations. National Standards such as MPT1411 and MPT 1327 are being replaced mainly by systems based on ETSI harmonized standards such as Tetra and DMR.

These narrow band systems operate in accordance with a number of ETSI Standards, e.g. EN 300 113, EN 302 561, point-to-point and point-to-multi-point spectrum planning arrangements.

Critical and emergency voice communications systems operate in 6.25 kHz channels (dPMR), 12.5 kHz channels (DMR) and 25 kHz channels (TETRA). In some cases, new network investments are integrating critical voice and operational data in the same communications network.

Fixed and Mobile satellite networks – geosynchronous, medium earth orbit and low earth orbit satellites play a complementary role in smart grid networks for both voice and data, especially in remote areas where they provide the most cost-effective solution and where their independence of ground infrastructure based services offers enhanced resilience and redundancy.

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

8.1   IEEE

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 frequency 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.

–   Cognitive radio sharing technologies developed within the IEEE 802 Standards can make some use of spectrum while doing all possible to not harm other primary users operating in these frequency 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.

8.2   3GPP

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 wherever 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.

8.3   3GPP2

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 widespread geographic area.

–   Each base station has a large coverage area by design.

–   A complete set of specifications including network, security, test and performance specifications.

8.4   12.5 /25 kHz PMR/PAMR

Low data rate systems may be planned for very efficient spectrum use in licensed spectrum providing 24-hour operation within a 12.5 / 25 kHz narrow band channel to monitor and control many remote sites within a 30 km radius.

Standard narrow band system planning and interference management techniques within the 400 MHz band enable each radio link to have typically 99.9% availability. Higher availabilities and enhanced protection from interference may be achieved through link diversity.

As an example of system planning and interference management techniques, the core control system of the UK's electricity and gas grids operate within only 48 of 12.5 kHz narrow band 400 MHz band channels. (Note: higher data rates are typically accommodated by using 1.4 GHz and microwave fixed radio links.)

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 when like technologies are deployed within co-located and adjacent areas, and within co-channel spectrum.

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.

–   Existing regulations by regulators such as the Federal Communications Commission have successfully allowed for millions of wireless Smart grid devices (in home) and Ofcom UK has successfully allowed for millions of wireless Smart Meter devices (in home), to operate without harm to each other.

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 than the capacity of modern mobile wireless networks.

–   The licensed mobile wireless spectrum, which is typically managed by wireless carriers, can therefore where service is available potentially easily handle the incremental traffic, subject to the critical nature of the traffic.

–   Conversely, countries whose grid systems are monitored and controlled using only a few MHz of narrow band spectrum may need a small amount of additional spectrum to meet this need to transfer extra data.

Predictions conducted by the European Utilities Telecoms Council (EUTC)[8] suggest that 2×3 MHz of exclusive licensed 400 MHz spectrum (e.g. 120×25 kHz duplex channels or 2×1.4 MHz duplex LTE channels) should be sufficient.

NOTE – The continued access to the 400 MHz Band means that the existing radio system infrastructure, including resilience measures such as 72-hour power backup at base stations, can be re-used.

The continued use of an existing band also applies to the current wideband and broadband electricity grid systems operating within mainland Europe. Many are seeking increased access to spectrum within the 450 to 470 MHz band, e.g. Band 72 (451 to 456 MHz paired with 461 to 466 MHz). A diagram of the spectrum access arrangements within this band for many European countries is shown within § A3.3.

It should be noted that, because of the relatively small volume of critical data traffic required by utilities for the management and control of their networks, the overall spectrum requirement predicted by most utilities on a global basis is 20 MHz or less, representing around 1% of the spectrum likely to be allocated to mobile services by 2020. In addition, utilities can make significant use of existing spectrum available for professional land mobile services below 500 MHz.

Further considerations are:

–   IEEE 802 wireless standards use a variety of technologies, e.g. frequency hopping, mesh routing, fragmentation, coding, and high burst rate, together with interference cancellation and mitigation, plus MIMO which enable reliable wireless Smart Grid Networks.

–   In addition, wireless Smart Grid networks can be made to meet enhanced resilience requirements such as short-term link breaks, by using link diversity, and power outages by using power backup systems.

–   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.

–   Features embedded within IEEE 802 standards such as spectrum sensing, spectrum etiquette, channel set management and co-existence help to ensure minimal interference to themselves and others when like technologies are deployed within co-located and adjacent areas, and within co-channel spectrum.

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[8] http://eutc.org/wp-content/uploads/2016/04/EUTC-Spectrum-Position-Paper.pdf

–   Cellular wireless 3GPP technologies are continuously evolving and new features relevant to smart meters have been introduced in 3GPP Releases, see § A1.4.

–   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 in populated areas.

10   Summary

This Report is based mainly on the example of the electrical supply utility but has direct similar equivalents for the gas and water utilities.

The "Smart Grid" is a two-way electric power delivery network connected to an information and control network through sensors and control devices. This supports the intelligent and efficient optimization of the power network including the generation, transmission, distribution, and end user networks.

A smart meter is an electronic device that records consumption of electric energy in periodic intervals of an hour (or less) and reports this information to the electric utility for monitoring and billing. A smart meter enables two-way communication between the meter and the utility company. In addition to the function of automated meter reading it also can receive and handle control information regarding energy management from the utility, and report power quality monitoring information. The smart meter does not provide open access to its functionality to the users, regardless of its physical installation location (outdoor plant, in-building, in-home, etc.).

Smart Grid networks will enable the electricity energy industries to facilitate two-way flows into legacy networks which were not designed for this mode of operation. In particular, smart grids will enable electricity distribution networks to facilitate connection of embedded generation into their networks where much of the renewable sources of generation supply are located and enable new modes of operation such as demand management. New and emerging concepts including microgrids, islanded networks, storage, and electric vehicles, together with high voltage direct current (HVDC) transmission will then be able to be integrated into future networks.

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. A clear distinction needs to be made between two very separate activities:

–   the mission critical utilities transmission/distribution monitoring and control systems which need very rapid dynamic interactivity and extremely high reliability and security capable of operating for many days without power in harsh environments but with far fewer points of interactivity and again with relatively small data volumes; and

–   consumer information gathering and interactivity i.e. the "smart grid" of information flow at the consumer level consisting of relatively small amounts of individual Smart Meter data but aggregated up from millions of households.

Annex 1

Examples of existing standards related to power grid management systems

A1.1   ETSI Standards

ETSI has a variety of wireless standards that are applicable to power grid management systems. A summary of the technical features of the relevant ETSI wireless standards are given in Table A1.1 below.

For information, ETSI TR 103 401 V1.1.1 details "Smart Grid and Other Radio Systems suitable for Utility Operations, and their long-term spectrum requirements".

TABLE A1.1

Technical features of ETSI Standards

Standard	Channel (kHz)	Data rate (kbit/s)	Adjacent channel receiver selectivity (dBm)	Co-channel rejection (dB)	Receiver sensitivity for performance testing (dBm)
EN 301 166	6.25	Up to 4.8	−50	Greater than −15	−107
EN 301 166	The receiver blocking level shall not be less than 90.0 dBμV (−68 dBm).				
EN 300 113	12.5	9.6 to 16	−47	Between 17 and 0	−105
EN 300 113	12.5	>16 to 38.4	−47	Between 24 and 0	−98
EN 300 113	12.5	Greater than 38.4	−47	Between 29 and 0	−93
EN 300 113	25	9.6 to 38.4	−37	Between 12 and 0	−105
EN 300 113	25	>38.4 to 76.8	−37	Between 19 to 0	−98
EN 300 113	25	Greater than 76.8	−37	Between 24 to 0	−93
EN 300 113	For all channel widths, the receiver blocking level shall not be less than −23 dBm.				
EN 302 561	25	38.5 to 76.8	−63	−19	−104
EN 302 561	25	Greater than 76.8	−63	−24	−99
EN 302 561	50	76.9 to 153.6	−66	−19	−101
EN 302 561	50	Greater than 153.6	−66	−24	−95
EN 302 561	100	153.7 to 307.2	−67	−19	−98
EN 302 561	100	Greater than 307.2	−67	−24	−93
EN 302 561	150	230.5 to 460.8	−67	−19	−97
EN 302 561	150	Greater than 460.8	−67	−24	−91
EN 302 561	For all channel widths, the receiver blocking level shall not be less than −27 dBm.				

A1.2   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. See Recommendation ITU-R M.1450 Table 2-1, for technical parameters associated with IEEE Std 802.11.

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
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
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 kbit/s 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
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 behaviours 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
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

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.

A1.3   **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. Table A1.6 lists ITU-T Recommendations related to smart grid communications.

TABLE A1.6

ITU-T Recommendations related to Smart Grid Communications

Recommendation No./Technical Paper	Title
G.9901	Narrow-band OFDM power line communication transceivers – Power spectral density specification
G.9902	Narrow-band OFDM power line communication transceivers for ITU-T G.hnem networks
G.9903	Narrow-band OFDM power line communication transceivers for G3-PLC networks
G.9904	Narrow-band OFDM power line communication transceivers for PRIME networks
G.9905	Centralized metric based source routing
G.9958	Generic architecture of home networks for energy management
G.9959	Short range narrowband digital radiocommunication transceivers – PHY & MAC layer specifications
ITU-T 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.
ITU-T Technical Paper GSTP-HNSG	GSTP-HNSG - Technical paper on the use of G.hn technology for smart grid

A summary of the technical and operating features is given in the Tables below for the two field-proven NB-PLC technologies specified in ITU-T.

TABLE A1.7

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 kbit/s	128 kbit/s
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

TABLE A1.7 (*end*)

Item	G.9903 value	G.9904 value
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

A1.4   3GPP Standards

3GPP has a variety of wireless standards that are applicable to first mile applications for power grid management systems. Recent releases of the 3GPP standards have introduced enhancements for Machine Type Communications (MTC), e.g.

Release 10:

–   Introduction of the Delay tolerant access establishment cause and indication of Low access priority to support system control over MTC devices with relaxed latency requirements. This may be particularly useful in case of overload scenarios. (GSM/EDGE, UMTS, HSPA+, LTE)

–   Extended access barring and Implicit reject to support barring of delay tolerant devices configured for low access priority. (GSM/EDGE)

Release 11:

–   Extended access barring (UMTS, HSPA+, LTE)

Release 12:

–   UE power saving mode to support long battery life ranging up to several years in case of devices characterized by infrequent small data transmission. (GSM/EDGE, UMTS, HSPA+, LTE)

–   Low complexity UE category to enable reduced device cost to support flexible use across a range of MTC applications (LTE)

Release 13 and 14:

–   Extended DRX to support long battery life while maintaining mobile terminated reachability under network control (GSM/EDGE, UMTS, HSPA+, LTE)

–   Extended Coverage GSM Internet of Things (EC-GSM-IoT) (GSM/EDGE), LTE Physical Layer Enhancements for MTC (eMTC) (LTE), Narrow band Internet of Things (NB-IoT) to support low device complexity, 164 dB coupling loss, 10 years battery life, 10 seconds latency and a system capacity of at least 60 000 devices per square kilometre.

Release 15:

–   eMTC and NB-IoT enhancements for improving system capacity, user latency, data rate and power efficiency. NB-IoT TDD operation was also specified.

A summary of the technical and operating features, including above listed enhancements for MTC, of the relevant 3GPP wireless standards up to and including Release 15 are given in the Table below.

TABLE A1.8

Technical and operating features of 3GPP Technologies

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
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%)	Depends on deployment (typical > 99%)	Depends on deployment (typical > 99%)	Depends on deployment (typical > 99%)
Ability to maintain an appropriate connection	failure rate per 1000 sessions	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)	Depends on deployment (typical < 1%)
Voice		Yes	Voice messaging supported	Yes	Yes	Yes	Yes (Possibly with reduced coverage.)	Voice messaging supported

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Data	Max sustainable user data rate per user in Gbit/s / Mbit/s / kbit/s	GPRS: 172 kbit/s UL/DL EGPRS: 491 kbit/s UL/DL EGPRS2-A: 811 kbit/s DL 638 kbit/s UL	98 kbit/s UL/DL (Taking protocol limitations into account.)	1.92 Mbit/s DL 0.96 Mbit/s UL (Assuming only data connection.)	294 Mbit/s DL 58.65 Mbit/s UL (Assuming a 15% reduction in throughput compared to Peak over the air data rates)	DL: Ranging between 0.85 Mbit/s and 21.2 Gbit/s depending on UE category. UL: Ranging between 0.85 Mbit/s and 11.6 Gbit/s depending on UE category. (Assuming a 15% reduction in throughput compared to Peak over the air data rates)	Cat. M1: FD-FDD: 800 kbit/s – 1 Mbps DL 1 Mbit/s – 2.98 Mbit/s UL HD-FDD: 300 kbit/s – 588 kbit/s DL 375 kbit/s – 1119 kbit/s UL (Taking protocol limitations into account.) Cat. M2: FD-FDD: 4 Mbit/s DL 7 Mbit/s UL HD-FDD: 1.2 Mbit/s – 2.35 Mbit/s DL 2.6 Mbit/s UL (Taking protocol limitations into account.)	Cat. NB1: 21.3 kbit/s DL 62.5 kbit/s UL (Taking protocol limitations into account.) Cat NB2 with 2 HARQ processes: 126.8 kbit/s DL 158.5 kbit/s UL (Taking protocol limitations into account.)
Video		Yes	No	Yes	Yes	Yes	Yes (Possibly with reduced coverage.)	No

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Geographic coverage area	km²	35 km radius with normal timing advance; 120 km radius with extended timing advance	35 km radius with normal timing advance	120 km radius for extended range cells	120 km radius for extended range cells	100 km radius	100 km radius	4120 km radius
Link budget	dB	EGPRS (Veh A50): 146.36/133.39 dB GPRS/EGPRS/EGPRS2-A: 144 dB	164 dB (Assumes 33 dBm MS power class. In addition, see 3GPP TR 45.820 for further assumptions)	Up to 147 dB	Up to 147 dB	Up to 143 dB DL; Up to 133 dB UL	155.7 dB (Assumes 20 dBm UE power class. In addition, see 3GPP TR 36.888 for further assumptions)	164 dB (Assumes 23 dBm UE power class. See 3GPP TR 45.820 for further assumptions)
Maximum relative movement rate	km/s	350 km/h	~100 km/h (No support for handover)	350 km/h	350 km/h	350 km/h	~100 km/h	~100 km/h (No support for handover)
Maximum Doppler	Hz	1 000 with channel tracking equalizer		648	648	648	70	

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Peak over the air uplink data rate	Instantaneous peak data rate in Gbit/s / Mbit/s / kbit/s	GPRS: 172 kbit/s EGPRS: 491 kbit/s EGPRS2-A: 638 kbit/s (Based on the number of information bits per radio block, see 3GPP TS 45.003.)	491 kbit/s (Based on the number of information bits per radio block, see 3GPP TS 45.003.)	1.024 Mbit/s UL (Assuming simultaneous speech (64 kbit/s) and data (0.96 Mbit/s) connections.)	69 Mbit/s UL (Assuming dual carriers, 64QAM and 2 MIMO layers.)	Ranging between 1 Mbit/s and 13.6 Gbit/s depending on UE category. (See 3GPP TS 36.306 for UE categories up to Cat .)	Cat M1: FD-FDD: 1 – 2.98 Mbit/s HD-FDD: 1 – 2.98 Mbit/s Cat. M2: FD-FDD: 6.97 Mbit/s HD-FDD: 6.97 Mbit/s (See 3GPP TS 36.306 for UE categories)	Cat. NB1: 250 kbit/s Cat NB2: 258 kbit/s (See 3GPP TS 36.306 for UE categories)

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Peak over the air downlink data rate	Instantaneous peak data rate in Gbit/s / Mbit/s / kbit/s	GPRS: 172 kbit/s EGPRS: 491 kbit/s EGPRS2-A: 811 kbit/s (Based on the number of information bits per radio block, see 3GPP TS 45.003.)	491 kbit/s (Based on the number of information bits per radio block, see 3GPP TS 45.003.)	2.048 Mbit/s DL (Assuming simultaneous speech (128 kbit/s) and data (1.92 Mbit/s) connections.)	346 Mbit/s DL (Assuming 15 HS-PDSCH codes, four carriers, 64QAM and 4 MIMO layers.)	Ranging between 1 Mbit/s and 25 Gbit/s depending on UE category (See 3GPP TS 36.306 for UE categories.)	Cat. M1: FD-FDD: 1 Mbit/s HD-FDD: 1 Mbit/s Cat. M2: FD-FDD: 4.01 Mbit/s HD-FDD: 4.01 Mbit/s (See 3GPP TS 36.306 for UE categories)	Cat. NB1: LTE in-band operation: 170 kbit/s Standalone operation: 226.7 kbit/s Cat. NB2: LTE in-band operation: 174.4 kbit/s Standalone operation: 258 kbit/s (See 3GPP TS 36.306 for UE categories)

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Peak goodput uplink data rate	Max sustainable user data rate in Gbit/s / Mbit/s / kbit/s	See Data row	See Data row	See Data row	See Data row	See Data row	See Data row	See Data row
Peak goodput downlink data rate	Max sustainable user data rate in Gbit/s / Mbit/s / kbit/s	See Data row	See Data row	See Data row	See Data row	See Data row	See Data row	See Data row
Public radio standard operating in unlicensed 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.	Can be operated, but not currently specified.	Yes (License Assisted Access)	Can be operated, but not currently specified.	Can be operated, but not currently specified.
Public radio standard operating in licensed bands	GHz L/UL	Multiple bands per 3GPP 45.005	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	Multiple bands as per 3GPP 36.101 and 36.104	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.	Can be operated, but not currently specified.	Yes, incl. push-to-talk and direct device-to-device technology	Can be operated, but not currently specified.	Can be operated, but not currently specified.
Duplex method	TDD/FDD	Half-duplex FDD	Half-duplex FDD	FDD and TDD	FDD and TDD	FDD and TDD, incl. full- and half-duplex FDD	FDD and TDD, incl. full- and half-duplex FDD	Half-duplex FDD, TDD

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Carrier bandwidth	kHz	200 kHz	200 kHz	5 MHz for FDD	5 MHz for FDD	1.4, 3, 5, 10, 15, 20 MHz Up to 640 MHz of aggregated bandwidth using Carrier Aggregation	1.4 MHz, 5 MHz	180 kHz
Channel separation	kHz	200 kHz	200 kHz	5 MHz for FDD	5 MHz for FDD	Nominal channel spacing = (BWChannel(1) + BWChannel(2))/2, where BWChannel(1) and BWChannel(2) are the channel bandwidths of the two respective carriers	Nominal channel spacing = (BWChannel(1) + BWChannel(2))/2, where BWChannel(1) and BWChannel(2) are the channel bandwidths	LTE in-band operation: 180 kHz Standalone operation: 200 kHz
Number of non-overlapping channels in band of operation		See 3GPP 45.005	See 3GPP 45.005	See 3GPP 25.101	See 3GPP 25.101	See 3GPP 36.101 and 36.104		See 3GPP 36.101 and 36.104

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TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Peak Spectral Efficiency	bits/sec/Hz	GPRS: 0.86 bit/s/Hz EGPRS: 2.46 bit/s/Hz EGPRS2-A: 4.05 bit/s/Hz DL 3.19 bit/s/Hz UL	2.46 bit/s/Hz	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	Cat. M1: LTE in-band operation: 1.56-2.77 bit/s/Hz UL 1.56 bit/s/Hz DL Standalone operation: 1.56-2.77 bit/s/Hz UL 1.56 bit/s/Hz DL	Cat. NB1: LTE in-band operation: 1.39 bit/s/Hz UL 0.94 bit/s/Hz DL Standalone operation: 1.25 bit/s/Hz UL 1.13 bit/s/Hz DL Cat. NB2: LTE in-band operation: 1.43 bit/s/Hz UL 0.97 bit/s/Hz DL Standalone operation: 1.29 bit/s/Hz UL 1.29 bit/s/Hz DL
Average Cell Spectral Efficiency	bits/sec/Hz/cell	1.1760 Mbit/s/MHz/cell (Veh A50) (EGPRS)	Depending on deployment scenario	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	Depending on deployment scenario	Depending on deployment scenario

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Frame duration	Ms	120/26 ms TDMA frame GPRS: 20 ms TTI EGPRS/EGPRS2-A: 10, 20 ms TTI	20-80 ms TTI	10 ms (2 ms TTI)	10 ms (2 ms TTI)	10 ms (1 ms TTI)	10 ms (1 ms TTI)	10 ms (1 ms minimum TTI)
Maximum packet size	Bytes	1560 octets at RLC interface	1560 octets 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)	42192 bits per stream on DL; 22996 bits for UL	8188 bytes for DL/UL	8188 bytes for DL/UL	1600 bytes for DL/UL
Segmentation support	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Diversity technique	antenna, polarization, space, time	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Beam steering	Yes/No	No	No	No	Yes	Yes	Yes	No
Retransmission	ARQ/HARQ/-	Yes, e.g. ARQ, HARQ - Incremental Redundancy	Yes, e.g. ARQ, HARQ -Incremental Redundancy	Yes, e.g. ARQ/HARQ	Yes, e.g. ARQ/HARQ	Yes, e.g. ARQ/HARQ	Yes, e.g. ARQ/HARQ	Yes, e.g. ARQ/HARQ

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Error correction technique		Punctured convolutional coding Turbo added in EGPRS2-A	Punctured convolutional coding	Convolutional and Turbo	Convolutional and Turbo	Turbo; Tail Biting Convolution on BCH	Turbo; Tail Biting Convolution on BCH	Tail Biting Convolutional in DL; Turbo in UL
Interference cancellation		Yes	Yes	No	Yes	Yes	Yes	Yes
RF frequency of operation		Multiple bands per 3GPP 45.005	Multiple bands per 3GPP 45.005	Specified in 3GPP 25.101	Specified in 3GPP 25.101	Specified in 3GPP 36.101	Specified in 3GPP 36.101	Specified in 3GPP 36.101
Retries		Configurable	Configurable	Configurable	Configurable	Configurable	Configurable	Configurable

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Receive signal strength indication (RSSI)		Yes; 64 levels between −110 dBm+ scale and −48 dBm+ scale	EC-GSM-IoT reports received useful signal in 75 levels between −122 dBm and −48 dBm	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.	LTE reports Reference Signal Received Power (RSRP) for LTE neighbor cells. See 3GPP TS 36.133.	NB-IoT measures Narrowband Reference Signal Received Power (NRSRP) based on narrowband reference signals, the narrowband secondary synchronization signal, or transmissions of the narrowband physical broadcast channel. See 3GPP TS 36.214.
Lost packets		Depends on operating point but typically 1% residual BLER after HARQ	Depends on operating point but typically 1% residual BLER 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	Depends on operating point but typically 1% residual BLER after HARQ	Depends on operating point but typically 1% residual BLER after HARQ

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Mechanisms to reduce power consumption		Yes, e.g. DTX, DRX, extended DRX, Power Save Mode and power control	Yes, e.g. extended DRX, and Power Save Mode	Yes, e.g. DTX, DRX, extended DRX and Power Save Mode	Yes, e.g. DTX, DRX, extended DRX and Power Save Mode	Yes, e.g. DTX, DRX, extended DRX and Power Save Mode	Yes, e.g. extended DRX, Power Save Mode, wake-up signalling, early data transmission, re-synchronization signal, and early termination of PUSCH transmission.	Yes, e.g. extended DRX, Power Save Mode, wake-up signalling, and early data transmission.
Low power state support		Yes, e.g. extended DRX, Power Save Mode.	Yes, e.g. extended DRX, and Power Save Mode.	Yes	Yes, e.g. Longer DTX/DRX cycles in all states	Yes, e.g. extended DRX, Power Save Mode.	Yes, e.g. extended DRX, Power Save Mode, and support for wake-up receiver-based UE architectures	Yes, e.g. extended DRX, Power Save Mode, and support for wake-up receiver-based UE architectures
Point to point		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Point to Multipoint		Yes	No	Yes	Yes	Yes	Yes	Yes
Broadcast		Yes	No	Yes	Yes	Yes	ETWS, CMAS, SIB16 time info	SIB16 time info
Handover		Yes	No	Yes	Yes	Yes	Yes	No

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Media Access Method		circuit-switched TDMA/FDMA Scheduled packet based TDMA/FDMA	Scheduled packet based TDMA/FDMA	circuit-switched CDMA	Scheduled packet based CDMA	Scheduled packet based OFDMA	Scheduled packet based OFDMA	Scheduled packet based OFDMA
Discovery		Sync and Broadcast channel	Sync and Broadcast channel	Sync and Broadcast channel	Sync and Broadcast channel	Sync and Broadcast channel	Sync, Broadcast channel, and wake-up signal	Sync, Broadcast channel, and wake-up signal
Association		Temporary Block Flow (TBF)	Temporary Block Flow (TBF)	Through various RNTIs	Through HRNTI and ERNTI assigned to UEs	Through CRNTI	Through CRNTI	Through CRNTI
Traffic priority	diffserv, resserv	3GPP-defined priorities	3GPP-defined priorities	3GPP-defined priorities	3GPP-defined priorities	3GPP-defined priorities	3GPP-defined priorities	3GPP-defined priorities
Radio queue priority		Scheduler in base station	Scheduler in base station	Yes at the Node B scheduler	Yes at the Node B scheduler	Yes at the eNode B scheduler	Yes at the eNode B scheduler	Yes at the eNode B scheduler
Location awareness (x,y,z coordinates)		aGPS and UTDOA methods as per 3GPP spec	Timing Advanced based method 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	A-GNSS, E-CID OTDOA methods as per 3GPP spec	A-GNSS, E-CID OTDOA methods as per 3GPP spec
Ranging (distance reporting)								

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Encryption	Algorithms supported	A5/3, A5/4, GEA3	KASUMI and SNOW 3G	KASUMI	KASUMI and SNOW 3G	SNOW 3G, AES, ZUC	SNOW 3G, AES, ZUC	SNOW 3G, AES, ZUC
Authentication		UE-to-NW (2G AKA) and mutual (3G AKA)	Mutual	UE-to-NW (2G AKA) and mutual (3G AKA)	UE-to-NW (2G AKA) and mutual (3G AKA)	Mutual	Mutual	Mutual
Replay protection in key exchange protocol		No (2G AKA) and yes (3G AKA)	Yes	No (2G AKA) and yes (3G AKA)	No (2G AKA) and yes (3G AKA)	Yes	Yes	Yes
Key exchange	Protocols and algorithms supported	Proprietary, 2G MILENAGE (2G AKA) and proprietary, MILENAGE, TUAK (3G AKA)	Proprietary, MILENAGE, TUAK	Proprietary, 2G MILENAGE (2G AKA) and proprietary, MILENAGE, TUAK (3G AKA)	Proprietary, 2G MILENAGE (2G AKA) and proprietary, MILENAGE, TUAK (3G AKA)	Proprietary, MILENAGE, TUAK	Proprietary, MILENAGE, TUAK	Proprietary, MILENAGE, TUAK
Interference sources		Other users, cells and networks	Other users, cells and networks	Other users, cells and networks	Other users, cells and networks	Other users, cells and networks	Other users, cells and networks	Other users, cells and networks

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
– Co-channel interference – Adjacent channel interference – Alternate channel interference – Collision avoidance – Protection mechanisms – Sensitivity to other interfering radio technologies – Degree of interference caused to other radio technologies – 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	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	Yes	Yes

TABLE A1.8 (*cont.*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
SIM card		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other identity		IMEI	IMEI	IMEI	IMEI	IMEI	IMEI	IMEI
Rogue detection		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Base Standard SDO	SDO name	ATIS (3GPP Organizational Partner)	ATIS (3GPP Organizational Partner)	ATIS (3GPP Organizational Partner)	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 45.005	As per 3GPP 25.101 and 25.102	As per 3GPP 25.101 and 25.102	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104
RF Noise sources - other radios		As per 3GPP 45.005 and 45.050	As per 3GPP 45.005 and 45.050	As per 3GPP 25.942	As per 3GPP 25.942	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104
RF Noise sources - other electrical equipment		As per 3GPP 45.005 and 45.050	As per 3GPP 45.005 and 45.050	As per 3GPP 25.943	As per 3GPP 25.943	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104
Rx sensitivity	dBm	As per 3GPP 45.005	As per 3GPP 45.005	As per 3GPP 25.101 and 25.102	As per 3GPP 25.101 and 25.102	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104
Tx Power peak	dBm	As per 3GPP 45.005	As per 3GPP 45.005	As per 3GPP 25.101 and 25.102	As per 3GPP 25.101 and 25.102	As per 3GPP 36.101 and 36.104	Lowest UE power class of 14 dBm As per 3GPP 36.101 & 36.104	Lowest UE power class of 14 dBm As per 3GPP 36.101 & 36.104

TABLE A1.8 (*end*)

Functionality Characteristic	Measurement Unit	GSM/EDGE	EC-GSM-IoT	UMTS	HSPA+	LTE Advanced Pro	eMTC	NB-IoT
Tx Power steps	dB	As per 3GPP 45.005	As per 3GPP 45.005	As per 3GPP 25.101 and 25.102	As per 3GPP 25.101 and 25.102	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104
Antenna gain	dBi	As per 3GPP 45.005	As per 3GPP 45.005	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 and 25.102	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104
Noise floor	dBm	As per 3GPP 45.050	As per 3GPP 45.050	As per 3GPP 25.101 & 25.102	As per 3GPP 25.101 and 25.102	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104	As per 3GPP 36.101 and 36.104
Modulation	GFSK, OFDM, BPSK, GMSK	GMSK, 8-PSK 16QAM/32QAM added in EGPRS2-A	GMSK, 8PSK	BPSK/QPSK	QPSK, 16QAM/64QAM	QPSK, 16QAM/64QAM/256QAM	pi/2-BPSK, QPSK, 16QAM, 64 QAM	pi/2-BPSK, pi/4QPSK, QPSK
Forward error Coding		Punctured convolutional code	Punctured convolutional code	Convolutional and Turbo	Convolutional and Turbo	Turbo; Tail Biting Convolution on BCH	Turbo; Tail Biting Convolution on BCH	Turbo in UL; Tail Biting Convolution in DL

A1.5   3GPP2 Standards

3GPP2 has a variety of wireless standards that are applicable to power grid management systems.

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.

A summary of the technical and operating features of the relevant 3GPP2 wireless standards are given in Table A1.9 below.

TABLE A1.9

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

TABLE A1.9 (*cont.*)

Item	Value		
	cdma2000 1x	**cdma2000 high rate packet data (HRPD/EV-DO)**	**Extended high rate packet data (xHRPD)**
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
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

TABLE A1.9 (*end*)

Item	Value		
	cdma2000 1x	**cdma2000 high rate packet data (HRPD/EV-DO)**	**Extended high rate packet data (xHRPD)**
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, resources[9]. 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 time[10].

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

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[9] 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).

[10] 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."

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 ..."*[11]

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"*[12].

Similar emphasis on advanced communications functionality has been put forth by state authorities[13] 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"[14].

Annex 3

Smart grid in Europe

A3.1 Introduction

In 2019, the EU completed a comprehensive update of its energy policy framework[15]. The Clean Energy for All Europeans package includes 8 different legislative acts as shown below:

– Energy Performance in Buildings Directive (EU) 2018/844

– Renewable Energy Directive (EU) 2018/2001

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[11] 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).

[12] *Id*.

[13] "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. "Communications is a foundation for virtually all the applications and consists of high speed two-way communications throughout the distribution system and to individual customers.")

[14] 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.

[15] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

–   Energy Efficiency Directive (EU) 2018/2002

–   Governance Regulation (EU) 2018/1999

–   Electricity Directive (EU) 2019/944

–   Electricity Regulation (EU) 2019/943

–   Risk-Preparedness Regulation (EU) 2019/941

–   Regulation (EU) 2019/942 for the Agency for the Cooperation of Energy Regulators (ACER).

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 the following initiatives:

–   The European Technology & Innovation Platform Smart Networks for Energy Transition (ETIP SNET)[16] guides Research, Development & Innovation (RD&I) to support Europe's energy transition. The European Technology & Innovation Platform Smart Networks for Energy Transition (ETIP SNET) Vision 2050 presents consolidated and qualitative ETIP SNET stakeholders' views for the energy system of 2050 and the associated high-level research, development and innovation (RD&I) challenges. It also indicates the framework in which RD&I efforts should be pursued in the decades to come.[17]

–   BRIDGE[18] is a European Commission initiative which unites Horizon 2020 Smart Grid and Energy Storage Projects to create a structured view of cross-cutting issues which are encountered in the demonstration projects and may constitute an obstacle to innovation.

A3.2   European activities in some Member States[19]

The Joint Research Centre (JRC), the European Commission's science and knowledge service, has published "Smart grid projects outlook 2017"[20]. It concludes that strong differences exist between EU Member States in the number of projects and the overall level and pace of investment. This study goes hand in hand with interactive visualisation tools, allowing the user to generate customisable maps, graphs, and charts to track progress on smart grid projects realised in the EU Member States, plus UK, Switzerland and Norway.[21]

The Joint Research Centre has also published "Smart Grid Laboratories Inventory 2018"[22] with information from 89 labs worldwide. It presents aggregated information about the smart grid topics

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[16] https://www.etip-snet.eu/

[17] ETIP SNET VISION 2050 – Integrating Smart Networks for the Energy Transition: Serving Society and Protecting   the   Environment,   available   at   https://www.etip-snet.eu/wp-content/uploads/2018/05/VISION2050-v10PTL.pdf

[18] https://www.h2020-bridge.eu/

[19] Source for whole paragraph: European Regulators' Group for Electricity and Gas Position Paper on Smart Grids – Ref: E09-EQS-30-04, Annex III https://www.ceer.eu/documents/104400/3751729/E09-EQS-30-04_SmartGrids_10+Dec+2009_0.pdf/c481db2a-3cfb-6d6f-4b58-da3dee68de4a?version=1.0&previewFileIndex=

[20] Available   at   https://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/u24/2017/sgp_outlook_2017-online.pdf

[21] https://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/u24/2017/org.html

[22] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC114966/jrc114966_kjna29649enn_track_changes_v12.pdf

of research, the technologies, the standards and the infrastructure used by top organizations that hold smart grid activities at a lab level.

The ERA-Net SES focus initiative Smart Grids Plus[23] supports deep knowledge sharing between regional and European smart grids initiatives by promoting and financing joint projects and joint accompanying activities, building on the knowledge base, R&D initiatives as well as research and demonstration facilities a ready in place at regional, national and European level.

A3.2.1 The European Industrial Initiative on electricity grids

The European Industrial Initiative on electricity grids[24] was launched by the European Commission within the European Strategic Energy Technology (SET) Plan [25].

The SET Plan was established in 2007 to better coordinate national and European research and innovation efforts by promoting cooperation among EU countries, industries and research institutions, and within the EU organisation itself. It supports impactful technologies that will help transform Europe's energy system while it also stimulates joint activities especially between countries participating in the SET Plan.

In September 2015, the European Commission released a new strategy for the SET Plan[26] with 10 actions structured in line with the Energy Union R&I priorities. The new approach builds on two main elements: a more integrated approach that goes beyond the concept of 'technology silos'; and a strengthened partnership among the SET Plan community consisting of the European Commission, the SET Plan countries and the industry and research stakeholders.

In 2016, the SET Plan community agreed on ambitious targets in line with its 10 R&I actions. The important progress achieved so far was captured in the Integrated SET Plan process report 2016 edition entitled "Transforming the European Energy System through INNOVATION"[27]. Also in 2016, the SET Plan activities were further boosted by the Communication Accelerating Clean Energy Innovation (ACEI)[28], which provides an enabling framework towards a faster market uptake of R&I output. The results of the SET Implementation Plans in 2018 have been published.[29]

The European Industrial Initiatives (EII) within the SET Plan are:

– Wind (The European Wind Initiative)

– Solar (The Solar Europe Initiative - photovoltaic and concentrated solar power)

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[23] https://www.eranet-smartenergysystems.eu/Calls/SG_Plus_Calls/Focus_Initiative_Smart_Grids_Plus

[24] 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.

[25] 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.

[26] https://setis.ec.europa.eu/system/files/Communication_SET-Plan_15_Sept_2015.pdf

[27] https://ec.europa.eu/energy/sites/ener/files/documents/set-plan_progress_2016.pdf

[28] COM/2016/0763 final: http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52016DC0763

[29] https://setis.ec.europa.eu/sites/default/files/setis%20reports/setplan_delivering_results_2018.pdf

–   Electricity Grids (The European Electricity Grid Initiative)

–   Carbon Capture and Storage (The European CO2 Capture, Transport and Storage Initiative)

–   Nuclear Fission (The Sustainable Nuclear Initiative)

–   Bio-energy (The European Industrial Bioenergy Initiative)

–   Smart Cities (Energy Efficiency - The Smart Cities Initiative)

plus

–   Fuel Cells and Hydrogen (Joint Technology Initiative)

–   Nuclear Fusion (International + Community Programme - ITER).

EIIs are joint large scale technology development projects between academia, research and industry. The goal of the EIIs is to focus and align the efforts of the Community, Member States and industry in order to achieve common goals and to create a critical mass of activities and actors, thereby strengthening industrial energy research and innovation on technologies for which working at the Community level will add most value.

A3.2.2 National technology platform – smart grids Germany

Germany is currently promoting various projects and activities to support the transformation of the distribution network into a smart grid. In 2016, the rollout of smart meters, an important data source in the lower voltage levels, has been legally fixed in the law on the digitization of the energy transition ("Gesetz zur Digitalisierung der Energiewende"). The communication unit of these devices, the so-called smart meter gateway, has to meet high standards in terms of data protection, data security and interoperability. Therefore, the manufacturers had to pass through an extensive certification process. The first smart meter gateway completed this process in December 2018 and was available for installation. The mandatory rollout, the start of which in Germany required certified smart meter gateways from three independent manufacturers, was able to start in February 2020. As the first step, this mandatory rollout of the smart meters includes all consumers with an annual consumption of over 6 000 kWh and less than 100 000 kWh. These are around 3.7 million installation cases. The groups of consumers with more than 100 000 kWh/a, consumers with flexible consumption devices and the generation systems will follow at a later point in time, as further the development of the smart meter gateways or an adjustment of the legal framework is required here.

In order to be able to connect the smart meters for communication across the board, the creation of appropriate telecommunication resources is a basic requirement. So far, the operators of critical infrastructures have not had any broadband frequencies or exclusive frequency ranges available. Therefore, the 450 MHz frequency band is and will be dedicated to the critical infrastructure and the actual use of the frequency will be awarded with the provision that a communication network for the critical infrastructures and smart meters is to be set up. With the dedication of the 450 MHz frequencies for critical infrastructures, the course can be set for the digitization of the energy transition. These frequencies are particularly suitable for building a comprehensive, highly available and at the same time black-out proof radio network infrastructure in the areas of electricity, gas, (waste) water and district heating. Various pilot projects have already been successfully completed.

Besides that, the Federal Ministry for Economic Affairs and Energy has implemented the so-called Smart Energy Showcases - Digital Agenda for the Energy Transition (SINTEG) funding programme that will run until 2021. It delivers the framework to set up large-scale showcase regions for developing and demonstrating model solutions that can deliver a secure, efficient and environmentally compatible energy supply with electricity being generated to a large extent from volatile sources such as wind or solar. The solutions developed could then be rolled out on a wider scale.

The programme places a clear focus on building smart networks linking up the energy supply and demand sides, and on the use of innovative grid technology and operating strategies. It thus addresses key challenges of the energy transition including the integration of renewables into the system, flexibility, digitisation, system security, energy efficiency and the establishment of smart energy systems and market structures. The project makes an important contribution to moving forward the digital transformation and the energy transition.

A3.2.3 Grid Control, Smart Grids and Smart Meters in the UK

The UK uses 12.5 kHz narrow band Scanning Telemetry (ST) systems to monitor and control power utility systems. These narrow band systems typically offer very efficient operation. It is usual for only the minimum spectrum to be occupied with the available channels. Typically having full 24-hour control and monitoring activity. For example, it may use only a single 12.5 kHz channel and cover an area with a 35 km radius.

The UK's core control networks of the existing intelligent electricity, gas, and water grid control systems share 2×1 MHz within the 450 to 470 MHz band. Recently, Ofcom (UK) announced that there will be no changes to the allocations within the 450 to 470 MHz band for ten years. Thereby ensuring continued access by the electricity, gas, and water users for Smart Grid Control solutions within the 400 MHz Band (406.2 to 470 MHz).

In each case, the core of the UK's existing grid control systems operates within 12.5 kHz narrow-band channels. See Ofcom (UK) OfW49. Recently, OfW49 has been updated to allow 25 kHz narrow-band systems. This change will enable data rates to be increased from 9.6 kbit/s to 64 kbit/s, etc. Thereby negating the potential need to migrate from the 400 MHz band.

12.5 kHz Scanning Telemetry systems are point to multi-point systems and may be the core of a SCADA system. As an example of a typical requirement in the UK, the power (electricity and gas) and water utilities have primary access to 80×12.5 kHz channels for ST systems.

The basic parameters for these systems are:
–   System availability approaching 99.9%;
–   Cells each with a 25 km radius;
–   6 channels per cell, giving 2 channels per utility;
–   12 cells per cluster, giving a co-channel re-use distance of 150 km.

Potential channel re-use of 23 times across the UK. The existing intelligent electricity grid control system needs will be expanding from its current monitoring of approximately 10 000 sites to in-excess of 1 million active assets as a consequence of Smart Grid developments approximately 250 000 sites. These are planned to include the low voltage 11 kV / 240 V sub-stations that feed the end user. This expansion will require a transition to a higher bandwidth network solution that an increase in the number of narrow band links but will enable electricity consumption to be monitored and controlled to the very edge of the network. This will enable the accurate measurement of energy needs, in almost real time, and the collation of very localised energy demand cycles across the whole network. (The UK's existing narrow band and public mobile operated Smart Meters may also be used to supplement / confirm the identification of these localised energy demand needs. NB: Smart Meter feedback will be on a non-real-time basis.) To this end, various broadband technologies are also being trialled in the UK within the 400 MHz band for Smart Grid systems. These broadband technologies vary in bandwidth from 2×3 MHz to 2×5 MHz.

The UK has a unique responsibility in that it needs to protect the operation of a radar system operating within the 400 MHz band. Broadband Smart Grid systems in geographic proximity to that radar may not be suitable within the 400 MHz Band. The planned expansion of the existing narrow band system is perhaps the only solution within the 400 MHz band.

Further information with regard to Smart Grid systems is contained in ETSI TR 103 401 V1.1.1.

Information regarding the UK's Engineering Private Mobile Radio (PMR) Communications systems is contained within Annex 8.

A3.3   Smart Grids spectrum arrangements within parts of Europe

Many European countries already have access to 2×3 MHz of spectrum for Smart Grids within the 400 MHz Band. This has typically enabled two adjacent CDMA channels to operate.

Figure A3-1 shows the Allocation of spectrum in 450-470 MHz to broadband services for several European countries.

Figure A3-2 shows the relevant harmonised 3GPP bands for the 450-470 MHz band.

FIGURE A3-1

Example 400 MHz band spectrum arrangements within Europe
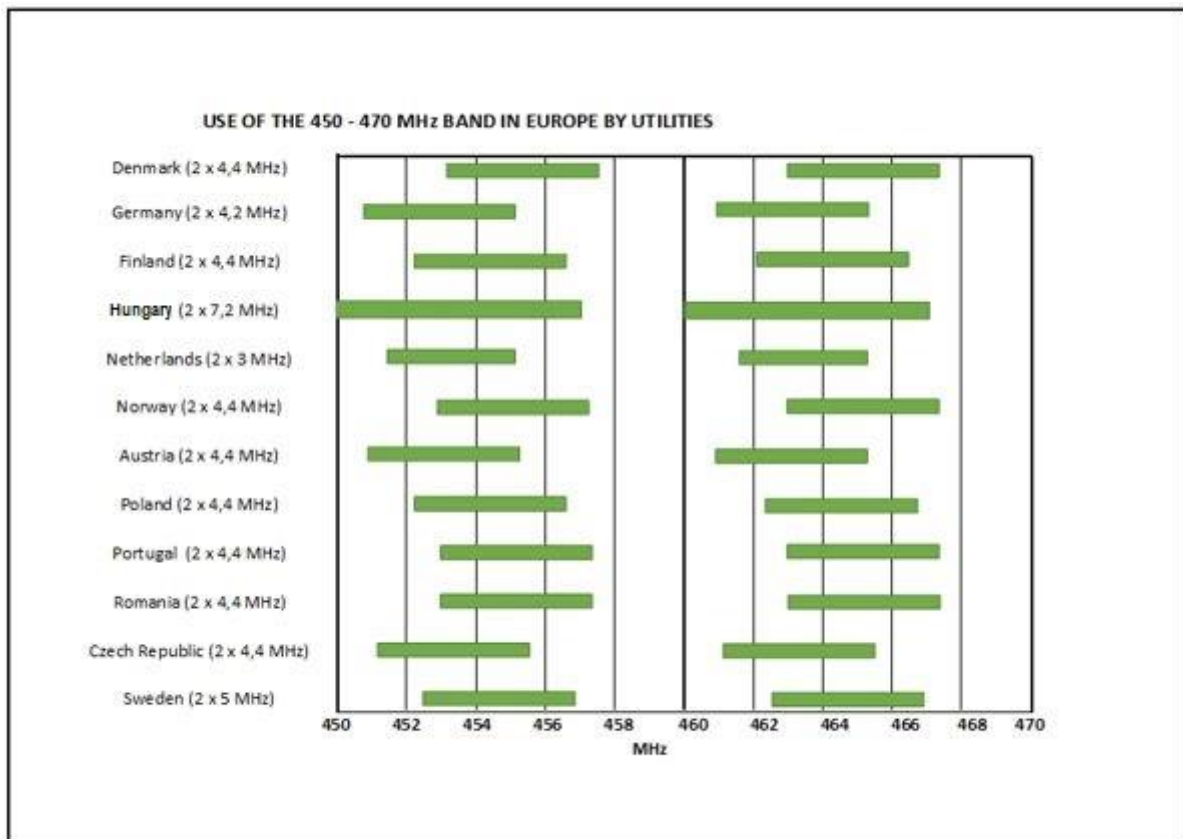
Several of the Smart Grid operators within those countries are seeking to migrate to 2×5 MHz LTE systems. For simplicity, they are typically seeking to obtain an increase in the bandwidth to their currently accessed spectrum, e.g. to Band 72 (451 to 456 MHz paired with 461 to 466 MHz).

FIGURE A3-2

Harmonised 3GPP bands for 450-470 MHz spectrum
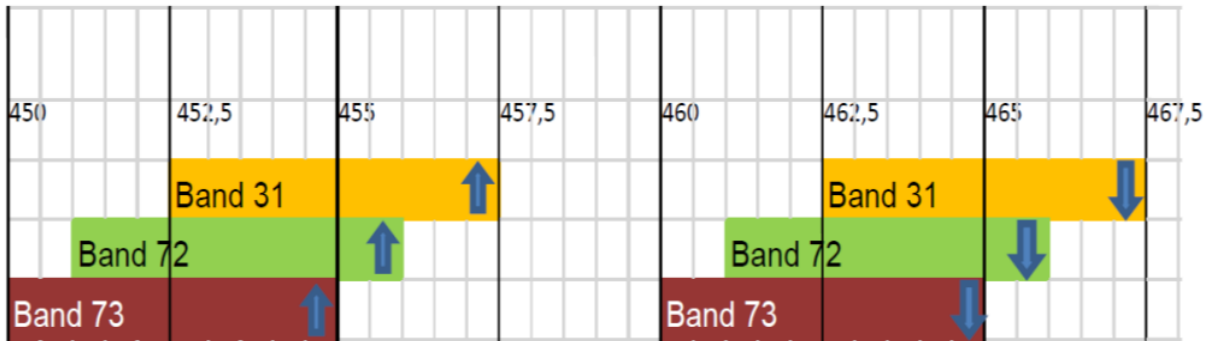
Annex 4

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 leaded by ABRADEE 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.

– 	ABRADEE – 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 costumer 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%.

FIGURE A4-1

Report SM.2351-A4-01
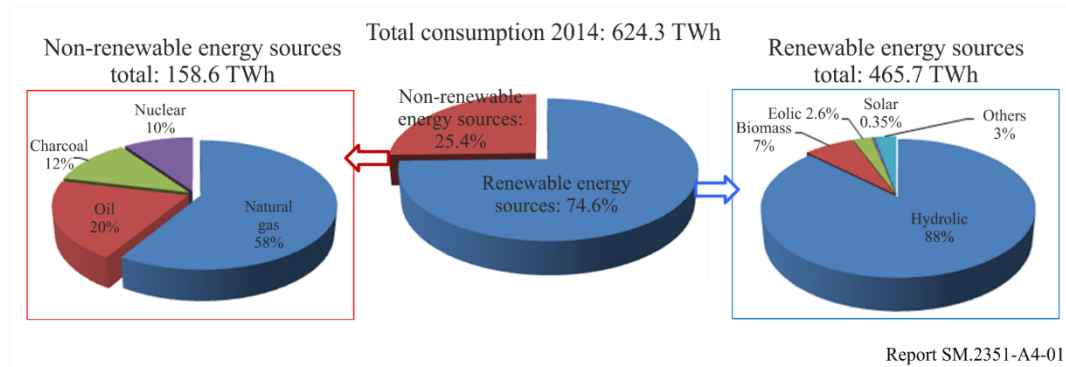
The average consumption in Brazil is 68 GW with peaks over 80 GW. Recently, the electric sector informed that it is foreseen that the consumption will increase around 44%, what demands energy efficiency for the electric system.

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 ABRADEE/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 ABRADEE/APTEL study has realized the needs of investments around 19 billion of "Reais" in telecommunications assets and 3 billion "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 fibre 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 fibres 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 ABRADEE/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 analyser 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 ABRADEE/APTEL study recommended, among other 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 road map to Smart grid

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" [30] as its vision and first announced a road map for smart grid.

In 2012, 'the first basic plans for Smart grid' was established. In line with the plans, infrastructure related to renewable energy, ESS (Energy Storage System), smart meters have been built. Moreover, AMI (Advanced Metering Infrastructure), renewable energy, EV (Electric Vehicle), ESS and a virtual power market were introduced to 6,000 households in Gujwa-eup of Jeju island to realize the Smart grid plans.

In 2018, it established the 2nd basic plans for Smart grid over the next 5 years and has been pushing for 4 following areas to rationalize power consumption, efficiently produce power and create new energy industry.

1)   Promoting new services of Smart grid

2)   Building first-hand experience Smart grid centre

3)   Expanding Smart grid infrastructure and facilities

4)   Laying a foundation to expand Smart grid.

First, to promote new services of Smart grid:

–   Providing different power rating systems depending on seasons and time zones.

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[30] http://www.greengrowthknowledge.org/sites/default/files/downloads/resource/Koreas-Green-Growth-Experience_GGGI.pdf

– Changing the resource transaction market from a market for large plants to a nationwide DR market.

– Providing business players with nationwide power consumption data stored in the big data platform.

– Operating a power brokerage market where small-size energy resources such as renewable energy, ESS and EV can be traded.

Second, first-hand experience Smart grid centre will be built for people to experience new services.

Third, transmission and distribution lines, substations, AMI, ICT infrastructure are going to be expanded and DER (Distribution Energy Resources) control system will be built in the public sector.

Fourth, a consultative group consisting of public and private sectors will be formed to foster experts in developing core technologies such as AI and Block Chain.

From the national standpoint, Smart grid project aims to raise energy efficiency and implement green-energy infrastructure by building eco-friendly infrastructure that reduces CO_2 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.
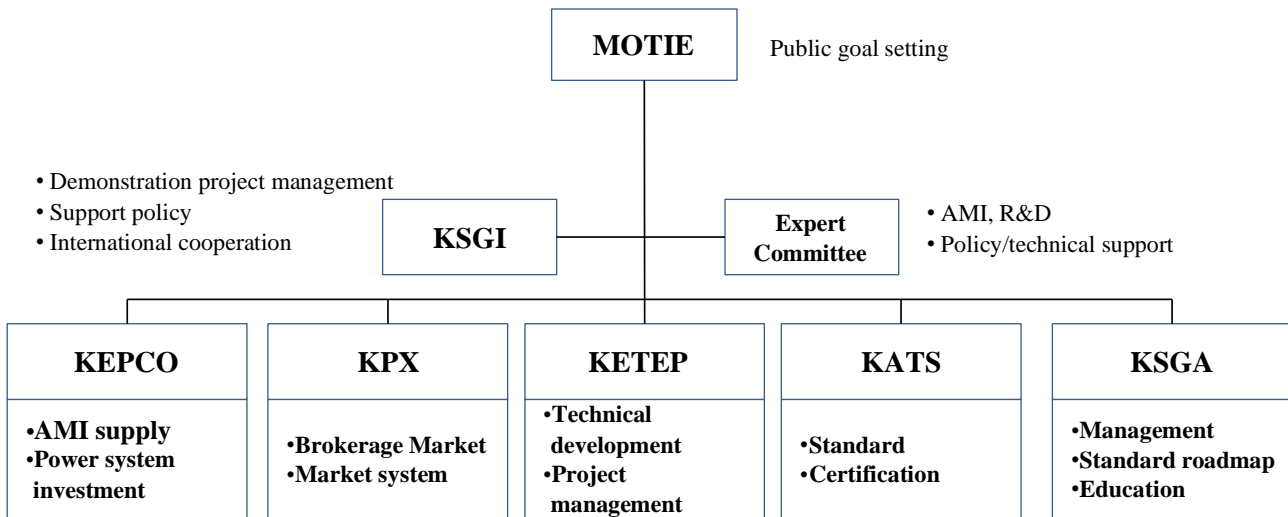
FIGURE A5-1

Conceptual diagram for the Smart grid system
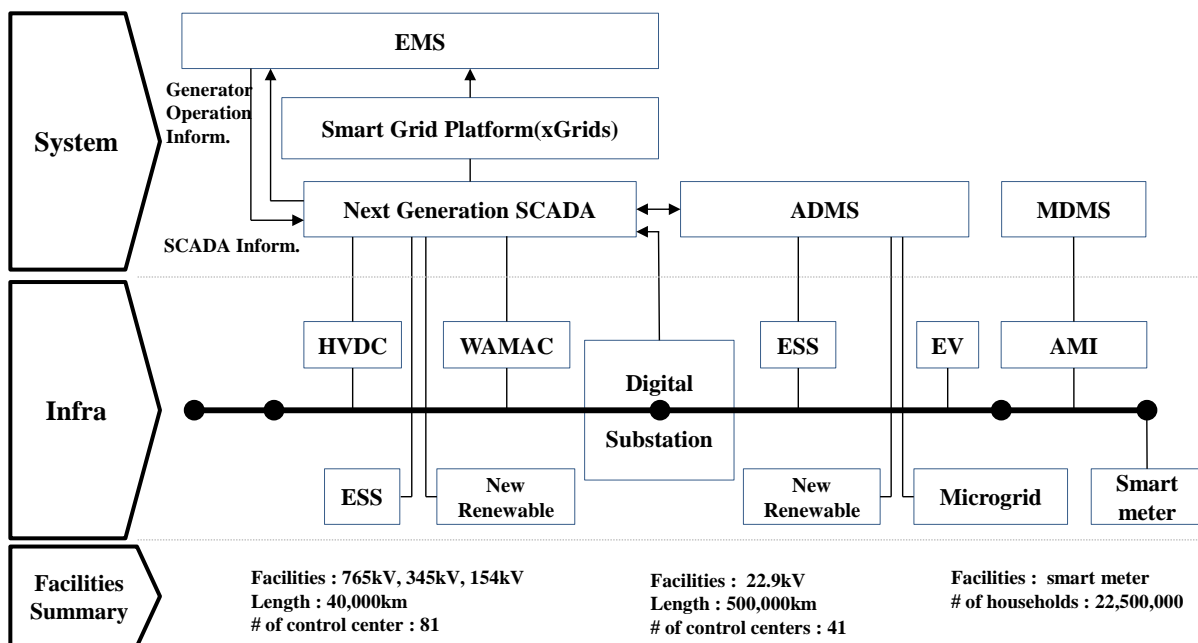
* EMS: Energy Management System
* SCADA: Supervisory Control and Data Acquisition
* ADMS: Advanced Distribution Management System
* MDMS: Meter Data Management System
* HVDC: High-Voltage, Direct Current
* WAMAC: Wide Area Monitoring and Control

FIGURE A5-2

Smart grid Policy Consultative Council

* MOTIE: Ministry of Trade, Industry and Energy
* KSGI: Korea Smart Grid Institute
* KATS: Korea Agency for Technology and Standards
* KSGA: Korea Smart Grid Association

The Policy Consultative Council consists of KEPCO (Korea Electric Power Corporation), KPX (Korea Power Exchange), a Smart grid task force, KETEP (Korea Institute of Energy Technology Evaluation and Planning), related associations and experts. The main roles of the council are to serve as a control tower for Smart grid plans, set policy directions and implementation strategies, review performances of each institute and identify regulations to improve and business to export.

A5.2   Communication network

Due to the expansion of the Smart grid, there is an increasing demand for wireless communication. Especially, the current Smart grid communication environment is mixed with a control system area where reliability, security and speed should be guaranteed and an IoT area where various terminals communicate with each other. Currently, a communication method with a mixture of wired and wireless communications is used. As the service range widens, an optimal communication network suitable for the new environment is necessary.

TABLE A5.1

Communication methods of Smart grid

Classification	Wired network	Wireless network
Power Control	Optical	TRS (380 ~399.9 MHz)
Smart Metering	PLC, HPGP	Wi-SUN (917 ~ 923.5 MHz)
		LTE (800 MHz, 900 MHz, 1.8 GHz, 2.1 GHz, 2.6 GHz)
New and Renewable Power Generation	Optical	TRS (380 ~ 399.9 MHz)

Wired network using fibre-optic cable is mainly used for the power control requiring high reliability. Wired PLC and a number of wireless communications methods are used for smart metering and optical communication method. TRS wireless communication is used for renewable power generation.

Various wireless communication methods are applied, and 320 MHz band will be used for IoT frequency band to satisfy the demand for wireless communication.

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 seven important domains: 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 analogue 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
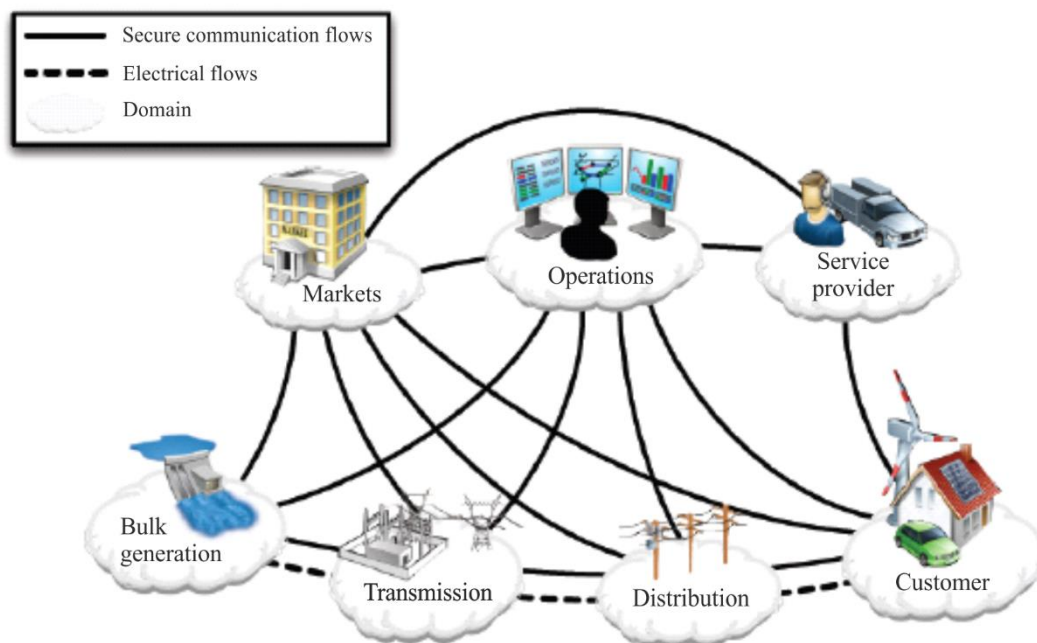
Report SM.2351-A6-01

Smart grid as system to system, which has three main layers: 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
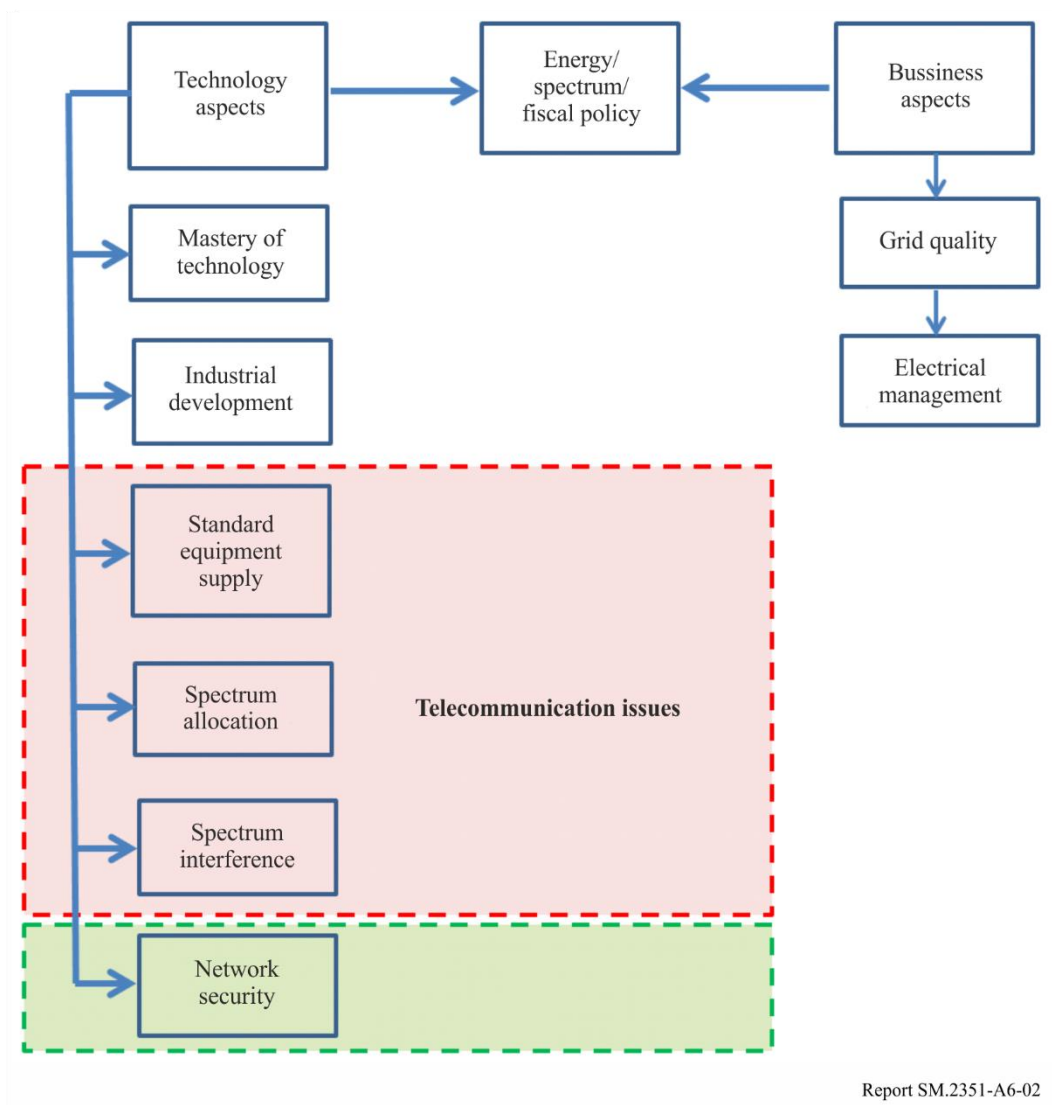
Report SM.2351-A6-02

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

Research 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, millisecond-level precise load control, 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 research and construction of a new generation of power communication network in smart grid construction.

A7.2 Wireless access technologies for Smart grid in China

A7.2.1 Introduction

In China, both SWIN system (230 MHz discrete multi-carrier power wireless communication system: SWIN) and IoT-G 230 system (230 MHz discrete multi-carrier electric wireless communication system: IoT-G 230), are the options for wireless smart grid applications, and have been used to achieve broadband transmission by aggregating multiple 25 kHz discrete narrowband carriers at 223-235 MHz range (also referred here as 230 MHz band) to provide wireless service for smart grid. The 230 MHz spectrum provides good propagation characteristics suitable to meet the wide area coverage requirement of many smart grid applications.

Both SWIN and IoT-G) are designed to take full account of the service demands of smart grid. The systems have 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 Ministry of Industry and Information Technology. Both technologies have a number of key technologies taking into account the unique 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.

IoT-G 230 also supports broadband transmission by aggregating multiple 25 kHz narrowband carrier for each transmission. In addition, to further extend coverage, IoT-G 230 supports multiple antenna technology to obtain space diversity gain and power combining gain. Also, to guarantee power grid safety and security, IoT-G 230 supports end-to-end services isolation for services in I/II production area and services in III/IV management areas. Last but not least, to ensure coexistence with other narrowband systems, IoT-G 230 supports inter-carrier frequency hopping across the whole 230 MHz band and in the granularity of 10 ms to improve communication reliability and robustness.

TABLE A7.1

Technical and operation features of SWIN and IoT-G 230

Item	SWIN	IoT-G 230
Supported frequency bands, licensed or unlicensed (MHz)	Licensed frequency bands: 223-235 MHz	Licensed frequency bands: 223-235 MHz
Nominal operating range	3~30 km	3~30 km
Frame length	25 ms	10 ms
Subcarrier spacing	2 kHz	3.75 kHz
Mobility capabilities (nomadic/mobile)	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)	11.27 UL/9.92 DL Mbit/s (7M BW)
Duplex method (FDD, TDD, etc.)	TDD	TDD
Nominal RF bandwidth	Selectable: 25 kHz – 12 MHz	Selectable: 25 kHz – 12 MHz
Support for MIMO	No	Yes
Retransmission	HARQ	HARQ
Forward error correction	Convolutional, Turbo	Convolutional, Turbo
Interference management	Fractional frequency re-use, spectrum sensing	Frequency hopping across whole band spectrum sensing
Power management	Yes	Yes
Connection topology	point-to-multipoint	point-to-multipoint
Medium access methods	Random Access (Contention based and non-contention based)	Random Access (Contention based and non-contention based)

TABLE A7.1 (*end*)

Item	SWIN	IoT-G 230
Multiple access methods	SC-FDMA (uplink) and OFDMA (downlink)	TDMA and FDMA
Channel coding	Turbo coding, Tail biting convolutional coding	Turbo coding, Tail biting convolutional coding, Reed-Muller coding
Modulation	QPSK/16QAM/64QAM	QPSK/16QAM/64QAM
Discovery and association method	Autonomous discovery, association through Bearer	Autonomous discovery, association through Bearer
QoS methods	QoS differentiation (5 classes supported, scalable)	QoS differentiation (5 classes supported, scalable)
Location awareness	Yes	Yes
Encryption	ZUC	ZUC/SNOW3G/AES
Authentication/replay protection	Yes	Yes
Key exchange	Yes	Yes
Rogue node detection	Yes	Yes
Unique device identification	15 digits (IMEI)	15 digits (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 trial network has been deployed in power distribution and utilization communication networks in some 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.

The laboratory test for IoT-G 230 was completed in October 2018, and the field test for IoT-G 230 was completed in November 2018 in Suzhou, Jiangsu Province of China. IoT-G 230 passed all the field test cases including interference tests, system security tests, stability tests, etc.

A7.2.4 Standardization

Both SWIN and IoT-G 230 technologies belong to the series specifications under Q/GDW11806.

Specifications of SWIN system "Q/GDW11806.2 230 MHz discrete multi-carrier electric wireless communication system – Part 2: Technical specification for LTE-G 230 MHz" and "Q/GDW11806.3 230 MHz discrete multi-carrier electric wireless communication system – Part 3: Test specification for LTE-G 230 MHz" were published in Nov, 2018.

Specifications of IoT-G 230 system "Q/GDW11806.4 230 MHz discrete multi-carrier electric wireless communication system – Part 4: Technical specification for IoT-G 230 MHz" and "Q/GDW11806.5 230 MHz discrete multi-carrier electric wireless communication system – Part 5: Test specification for IoT-G 230 MHz" are under study.

A7.3　Conclusion

China's research on wireless access technologies for Smart grid are introduced. Both SWIN and IoT-G 230 can provide satisfied wireless communication for Smart grid, by which the cost of construction and operation of smart grid can be reduced.

Annex 8

PMR / PAMR Engineering Communications (Voice/Data) Systems

A8.1　General description of PMR/PAMR systems with channel bandwidths of 25 kHz, 12.5 kHz and 6.25 kHz

Professional/Private Mobile Radio (PMR) may be used for day-to-day and/or emergency engineering communications systems.

PMR is characterised by being private (individually authorised) access, professional sector specific group communication, tailor-made design, using portable, mobile, base stations and remote fixed stations (including e.g. data terminals, and Supervision, Control, and Data Acquisition (SCADA) systems), allowing the licensed users to stay in full control over their tasks at hand and deliver mission critical or business critical applications such as instantaneous voice and group communications in order to optimise their operations.

A8.2　Services using channel bandwidths up to 25 kHz

PMR/PAMR services include Group Call Voice Services (commonly referred to as 'all informed net' and/or 'talk group call'). This service is in the portable radio environment sometimes also used with a voice-activated head-set (VOX) to allow the user both hands free while communicating (Examples hands-free operation within nuclear power stations.

Other Services include Pre-Emptive Priority Call (Emergency Call), Call Retention, Priority Call, Dynamic Group Number Assignment (DGNA), Ambience Listening, Call Authorized by Dispatcher, Area Selection, Late Entry, Direct Mode, Short Data Service and Packet Data Services.

Where required and specially authorised, encrypted communication channels may also be applied.

A specialised supply sector is serving this market with solutions ranging from very small single site systems to huge nationwide PMR/PAMR networks which are often very much customised to the specific needs of the users of such networks, e.g. on-site systems at individual electricity stations up to wide area systems covering an entire electricity network region.

Key services of such PMR/PAMR land mobile radio systems include:

–　　　Push-to-talk, release to listen — a single button press opens communication on a radio frequency channel;

–　　　Wide coverage areas;

–　　　Closed user groups;

–　　　Many systems operating with the remote or mobile stations being able to hear all the calls being made. This may not always be satisfactory, and a system of selective calling may be required;

–　　　Call set-up times which are generally short compared with cellular systems.

A8.3　Systems with channel bandwidths up to 25 kHz

These narrow band systems are almost exclusively used by PMR. These include analogue, MPT 1327, and digital (dPMR, DMR, TETRA and TETRAPOL).

Mission-critical PMR/PAMR networks normally require some customisation following key requirements from their users, including:

–　Very high coverage availability within the defined service area, including in some cases remote and unpopulated areas;

–　Designed often to meet exact technical requirements, rather than for economic gain;

–　Designed to cover the areas required including isolated non-populated regions beyond mobile phone etc service areas.

–　Ability for best practice resilience / resilient M2M (RM2M) operation;

–　Instant and guaranteed channel access;

–　System and transmitted data have high levels of network security and integrity. This may include: no connection to external and / or public communications systems such as public mobile networks and the public Internet;

–　Network hardened to ensure reliable operation in severe environmental conditions, including electromagnetic disturbances such as lightning strikes;

–　Up to 96 hours power backup;

–　Longevity of life and support, e.g. 10 to 20 years.

A8.4　PMR/PAMR standards:

Table A8.1 below shows the typical standards used for 6.25 / 12.5 / 25 kHz narrow-band PMR.

TABLE A8.1

Typical PMR Standards used by the electricity utilities

Technology	Channel width (kHz)	Standard / Specification
Digital	6.25	ETSI EN 301 166
Analogue	12.5	ETSI EN 300 086
Digital	12.5	ETSI EN 300 113
Digital	25	ETSI EN 300 113, ETSI EN 302 561

Annex 9

Example list of frequency bands used for wireless smart metering and smart grid systems

Table A9.1 contains an example list of frequency bands used for wireless Smart Metering and Smart Grid Systems in some parts of the world.

TABLE A9.1

**Example of frequency bands used for wireless Power Grid Management
Smart Metering and Smart Grid Systems**

Frequency (MHz)	Area/Region	Comments related to the actual use
40-230 (part of), 470-694/698	North America, UK, many parts of Europe, Africa, and Japan	TV white space, rulemaking finished in USA and in 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	Licenced band
410-430	Parts of Europe	UK: 412-414 MHz paired with 422-424 MHz
450-470	North America, and many parts of Europe	Europe: includes Austria, Denmark, Finland, Hungry, Netherlands, Norway, Poland, Portugal, Romania, and Sweden. UK: 457.5-458.5 MHz paired with 463-464 MHz
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
868-870	Europe	European Radiocommunication Committee (ERC) Recommendation 70-03
873-876	Parts of Europe	ERC Recommendation 70-03 UK: public mobile networks incorporating 868 and& 870 MHz licence-exempt bands for Smart Meter range extension in the middle and South UK.
896-901	North America	Licenced band, Part 90 in the USA.
901-902	North America	Licenced 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

TABLE A9.1 (*end*)

Frequency (MHz)	Area/region	Comments related to the actual use
917-923.5	Korea	
920-928	Japan	
928-960	North America	Licenced 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: – 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

Annex 10

Relevant ITU-R Recommendations and Reports

Report ITU-R M.2440 – The use of the terrestrial component of International Mobile Telecommunications for narrowband and broadband machine-type communications. Section 5 contains information on "Technical and operational aspects of terrestrial IMT-based radio networks and systems to support narrowband and broadband MTC".

Report ITU-R M.2479 – The use of land mobile systems, excluding IMT, for machine-type communications.

Report ITU-R M.2441 – Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT). Section 5.4 contains information related to smart grids.

Recommendation ITU-R M.1036 – Frequency arrangements for implementation of the terrestrial component of International Mobile Telecommunications (IMT) in the bands identified for IMT in the Radio Regulations.

Recommendations ITU-R M.1457 and ITU-R M.2012 provide the IMT specifications for IMT-2000 and IMT-Advanced respectively.

Recommendation ITU-R M.2002 – Objectives, characteristics and functional requirements of wide-area sensor and/or actuator network (WASN) systems.

Report ITU-R M.2224 – System design guidelines for wide area sensor and/or actuator network (WASN) systems.

Attachment

Acronyms and Abbreviations

3G	Third Generation
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
4G	Fourth Generation
ABRADEE	Brazilian Association of Distributors of Electric Power
AES	Advanced encryption standard
AES-CCM	Advanced encryption standard – constant coding and modulation
AKA	Authentication and Key Agreement
AMI	Advanced metering infrastructure
AMM	Automated meter management
AMR	Automated meter reading
ANEEL	Agência Nacional de Energia Elétrica
APTEL	Association of Private Companies Proprietary of Infrastructure and Telecommunications Systems
ARIB	Association of Radio Industries and Businesses
ARQ	Automatic repeat request
AS	Assured forwarding
BE	Best effort
BPSK	Binary phase shift keying
BS	Base station
CA	Carrier access
CARB	California Air Resources Board
CAVE	Cellular authentication and voice encryption
CC	Climate change
CCM	Constant coding and modulation
CCSA	China Communications Standards Association
CCTV	Closed-Circuit TeleVision

CDMA	Code-division multiple access
CEC	California Energy Commission
CENELEC	European Committee for Electrotechnical Standardization
CEPT	European Committee for Electrotechnical Standardization
CHAP	Challenge Handshake Authentication Protocol
CID	Cell identifier
CIM	Common information model
CISPR	Comité International Spécial des Perturbations Radioélectriques
CMAC	Cypher-based message authentication code
CMEA	Cellular message encryption algorithm
CSMA	Carrier sense multiple access
DA	Distributed automation
DAM	Dynamic asset management
DAP	Data aggregation point
dB	Deci Bel
DECC	United Kingdom Department of Energy and Climate Change
DER	Distributed energy resources
DGNA	Dynamic group number assignment
DSSS	Cross-spectrum symbol synchronizer
DMR	Digital Mobile Radio
DMS	Distribution management system
DOE	U.S. Department of Energy
dPMR	Digital private mobile radio
DSCP	Differentiated service code point
EAP	Extensible authentication protocol
EC	European Commission
ECC	European Communications Committee
EDGE	Enhanced data GSM environment
EF	Expedited forwarding
EII	European Industrial Initiatives
eMTC	Enhanced machine-type communications
EPON	Ethernet passive optical network
EPRI	Electric Power Research Institute
ERC	European Radiocommunication Committee
ESFF	Electricity Sector Framework for the Future
ETSI	European Telecommunications Standards Institute

EU	European Union
EUTC	European UTILITIES TELECOMS COUNCIL
EV	Electric vehicles
EVDO	Evolution-data optimized
E3	Energy and environmental economics, Inc.
FAN	Field area network
FCC	Federal Communications Commission
FDD	Frequency division duplex
FDMA	Frequency division multiple access
FEP	Front-end processor
FG	Focus Group
FM	Frequency modulation
GNSS	Global navigation satellite system
GPRS	General packet radio service
GSI	Global strategic initiative
GSM	Global system for mobile communications
GW	Giga Watts
HAN	Home area network
HARQ	Hybrid automatic repeat request
HMAC	Hashed message authentication code
HN	Home networking
HRPD	High-rate packet data
HSPA	High speed packet access
HVDC	High voltage direct current
ICT	Information and communication technologies
ICV	Integrity check value
ID	Identity
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of things
IoT-G	Internet of things-grid
ISM	Industrial, scientific, and medical
ISO	International Organisation for Standardisation
IT	Information technology
ITS	Intelligent transport systems
ITU	International Telecommunications Union

ITU-R	International Telecommunications Union – Radiocommunications
ITU-T	International Telecommunications Union – Telecommunications
JCA	Joint Co-ordination Activity
JRC	Joint Radio Company Limited
kHz	Kilo Hertz
LDPC	Low-density parity-check
LF	Low frequency
LTE	Long-term evolution
MAC	MAC message authentication code
MEID	Mobile equipment identifier
MEP	Member of the European Parliament
MHz	Mega Hertz
MIMO	Multiple input multiple output
MPDU	MAC (Media Access Control) Protocol Data Unit
MPLS	Multi-protocol label switching
MPT	United Kingdom Ministry of Posts and Telecoms (now Ofcom)
MR-FSK	Multi-regional frequency shift keying
MTC	Machine-type communication
M2M	Machine to machine
MW	Mega Watts
NAN	Neighbourhood area network
NB	Narrow band
NB-PLC	Narrow band power line communications
NISTIR	National Institute of Standards and Technology Interagency/Internal Report
OFDM	Orthogonal frequency division modulation
PHY	Physical
PKMv2	Privacy Key Management version 2
PLC	Power line communications[31]
PLT	Power line telecommunications[32]
PAMR	Public access mobile radio
PMP	Point to point
PMR	Professional / Private mobile radio
PRIME	PoweRline intelligent metering evolution
PSK	Phase shift keying

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[31] The terms PLT and PLC are often used interchangeably.

PUC	Public Utilities Commission
QAM	Quadrature amplitude modulation
QoS	Quality of service
RF	Radio frequency
RFID	Radio frequency identification
RM2M	Resilient machine to machine
RSA	Rivest, Shamir and Adleman algorithm
SCADA	Supervisory, control, and data acquisition
SDO	Standards developing organizations
SDMA	Space division multiple access
SET	European Strategic Energy Technology Plan
SFID	Service flow identifier
SHA	Secure hash algorithm
SIM	Subscriber identity module
SG	Smart grid
SGIP	Smart grid interoperability panel
SRD	Short range device
ST	Scanning telemetry
SWIN	Smart and wide-coverage industry-oriented wireless network
TDD	Time division duplex
TDMA	Time division multiple access
TETRA	Trans European Trunked RAdio
TLS	Transport layer security
TR	ETSI Technical Report
TSAG	Telecommunications Standardization Advisory Group
UHF	Ultra-high frequency
UK	United Kingdom
UMTS	Universal mobile telecommunications system
USA	United States of America
UT	User terminal
UTC	Utilities technology council
VHF	Very high frequency
VOX	Voice operated switch
VPN	Virtual private network
WAN	Wide area network
WASN	Wide-area sensor and/or actuator network

WCDMA   Wide band code-division multiple access

Wh   Watt hours

xHRPD   Extended high-rate packet data

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