New Zealand Smart Grid ICT Infrastructure

A Discussion on Technologies and Opportunities

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Notice
This work supported financially by the New Zealand Ministry of Business, Innovation and Employment (MBIE) GREEN Grid project funding. The GREEN Grid project is a joint project led by the University of Canterbury with the University of Auckland’s Power System Group and the University of Otago’s Centre for Sustainability, Food, and Agriculture, and with a number of electricity industry partners. The project, officially titled “Renewable Energy and the Smart Grid” will contribute to a future New Zealand with greater renewable generation and improved energy security through new ways to integrate renewable generation into the electricity network. The project aims to provide government and industry with methods for managing and balancing supply and demand variability and delivering a functional and safe distribution network in which intermittent renewable generation is a growing part of the energy supply. New Zealand currently generates about 75 percent of its electricity from renewable generation, making it a world-wide leader in this area.

March 2015
Executive Summary

In light of the technological developments in the field of Information and Communication Technology (ICT), the distribution companies are facing increased expectation from variety of stakeholders to help in achieving national energy efficiency and climate change policy targets. Due to the rapid growth in ICT sector, there are many different technologies available in the market with different data speed and coverage. The implementation of these technologies in the distribution companies to make their grid smarter and to extract maximum benefits from smart grid requires the thorough understanding of ICT and its capabilities.

Compared to international practices, New Zealand is also progressing towards installing Smart Grid infrastructure. To assess energy efficiency measures and enable existing network smarter operation, adequate information flow between all participating entities is required. This necessitates the usage of the advanced information and communication technologies. The main objective of this report is to address the different ICT practices available in the market and to highlight their capabilities. With that background, current status of ICT in New Zealand is discussed. The practices followed by other parts of the world is also covered which gives the comparison of technologies followed in New Zealand with the rest of the world. The report also addresses the smart grid applications with examples (already tested in other parts of the world).

The implementation of ICT in power sector would help in making tradition grid smarter and intelligent. It will help in exchanging the information between different stakeholders of electric grid. Utility needs to have different technologies to achieve this. The overall communication network architecture can be divided into three parts as Premises Networks (which is conceptualized to form communication access for consumer devices; further divided into HAN, BAN and IAN), Neighborhood Area Network (which would cater the communication link between Premises Networks and Wide Area Networks) and Wide Area Networks (Which connects Neighborhood Area Network to the utility). There are different communication technologies available which connects these networks together. Communication technologies can be broadly classified into Wireless and Wireline communications. The available Wireless communications for Smart grid are Bluetooth, Wireless Mesh Network, WiMax, ZigBee, Z-wave, Cognitive Radio Networks, Dash7 and Cellular (3G and LTE) technologies. Similarly, the potential wireline communications available for Smart grid are Fibre-optic, DSL and Power Line Communications. The data speed offered by these communication technologies along with their coverage area are discussed in the report.
The New Zealand electricity distribution utilities are in the transition stage from traditional grid towards smart grid. Currently radio links like VHF, UHF and Microwave are being widely used throughout NZ. Where there are gaps in radio network, cellular communications such as 3G / GPRS are used. Fibre-Optic and Copper cables are also used as wireline communication. With the rollout of Advanced Metering Infrastructure, distribution companies are implementing alternate modes of communication which can handle higher data transfer rates and more coverage. Commonly preferred technologies are Radio Mesh Networks and GPRS. It is noted that, Radio mesh network is being implemented in most of the distribution companies in New Zealand for communicating with smart meters. Rest of the distribution companies use GPRS for communication. This establishes the communication link between Premises Network (through Smart meter) and Neighborhood Area Networks.

It is also noted that most of the distribution companies in New Zealand have their own fibre-optic and/or are using leased fibre-optic. Fibre-optic connects to most of the major zone substations in these distribution companies and it has been mainly used for SCADA communication (either Primary or as backup) and protection signaling. Further as per the government objective, 75 % of the New Zealand population should have the Ultrafast Broadband by 2019 which is also known as Fibre to the Premises (FTTP) network. This project covers 33 largest towns and cities in New Zealand.

In view of the current infrastructure, future plan of distribution companies and the mass rollout of fibre-optic by the Government of New Zealand shows that the future communication medium for WAN would mainly be Fibre optic and Cellular communications. Interaction between HAN and NAN / FAN would be either by Radio Mesh networks or through GPRS.

Compared to NZ practice, it is noted that PLC is the preferred communication technology for NAN / FAN in most of the European countries except UK. UK has used GPRS during pilots and prefers either Radio Frequency mesh or GPRS for complete roll out. Wireless communication technologies like RF Mesh network are preferred communication links for NAN / FAN in USA. WiMax has widely been deployed in Victoria Australia by SP Ausnet. Long Term Evolution (LTE) is in limited deployment in private utility networks including Ausgrid and a partnership between Green Mountain Power and Vermont Telephone Company in USA; however it is gaining traction as the first global cellular standard because of its performance characteristics and support for IP. Fibre optic is the commonly chosen technology for WAN, since it is reliable and offers high performance.
Finally, the report addresses some ICT Smart Grid applications. Most of the applications are presented with the help of already executed projects / pilot projects across the world with an emphasis on the NAN/FAN applications. Typical data size (bytes) and data sampling requirement, Latency, and the suitable communication technologies for the applications of each area are also summarized.

Overall, this report may be particularly worthwhile for the NZ distribution utility engineers in leveraging their ICT infrastructures and also the upcoming plans for their future Smart Grid networks and designing the associated applications.
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1. Introduction

The electrical grid refers to the interconnected power system network, which transfers power from all participating generators to consumers spread throughout. It has undergone several changes since its inception. The emerging grid is expected to make use of the advanced technologies from Information and Communication Technology (ICT) to gather the information from across its various participants. The information gathered from different stakeholders would be used to control and monitor in order to improve the efficiency, reliability, flexibility and for economic benefits [5].

Traditional energy sector value chain is pictorially represented in Figure 1. In spite of technological advancements in electricity sector, still there is information gap. There has to be a real-time coordination between the stakeholders in the electricity sector, which could be achieved by properly using the ICTs in the smarter grid [1] [5].

![Figure 1: Traditional Energy Sector Value Chain](image)

In addition to the information gap, other challenges faced by the electricity sector globally are [5].

I. **Generation**: Large-scale Renewable Energy integration, Distributed small scale generation

II. **T & D**: T & D Grid management, Real-time coordination between retailers and distribution companies, Load management, Power Quality issues etc.

III. **Storage**: Data management and storage challenges

IV. **Retail**: Dynamic & Real-time pricing for electricity consumption and distributed generation, Coordination with distribution companies

V. **Consumption**: Electricity conservation and energy efficiency, Remote demand management, Integration of electric vehicles and in-house solar generation
To overcome these challenges, power system industry is witnessing the transition from traditional electricity grid towards Smart Grid. This transition has resulted in deployment of various advanced technologies and appliances.

Further, various Smart Grid pilot projects with different communication technologies have been carried out and being implemented in different parts of the world. Similarly, Smart Grid related projects are being rolled out in New Zealand. It is noted that the distribution companies in New Zealand currently use different communication technologies for SCADA communication, monitoring, control and protection signaling. On the other hand, the New Zealand Government is investing on Ultra-Fast Broadband (UFB) and has an objective for 2019 to reach up to 75% of New Zealanders with fibre-optic.

2. Objectives and Organization

Internationally, countries are working or planning to implement advanced ICTs in their electrical power system infrastructure. New Zealand is one that has already started implementing the advanced ICTs for network operation. Hence, a detailed survey has been carried out on present communication technologies followed by different distribution companies and their plan for future communication system up-gradation [5].

This report would address the current ICT practices which are being implemented/planned in New Zealand and would be compared with practices followed by the rest of the world. In addition to this, Smart Grid applications would also be addressed with the help of already executed projects in other countries. The document is organized as follows.

Section 3: addresses the conceptual network architecture for the Smart Grid like premises network, neighborhood area network and wide area network. A brief overview of communication solutions such as WIMAX, ZigBee, Z-wave, cellular technologies, PLCs etc. is also discussed.

Section 4: addresses the communication technologies that are being used / planned in other parts of the world.

Section 5: addresses the communication technologies that are being used / planned in New Zealand.

Section 6: addresses the specific Smart Grid applications which are implemented / tested abroad, which could be helpful for New Zealand.
3. Smart Grid Communication

The different stakeholders/participants in the power system industry are Generators, Transmission, Distribution, Retailers, Electricity markets and Electricity consumers. With Smart Grid in place, all these stakeholders can interact with each other using different communication technologies. A Smart Grid has different layers which enables the interaction between different stakeholders and is pictorially shown in Figure 2 [2].

<table>
<thead>
<tr>
<th>Smart Metering and Grid Applications</th>
<th>Customer Applications</th>
<th>Application Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authentication, Access Control, Integrity Protection, Encryption, Privacy</td>
<td>Security Layer</td>
<td></td>
</tr>
<tr>
<td>Cellular, WiMax, Fiber Optic</td>
<td>PLC, DSL, Coaxial Cable, RF Mesh</td>
<td>Communication Layer</td>
</tr>
<tr>
<td>Home Plug, ZigBee, WiFi, Z-Wave</td>
<td>Power Control Layer</td>
<td></td>
</tr>
<tr>
<td>WAN</td>
<td>NAN / FAN</td>
<td>Power System Layer</td>
</tr>
<tr>
<td>PMUs, Cap Banks, Reclosure</td>
<td>Switches, Sensors, Transformers, Meters, Storage</td>
<td></td>
</tr>
<tr>
<td>Power transmission / Generation</td>
<td>Power Distribution, Customer</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 2: System Architecture of Smart Grid [2].](image)

As shown in the Figure 2, Smart Grid architecture has five layers. The Power System layer represents the main functions of power system. Power control layer shows the different elements which are used to monitor and control the power system. Communication layer enables the communication between stakeholders using different communication technologies available. Security layer provides the data confidentiality, integrity, authentication and availability. Application layer provides different Smart Grid applications to its stakeholders. The Communication layer shown above plays a vital role in connecting all other layers together, enabling the communication and making the traditional grid to Smart Grid [2] [3].

3.1. Communication Network Architecture

The communication network architecture which connects all the stakeholders together is pictorially represented in Figure 3. The overall architecture can be divided into three main network areas as Premises Network, Neighborhood / Field Area Network (NAN / FAN) and Wide Area Network (WAN).
3.1.1. Premises Network

Premises Network furnishes the communication link between many electric appliances that are being connected such as electric vehicles, automated lightning etc. It is the end user part of the Smart Grid. Premises Network can be divided into Home Area Network (HAN), Business Area Network (BAN) and Industrial Area Network (IAN) [3].

Located in customer domain, HAN offers access to in-home smart devices and appliances. IED send data readings over HAN to AMI applications through the home smart meter or through the residential gateway. The HAN offers also different services to home automation network like home monitoring and control, demand response applications allowing efficient power management and user comfort [4]. Light control sensors, temperature and humidity sensors, remote care and control sensors, motions sensors, and security and safety sensors are among the various sensors that can be find in home automation network.

BAN and IAN networks refer to HAN parallel networks when implemented respectively in business/buildings or industrial areas. Due to its simplicity of application for a big number of
nodes, simple configuration, and cost effectiveness, wireless technology is the most suitable communication technology in premises networks [4]. Any individual in-home appliance generates specific data flow and may have particular communication requirement, but in general in-home wireless solution should be realized with multipath environment due to surface reflection and interference with other smart devices at home. It is anticipated that in near future smart meters to control some appliances in order to reduce energy use and aggregate loads through the AMI networks and to enable the customers to use the advantages of lower tariff and optimized energy cost at off-peak time [4].

3.1.2. Neighborhood / Field Area Network

Neighborhood / Field Area Network would cater the communication link between Smart or Advanced meters at a neighborhood level or devices like IEDs and field level [5]. A NAN which is in fact a distribution domain network can be considered as a mesh of smart meters. It connects the AMI applications access point to smart meters in customer domain and various gateways in the distribution domain. The main purpose of this network is data collection from smart meters for monitoring and control. Both wired and wireless communication technologies could be used for NAN networks. While wired technologies such as PLC and Ethernet could be the right solutions for NAN networks, WiMAX, 3G and 4G are the candidate wireless communications technologies [4].

FAN is the other communication network for distribution domain in the smart grid. The control centers use FAN networks to collect data, monitor and control different applications in distribution domain such as IED devices, PHEV charging stations, AMI applications in NAN networks and wireless sensor networks in feeders and transformers [4].

3.1.3. Wide Area Network

The Wide Area Network (WAN) is the final stage of the network architecture that connects Neighborhood / Field Area Network to the utility. It is composed of backhaul network and core network. The core network connects substations to utility systems, and backhaul network offers the connectivity between the NAN network and the core network. Different technologies such as WiMAX, 4G, and PLC could be used in WAN networks. Virtual technologies like IP/MPLS could also be used for the core network [4].

As it was mentioned different communication technologies are available to communicate in each network area and to interact between each other. The existing communication technologies can be broadly classified into Wireless communication and Wired / Wireline communication. The
different communication options available under each group are explained in the subsequent section of the report.

3.2. Wireless Communication Technologies

Wireless communication is considered as one of the fastest growing sectors in communication industry. This technology makes use of electromagnetic signals to connect and communicate with devices in a wireless form. Hence this technology does not require cables. The positioning of wireless nodes can be flexible and located as per the requirements and reach. With the help of this flexibility, wireless communication could reach the places which are cumbersome for wired communication to reach [3]. With this advantage, Wireless communication is getting popular and many advanced technologies are being evolved with better speed and reach. This section would explain the available Wireless communication technologies which can be used for WAN / LAN / HAN of Smart Grid.

3.2.1. Z-Wave

Z-Wave was initially developed by Zensys Inc and later it was acquired by Sigma Designs in 2008 [3, 6]. Z-Wave makes use of ITU-T G.9959 rPHY/MAC with protocol stack from Sigma Designs and uses low power sub 1 GHz RF and works within a mesh topology. The mesh topology of Z-Wave enables each device within a Z-Wave network to relay signals to other devices which makes network to be extended easily. 232 nodes (Z-Wave devices) can be connected to a Z-Wave hub [7].

Z-Wave offered a low data rate of 9.6 kbps. Later, it was extended to 40 kbps. Z-Wave 400 series also supports 2.4 GHz band and 200 kbps data rate. Its reach is limited to 30m indoor and could extend up to 100m in outdoor [8]. It currently utilizes the 908.4 MHz ISM band in the USA and 921.4 MHz band in New Zealand [9]. Z-Wave’s application space is home automation, light commercial, hospitality and some power metering [7].

3.2.2. Bluetooth

Bluetooth technology was initially developed by Ericson during 1994. Later, Bluetooth Special Interest group (SIG), Inc., was founded during 1998, a not for profit, non-stock corporation which is established to maintain and enhance the technology [8, 10]. Bluetooth follows IEEE 802.15.1. Blue tooth does not have a meshed network like other wireless technologies. Bluetooth uses 2.4 GHz spectrum and it can transmit data at a speed of approximately 1 Mbps with a reach up to 100m [11].
“Pairing” of two devices and establishing communication between them is very easy in Bluetooth. Since Bluetooth addresses are not encrypted, it is exposed to attacks (like viruses). The advantage of Bluetooth is that most of the computers and smart phones have the feature of Bluetooth and can communicate which makes it easy to integrate the controls to HAN with the devices that are already in use [11].

3.2.3. ZigBee

ZigBee is a reliable, cost effective and low power, two-way wireless communication standard developed by ZigBee Alliance, based on IEEE 802.15.4 standard. ZigBee uses 13 channels in the 915MHz band (North America), one channel in the 868 MHz band (Europe) and 16 channels in the 2.4GHz (ISM band worldwide) with DSSS modulation technique [3]. ZigBee offers 250kbps data rate at 2.4 GHz (16 Channels), 40 kbps per channel at 915 MHz (10 Channels) and 20 kbps at 868 MHz (1 channel). Transmission reach can vary from 10 m to 100 m which depends on power output and environmental characteristics [12].

ZigBee has a wireless mesh network in which multiple links connect each node and connections are dynamically updated and optimized. ZigBee meshed networks are de-centralized and each node has the capability to manage itself in dynamic conditions and has the ability to self-route and establish connection with new nodes as per requirement [8]. ZigBee relies on 128 bit AES encryption for security which also includes a 32 bit message integrity code (MIC) and a frame counter to address reply concerns [11].

3.2.4. WiMax

WiMax (Worldwide Inter-operability for Microwave Access technology) is a mode of wireless communication medium under IEEE 802.16. WiMax uses 2.5 GHz spectrum, which makes it less prone to interference from other sources and wireless devices [11]. The maximum theoretical data rate for WiMax is 75 Mbps and could reach up to 100 km [2] [4]. WiMax uses strong AES encryption method for security and also includes key management and authentication [11].

WiMAX also offers flexible broadband links and low latency (10-50ms). The bandwidth, flexibility and the range of WiMAX provide an acceptable substitute for last-mile access in comparison to the traditional cable, DSL and T1 communication channels. As WiMAX was initially intended for Wireless Metropolitan Area Networks (WMANs); it is therefore one of the promising solutions for Smart Grid NANs or WANs [3].
3.2.5. Wireless Mesh Network

Wireless mesh network is one of the easily deployable and cheaper communication technologies which can cover larger area. Wireless mesh network is the accumulation of mutually supportive wireless access points which can be arranged in such a manner to allow multiple paths back to a physical location, which is either a wired network or wireless hotspot. Wireless mesh networks are based on 802.11 protocols with the addition of some means of routing control [11].

Wireless mesh network has two major categories [13]:

- **Broadband Wireless Mesh**: These systems have sufficient transport capacity to backhaul a high amount of data with multiple RTU devices.
- **Narrowband Radio Frequency (RF) Mesh**: Narrowband wireless mesh technology is normally termed as RF mesh system. Its capacity is sufficient enough to connect individual devices with moderate data transmission requirements.

3.2.6. Cellular

Available communication technologies under cellular communication are 2G, 2.5G, 3G, 3.5G and 4G. Initially this technology was designed to support mobile communication services in 1980s. 2G standards such as GSM, IS-36, and IS-95 were rolled out in 1990s which could only cater for voice communications. With the evolution of 2.5G standards such as GPRS and EDGE, transmission of data by cellular networks was made possible. However, 3G and 4G mobile technologies now enable higher data rates and roaming capabilities. This presents the opportunity to use cellular technologies as a communication methodology in the Smart Grid vision [3].

Data rates for different cellular technologies are as follows:

- 2G: 14.4 kbps
- 2.5G: 144 kbps
- 3G: 2 Mbps
- 3.5G: 14 Mbps
- 4G: 100 Mbps

These cellular technologies have coverage up to 50 km [2].

3.2.7. Cognitive Radio Networks

Cognitive radio technology is a stand-alone radio based on IEEE 802.22 and enables the secondary users to access the spectrum when it is not used by the primary licensed user.
efficiently without causing any interference with primary users. This spectrum sensing technique could be widely deployed in Smart Grid WAN, backhaul and distributions networks over large geographic area. Cognitive radios make the smart grid “smarter” and provide to it more security, scalability, robustness, reliability and sustainability [4].

3.2.8. DASH7

Dash 7 is a technology for wireless sensors networks based on ISO/IEC 18000-7 standard and promoted by Dash 7 Alliance. It operates at a 28 kbps rate up to 200 kbps and it has coverage of about 250 m extendable to 5 km [4]. The dash 7 uses very small amount of energy for wake up signal up to 30-60 mW and it is low latency with around 2.5-5 s. It is widely deployed for military application and also commercial applications such building automation, smart energy, smart home, PHEVs, logistics control and monitoring. Dash 7 seems to be a suitable alternative to ZigBee [4].

3.3. Wired Communication

Wired or Wire line communication is a communication technology in which data is transmitted through the lines or cables. This technology requires the physical interconnection between two nodes to enable the data transfer between the nodes. Due to this requirement, wire line communication is expensive compared to the wireless communication. However, wireline communication offers higher data transmission rates and shorter delay compared to wireless communication. This section of the report addresses the different technologies in wireline communication available for Smart Grid.

3.3.1. Fibre-Optic

Fibre-Optic is one of the leading and much talked wireline communication technologies. Fibre-optic system consists of a transmitting device which converts an electrical signal into a light signal. This light signal is transmitted through the fibre-optic cable and finally the light signal is converted back to electrical signal. Fibre optic has many advantages over metallic based communications such as long distance signal transmission, larger bandwidth, light weight, non-conductivity and security [14]. Optical fibre networks differ based on the network topology and the technology used; such as PON (Passive Optical Network), WDM (Wavelength Division Multiplexing) and SONET (Synchronous Optical Network).

A Passive optical network is an architecture that brings fibre cabling to home using a point to multipoint scheme which enables a single optical fibre to serve multiple premises. It uses
passive elements like splitters and combiners and hence called as Passive Optical Network. Gigabit Passive Optical Network (GPON) is a standard which differs from PON and offers higher bandwidth and higher efficiency using larger variable length packets [15].

Optical Fiber Wavelength Division Multiplexing (WDM) is a standard which is achieved through refraction and diffraction technique for combining and separating optical signals for different wavelengths [16].

Synchronous Optical Networking (SONET) and Synchronous Digital Hierarchy (SDH) are standardized multiplexing protocols which transfer multiple digital bit streams over optical fiber using lasers or light-emitting diodes [17]. Data rates for different protocols are as follows [2].

- PON: 155 Mbps-2.5Gbps
- WDM: 40Gbps
- SONET/SDH: 10Gbps

### 3.3.2. DSL

Digital Subscriber Line (DSL) uses telephone lines for transferring the data. It is a high speed connection to internet that utilizes the twisted-pair copper wires which is mainly used to carry telephone signals. These pair of copper wires has the necessary required bandwidth to carry both data and voice. Since voice signals uses only a fraction of available bandwidth, data transfer through DSL can be maximized by utilizing the available bandwidth [3].

DSL includes a series of technologies such as HDSL (High bit-rate DSL), SDSL (Symmetric DSL), ISDN DSL (Integrated Services Digital Network DSL), RADSL (Rate Adaptive DSL), ADSL (Asymmetric DSL) and VDSL (Very high bit-rate DSL). Different DSL technologies, their speed and distances are tabulated in Table 1 [3].

<table>
<thead>
<tr>
<th>DSL Type</th>
<th>Max. Send Speed</th>
<th>Max Receive Speed</th>
<th>Max Distance</th>
<th>Lines required</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADSL</td>
<td>800 kbps</td>
<td>8 Mbps</td>
<td>18,000 ft</td>
<td>1</td>
</tr>
<tr>
<td>HDSL</td>
<td>1.54 Mbps</td>
<td>1.54 Mbps</td>
<td>12,000 ft</td>
<td>2</td>
</tr>
<tr>
<td>IDSL</td>
<td>144 kbps</td>
<td>144 kbps</td>
<td>35,000 ft</td>
<td>1</td>
</tr>
<tr>
<td>MSDSL</td>
<td>2 Mbps</td>
<td>2 Mbps</td>
<td>29,000 ft</td>
<td>1</td>
</tr>
<tr>
<td>RADSL</td>
<td>1 Mbps</td>
<td>7 Mbps</td>
<td>18,000 ft</td>
<td>1</td>
</tr>
<tr>
<td>SDSL</td>
<td>2.3 Mbps</td>
<td>2.3 Mbps</td>
<td>22,000 ft</td>
<td>1</td>
</tr>
<tr>
<td>VDSL</td>
<td>16 Mbps</td>
<td>52 Mbps</td>
<td>4,000 ft</td>
<td>1</td>
</tr>
</tbody>
</table>
3.3.3. Power Line Communication (PLC)

Power Line Communication (PLC) uses power lines as a communication channel for transmission of data. With the advantage of widespread availability of the electrical infrastructure, PLC reduces the deployment costs compared to other wired solutions as the only additional cost originates from deploying new modems to the electric grid. However, data signals cannot propagate through transformers and hence the power line communication is limited between transformers. It is considered to be suitable solution for Premises Networks, NANs and FANs. It can also operate over high voltage lines as well [3].

PLC technologies can be further classified into narrowband PLC (NB-PLC) and broadband PLC (BB-PLC). NB-PLC is known to operate usually below 500 kHz and BB-PLC is known to operate at frequencies about 1.8MHz. Some broadband PLC systems operate in the 230MHz band and can achieve data rates up to 200Mbps. Three PLC standards possibly used in the Smart Grid vision are IEEE P1901, ITU-T G.hn, and ANSI/CEA 709[3].

IEEE P1901 is a broadband over power lines (BPLs) standard. BPL is designed to have high data transmission rates beyond 100Mbps while using frequencies below 100MHz. ITU-T G.hn communication standard was originally developed for residential premises, small-scale offices, hotels, etc. G.hn technology is able to transmit data over various types of in-home wiring such as phone line, power line, coaxial cable, and Cat-5 cable, with expected high data rates as high as 1Gbps. It can also support up to 250 nodes. ANSI/CEA-709 series of standards have been developed for home control and automation. The 709.1 standard (also known as Lonworks) became an international standard in 2008. It operates in the frequency range of 115 to 132MHz and it is known to support up to 32,000 nodes [3].
4. Worldwide ICT Practices

As mentioned in the earlier sections, various communication technologies are available and being developed. It is to be noted that the communication technologies used by the utilities are differing mainly due to the availability of wide range of communication technologies and based on the utilities requirements. This section of the report would address the communication technologies required for WAN, NAN and HAN based on the literatures and international practices. The major available wired communication technologies that can be used for Smart Grid are copper pair communication, Power Line Communication and Optical Fibre communication. Out of these, PLC communication can be implemented at low cost considering the fact that the infrastructure is already available. PLC could be a best fit for HAN and NAN (up to 3 km) and the cheapest option [2] [33]. Optical fibre communication can be used in different topologies and it is mostly preferred for longer distances and for WAN [2]. Summary of communication technologies with advantages and disadvantages are tabulated in Table 2.

Table 2: Summary of communication technologies for Smart Grid [4]

<table>
<thead>
<tr>
<th>Family</th>
<th>Coverage</th>
<th>Application</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLC</td>
<td>NB-PLC: 150 km BB-PLC: 1.5 km</td>
<td>NB-PLC: AMI, FAN, WAN BB-PLC: HAN/AMI</td>
<td>Communication infrastructure is already established, Low cost, Separation from other communication networks</td>
<td>Non-interoperable High signal attenuation Channel distortion Interference with electric appliances and electromagnetic sources High bit rates difficulties Complex routing</td>
</tr>
<tr>
<td>Fiber</td>
<td>Between 10 km and 60 km depends on standard used</td>
<td>WAN AMI</td>
<td>Very Long-distance Ultra-high bandwidth Robustness against interference</td>
<td>High costs Difficult to upgrade Not suitable for metering applications</td>
</tr>
<tr>
<td>DSL</td>
<td>Between 300 m and 7 km depends on the variant used</td>
<td>AMI FAN</td>
<td>Commonly deployed for residential users Infrastructure is already established</td>
<td>High prices to use Telco networks Not suitable for long distances</td>
</tr>
<tr>
<td>WiFi</td>
<td>Between 300 m outdoors and up to 1 km depending on versions</td>
<td>V2G HAN AMI</td>
<td>Low-cost network deployment and equipment’s flexibility Has several use cases</td>
<td>High interference High power consumption Simple QoS support</td>
</tr>
<tr>
<td>WiMAX</td>
<td>Between 10 km and 100 km depends on performance</td>
<td>AMI FAN WAN</td>
<td>Suitable for high range of simultaneous Longer distances comparing with WiFi Connection-oriented Sophisticated QoS</td>
<td>Complex Network management High cost of terminal equipment Licensed spectrum use</td>
</tr>
<tr>
<td>3G</td>
<td>HSPA+: 0–5 km</td>
<td>V2G HAN AMI</td>
<td>Supports millions of devices Low power consumption Cellular SG specific service solutions High flexibility, suitable for Different use cases</td>
<td>Could have High prices for the use of Telco Operators networks Licensed spectrum use Latency</td>
</tr>
</tbody>
</table>
All the available communication technologies are tabulated together along with the respective network topology to which it can be applied and is presented in Table 3.

**Table 3: Communication technologies and Network topology [2]**

<table>
<thead>
<tr>
<th>Communication Technology</th>
<th>Network topology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HAN / BAN / IAN</td>
</tr>
<tr>
<td><strong>Wireline Communication</strong></td>
<td></td>
</tr>
<tr>
<td>Fibre Optic</td>
<td>✔</td>
</tr>
<tr>
<td>DSL</td>
<td></td>
</tr>
<tr>
<td>Coaxial Cable</td>
<td></td>
</tr>
<tr>
<td>PLC</td>
<td>✔</td>
</tr>
<tr>
<td>Ethernet</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Wireless Communication</strong></td>
<td></td>
</tr>
<tr>
<td>Z-Wave</td>
<td>✔</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>✔</td>
</tr>
<tr>
<td>ZigBee</td>
<td>✔</td>
</tr>
<tr>
<td>WiFi</td>
<td>✔</td>
</tr>
<tr>
<td>WiMAX</td>
<td></td>
</tr>
<tr>
<td>Wireless Mesh</td>
<td>✔</td>
</tr>
<tr>
<td>Cellular</td>
<td>✔</td>
</tr>
<tr>
<td>Satellite</td>
<td></td>
</tr>
<tr>
<td>Cognitive Radio Networks</td>
<td></td>
</tr>
<tr>
<td>Dash7</td>
<td>✔</td>
</tr>
</tbody>
</table>
Further, the communication technologies used in different parts of the world are analyzed and presented below.

The communication technologies used / planned for Smart Grid in European countries differs with each other slightly. It is noted that [34],

- Germany has a mix of PLC and GPRS (in pilots) and will continue to complete roll out. PLC is considered due to the low cost, but bandwidth is the concern.
- Netherland prefers PLC for cost, reliability and control.
- Sweden, Denmark and Finland have a mix of PLC and GPRS with PLC as preferred option due to its cost.
- In France, PLC is being tested in pilot projects. However other technologies are being analysed for complete roll outs.
- Spain has identified PLC as the preferred option.
- UK has used GPRS during pilots (and interest for PLC). UK prefers either Radio Frequency mesh or GPRS for complete roll out.

Table 4 is a consolidated presentation of the preferred / tested communication technologies for NAN / FAN in various countries.

Table 4: Preferred / tested communication technologies from various countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>PLC</th>
<th>GPRS</th>
<th>RF Mesh</th>
<th>WiMax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>✓</td>
<td>(Preferred)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Netherland</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>✓</td>
<td>(Preferred)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>✓</td>
<td>(Preferred)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>✓</td>
<td>(Preferred)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>USA</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Victoria, Australia</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
In general, PLC is the preferred communication technology for NAN / FAN in most of the European countries except UK. UK has used GPRS during pilots and prefers either Radio Frequency mesh or GPRS for complete roll out. Wireless communication technologies like RF Mesh network are preferred communication links for NAN / FAN in USA. The electricity distribution network in USA has number of small secondary transformers and each transformer serves a small number of connections (approximately 2 to 7). If PLC is used in such network configuration, then a heavy attenuation can occur, when communication signals on MV line passes through a secondary transformer to a LV line. Hence it would be difficult for distribution companies in USA to adopt PLC for their Smart Grid. On the other hand, distribution companies in Europe use large secondary transformers which can serve 100+ houses. Hence PLC can be deployed in Europe [2]. WiMax has widely been deployed in Victoria Australia by SP Ausnet. Long Term Evolution (LTE) is in limited deployment in private utility networks including Ausgrid and a partnership between Green Mountain Power and Vermont Telephone Company in USA; however it is gaining traction as the first global cellular standard because of its performance characteristics and support for IP. [35].

Fibre optic is the commonly chosen technology for WAN, since it is reliable and offers high performance [2].

5. Exiting NZ Communication Technologies

The New Zealand electricity sector is in the transition stage from traditional grid towards Smart Grid. There are many different communication technologies are being used in the traditional grid for SCADA communication, monitoring and control. Further, advanced communication links are being established as part of Smart Grid. This section of the report covers the different communication links that are currently being used or under implementation stage in New Zealand.

5.1. Fibre Optic

Most of the distribution companies in New Zealand have their own fibre-optic and/or are using leased fibre-optic. It is observed that, out of 29 distribution companies,

- 22 distribution companies (Around 75% of companies) are using Optical fibre cable as one of their communication links.
7 distribution companies (Around 25% of companies) have minimum or no Optical fibre cable in their network.

It is noted that, Fibre-optic is connected to most of the major zone substations in these distribution companies and it has been mainly used for SCADA communication (either Primary or as backup) and protection signaling [5].

Further as per the government objective, 75% of the New Zealand population should have the Ultrafast Broadband by 2019 which is also known as Fibre to the Premises (FTTP) network. This project covers 33 largest towns and cities in New Zealand.

The network which is being deployed is known as GPON (Gigabit Passive Optical Network) topology. GPON is a point to multipoint, fibre to the premises network architecture with a single optic fibre cable which is capable of providing service to multiple users. Splitters used in GPON, divide the signal from exchange normally between 32 and 64 individual houses and business units. This GPON technology can be used for both voice and broadband services. GPON topology is asymmetrical on a 2:1 ratio which means it offers twice the downstream capacity compared to its upstream. The project offers services of at least 100 Mbps downstream and 50 Mbps upstream. The upstream speed available which is minimum of 10 Mbps is much higher than that of currently used ADSL2+ copper broadband products in New Zealand [18] [19].

5.2. Communication between HAN and NAN

As part of the Advanced Metering Infrastructure, smart meters are being rolled out in New Zealand. Around 52% of the ICPs in New Zealand have smart meters. Majority of the meters are being supplied by four main meter equipment and service providers (AMS, Metrix, Arc Innovations and SmartCo) [20]. The smart meters installed require communication medium for data and information exchange. Hence, in addition to the rollout of smart meters, the communication medium required for smart meters is also being implemented. The smart meters installed in New Zealand can communicate using different communication technologies which are as follows.

- General Packet Radio Service (GPRS): Cellular transmission in 900MHz or 1800MHz frequency bands. It is a point-to-point communication from the smart meter to a cell phone tower, OR,
Radio Mesh: Radio transmission in the 900MHz frequency band – a point-to-many communication. These systems are relatively low power with a short range of a few kilometers. Information is collected into data concentration points and relayed [5].

It is noted that, Radio mesh network is being implemented in most of the distribution companies in New Zealand for communicating with smart meters. Rest of the distribution companies use GPRS for communication [5].

5.3. Other technologies

Almost all the distribution companies use radio links for voice and data communications. Commonly used radio links are VHF, UHF and Microwave radio links. Out of three, VHF and UHF are being used throughout New Zealand. Seven distribution companies (approximately 24%) are using Microwave radio links in addition to VHF and UHF. Where there are gaps in radio network, cellular communications such as 3G / GPRS is used. Further, 10 distribution companies (approximately 34%) are using copper cables for communication [5].

The existing communication technologies used in NZ by different distribution companies are pictorially shown in Figure 4.

Figure 4: Communication technologies used in NZ distribution companies

It should be noted that the communication technologies such as VHF, UHF, Microwave radio links and copper cables have played a vital role serving as communication medium in the
traditional electric grid in New Zealand. Most of the distribution companies are upgrading to fibre-optic (own links) [5].

In view of the current infrastructure, future plan of distribution companies and the mass rollout of fibre-optic by the Government of New Zealand shows that the future communication medium for WAN would mainly be Fibre optic and Cellular communications. Interaction between HAN and NAN / FAN would be either by Radio Mesh networks or through GPRS.

Compared to worldwide practices, it is noted that, Radio mesh network and GPRS are the main communication technologies that are being implemented / preferred in New Zealand distribution network for NAN and FAN. It is also observed that the Radio mesh is preferred by most of the distribution companies whereas remaining part uses / plans to use GPRS for communication [5].

6. Smart Grid Applications

As mentioned earlier, Smart Grid Communication infrastructure is classified into Premises Area Network, Neighborhood Area Network and Wide Area Network. Each network has its own range and set of suitable communication technologies to operate with. This section of the report addresses the Smart grid applications and is presented based on the type of the network.

6.1. Premises Area Network Applications

The electric power will pass through different stakeholder networks before finally being consumed at end user locations. In Smart Grid perspective, consumer will have his own network called Premises Area Network to which all the appliances are connected. Premises Area Network is further classified as HAN / BAN / IAN and it supports the communications among household appliances, electric vehicles and other electrical equipment at customer premises [2].

Smart meter plays a vital role in Premises area network. The household appliances in HAN are capable of sending and receiving signals from the smart meters, in-home displays (IHDs) and/or home energy management systems. Smart grid applications in premises area network include home automation, optimal thermostat set points for thermal zones, optimal water tank temperature set point, controlling and managing loads and providing total electricity costs. BAN and IAN are used for commercial and industrial customers, which has its applications on building automation, heating, ventilating, and air conditioning and other industrial energy management applications [2].
The premises area network is connected to utility through smart meter. With the help of communication link between customers and NAN / FAN (utility), utility can perform NAN / FAN applications in residential, commercial and industrial premises [2].

An example on HAN application is given based on the already executed project in Italy by Enel. The operator of Italian grid, Enel has performed the rollout of 32 million smart meters. The project began in 2001. Further, Enel has launched Energy@Home project is 2009. The project was aimed at developing a communication infrastructure that enables provision of Value Added Services based upon information exchange related to energy usage, energy consumption and energy tariffs in the Home Area Network (HAN). The main objective of the project was to develop a device which could increase the customer’s consciousness on their energy consumption. The architecture of the project is pictorially shown in Figure 5 [32].

![Energy@Home architecture](image)

**Figure 5: Energy@Home architecture [32]**

The Smart Info (SI) as shown in Figure 5 will collect data from the smart meter and make it available to different customer interfaces in the indoor environment (e.g. PC, TV, custom display, appliances). Customer can improve his awareness on energy consumption and cost using the information coming from grid and home itself [32]. In addition to this, Enel launched in-home displays (IHDs) to around 1000 households during 2008. The IHDs are connected to
smart meters. With the implementation of IHDs, around 57% of consumers have changed their consumption behavior [30].

6.2. Neighborhood Area Network applications

Neighborhood Area Network provides the platform for information exchange between HAN and utility (WAN). NAN includes a metering network (Smart meter and communication links), which is a part of AMI and enables the services such as remote meter reading, control and detection of unauthorized usage. It allows electricity usage information to be transmitted from Smart meters to utility and allows field devices to be controlled remotely. Smart grid applications in NAN / FAN include meter reading, distribution automation (DA), demand response (DR), prepayment, electric transportation, firmware updates and program/configuration, outage and restoration management, TOU/RTP/CPP pricing, service switch operation, customer information and messaging, and premises network administration. Typical NAN / FAN applications in terms of data sizes, data sampling requirements and latency requirements are explained below [2].

6.2.1. Meter reading

The traditional electricity meter was used to collect the usage information, based on which the billing was done. With the Advanced Metering Infrastructure in place, utility can perform real-time bidirectional communications between meters and a centralized management site, thus improving meter reading accuracy, and reducing operational costs. Meter reading has three different service types such as On-demand meter reading, scheduled interval meter reading and bulk transfer of meter reading [2].

On-demand meter reading allows readings to be taken when needed, for e.g., when the utility needs to answer customers' inquiries about their usage or to backfill missing information. A typical payload is 100 bytes for a data transmission from a meter to utility with a latency requirement of less than 15 s [2].

Scheduled meter interval reading allows to collect usage information from a meter to an AMI head end several times a day with interval usage information varying from 15 min to 1 h. These readings are normally stored in the smart meter and utility retrieves this at the later stage. Payload size depends on the number of readings collected from the meter at a given time [2].

Bulk transfer of meter reading allows a utility to collect usage information from all meters within a utility enterprise. Payload includes meter reading information from a number of meters, of which the payload size depends on the number of meters scheduled to be read [2].
6.2.2. Pricing

Pricing applications involve broadcasting of price information to meters and devices, e.g., smart appliances, plug-in hybrid electric vehicles (PHEVs) and load control devices at customer premises. These are typically associated with time-of-use (TOU), real-time pricing (RTP) and critical peak pricing (CPP) programs [2].

TOU programs allow customers to lower electric bills, as long as customers are able to shift their electricity usage to off-peak hours. Customers participating in this program typically accept different price schedules for different time periods, such as peak, shoulder, and off-peak [2].

RTP programs offer short-term time-varying pricing information, for e.g., every 5 min, 30 min or 1 hour, to end-use customers. Customers can use this information to reduce electricity bills by managing their energy consumption [2].

CPP programs are typically used during times of high peak demand. A utility needs to curtail loads and quickly sends CPP messages to enrolled customers for a radical load reduction. In these programs, customers are charged a higher price during a few hours and given a discount during remaining hours [2].

Typical data size for pricing application is 100 bytes and expects a data latency less than 1 min [2].

6.2.3. Remote Service connection / disconnection

Traditional electricity prepaid meter was measuring the usage and then deducting the credits as per the customer tariffs. The meter was issuing warnings, when the credit approaching to a threshold or zero and thereby disconnecting the service within a predetermined time. Based on successful recharge, service used to restore. In smart grid, a smart meter can effectively perform all these activities with the ability to remotely connect or disconnect the service. Typical data size for prepayment application is between 50 and 150 bytes, and the data latency requirement is less than 30 s when a utility sends information, such as price and available credit, to a customer [2].

6.2.4. Demand Response

The distribution companies can effectively utilize ICTs to manage their system loads. An Advanced Metering Infrastructure (AMI) coupled with dynamic pricing and connection to smart appliances at consumer location would help in shifting the timing of certain consumption of consumers. In addition to this, AMI can also feature the ripple control receivers which would
help the distribution company to cut off certain loads like hot water connection, street lights etc. Typical DR applications include direct load control programs for central air conditioning systems, heat pumps, electric water heaters and/or pool pumps, as well as real-time pricing and time-of-use programs. Typical data size for DR applications is 100 bytes, and the data latency requirement is less than 1 min [1] [2] [5].

Example (Executed project): A project called ADDRESS (Active Distribution network with full integration of Demand and distributed energy resources) was initiated during June 2008 in Europe. The project was aiming to study, develop and validate solutions to enable active demand and to exploit its benefits. In this context, Active demand refers to Active participation of domestic and small commercial consumers in power system markets and provision of services to the different power system participants, by means of real time (20-30min) interaction based on price and volume signals. Figure 6 shows the architecture of the project [31].

As shown in Figure 6, electrical appliances in Home Area Network are monitored and controlled by the Energy box. This is connected to the aggregator through communication channels. The aggregator has to collect the requests & signals coming from markets and other stake holders. In addition to this, the aggregator will also need to collect the flexibilities and contributions given by consumer in response to requests and signals. The aggregator uses mainly two types of signals: Real-time price signal and Real-time Volume Signal. The Distribution System Operator (DSO) can be benefitted from Demand Side Management. It can shave the peaks and postpone network reinforcements [30] [31].
6.2.5. Service Switch Operation

Utility service switch operation allows a utility to turn the service ON/OFF at customer premises. This feature enables a utility to switch a service without having to roll a service truck. This can be particularly useful for reducing service time and costs for establishing or terminating services. These applications include sending a service switch operation (service enabling/service cancelling) commands to a meter. For these applications require a typical data size of 25 bytes, and the data latency requirement of less than 1 min [2].

6.2.6. Distribution Automation

Distribution Automation (DA), provides real-time operation information of grid, information management, monitoring and control of the distribution grid. Major DA applications are distribution system monitoring and maintenance, Volt/Var control, distribution system demand response (DSDR) and fault locating, isolating and service restoration (FLISR) [2].

*Distribution system monitoring and maintenance* includes self-diagnostics on equipment, polling equipment status (open/closed, active/inactive) at scheduled intervals, and retrieving sensor data to monitor equipment conditions. Equipment to be monitored may include CBCs, fault detectors, reclosers, switches and voltage regulators [2].

*Volt/Var control* helps in adjusting the voltage along a distribution circuit and compensates the power factor [2].

*DSDR* aims to reduce distribution grid voltage to help manage system load during peak periods. It involves control of capacitor banks, automated feeder switches and voltage regulators [2].

*Fault Location, Isolation and Service Restoration (FLISR)* technology is one of the Distribution Automation (DA) tools which includes automatic sectionalizing, restoring the service by automatic circuit reconfiguration. This is achieved by coordinating operation of field services, software and dedicated communication networks to automatically determine the location of fault and rapidly reconfigure thereby changing the power flow direction so that some / all the consumers can avoid experiencing the power outages [36].

The fault is located with the help of line sensors and communicated the conditions to other devices and grid operators. After locating fault, FLISR then opens the switches on both the sides of the fault. Thus the fault is now isolated from the system. FLISR then closes the switches which are normally kept open and establishes a new path for the flow of power through alternate feeder.
FLISR improves network reliability by reducing SAIDI and SAIFI, intelligently reconfigures the feeders and also improves the power quality. It expedites fault detection and location and helps in quickly restoring the services [37].

In USA, under Smart Grid Investment Grant (SGIG) funding has accelerated the application of FLISR technologies. The experience of 5 utilities conducting smart grid projects (CenterPoint Energy, Duke Energy, NSTAR electric company, Pepco holdings Inc. and Southern Company) are discussed in this section. The project FLISR is known in different names and utilities use different devices to achieve that which are tabulated in Table 5 [36].

Table 5: Overview of FLISR projects in some of the Utilities in USA [36]

<table>
<thead>
<tr>
<th>Features</th>
<th>CenterPoint</th>
<th>Duke</th>
<th>NSTAR</th>
<th>PHI</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of FLISR System</td>
<td>Self-Healing Grid</td>
<td>Self-Healing</td>
<td>Auto Restoration</td>
<td>Automatic Sectionalizing &amp; Restoration (ASR)</td>
<td>Self-Healing Networks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Teams</td>
<td>Loops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Devices Involved</td>
<td>Intelligent Grid Switching Devices (IGSDs) act as switching devices and monitoring equipment</td>
<td>Electronic reclosers, circuit breakers, and line sensors</td>
<td>Telemetry communications, line sensors, and “smart” switches</td>
<td>Substation breakers, field switches, reclosers, and “smart” relays</td>
<td>Automated switches/reclosers, and fault indicators</td>
</tr>
<tr>
<td>Mode of FLISR Operation</td>
<td>Manual validation required</td>
<td>Fully automated</td>
<td>Transitioned to full automation during the project</td>
<td>Fully automated</td>
<td>Fully automated</td>
</tr>
<tr>
<td>Location of FLISR Operations</td>
<td>Dedicated server; to be transitioned to DMS</td>
<td>Dedicated self-healing application</td>
<td>DMS</td>
<td>Dedicated server in the substation</td>
<td>Dedicated server or DMS</td>
</tr>
</tbody>
</table>

Mostly, the field devices and field installed electronic reclosers & switches use digital-cell or radio communications. These five projects provided quantitative metrics for 266 FLISR operations collectively implemented between Aril 2013 and March 2014. During this time period, FLISR reduced the number of customers interrupted (CI) by up to 45%, and reduced the customer minutes of interruption (CMI) by up to 51% for an outage event [36].

In NZ, Unison networks is implementing FLISR and the project is known as Self-healing Network. It comprises of sensors, automated controls, and advanced software that utilizes real-time distribution data to detect and isolate faults and to reconfigure the distribution network to
minimize the customers impacted [20]. Unison networks prefers Mesh radio network as communication link for FLISR [37].

Based on the projects executed in USA which are mentioned above, it is learnt that the communication medium plays a vital role in the success of FLISR operations. These utilities found that communication networks require greater resilience than power delivery systems because they must be able to control automated switches under conditions where the grid system is damaged or not functioning properly due to downed lines, faults, or other grid disturbances. Utilities with legacy communication networks should conduct evaluations and implement upgrades before deploying FLISR technologies and systems [36].

A typical data size for DA applications ranges from 25 bytes to 1000 bytes, and the data latency requirement is less than 4–5 s [2].

6.2.7. Power Quality

An adequate power quality guarantees the necessary compatibility between all equipment connected to the grid. Hence it is an important aspect for the successful and efficient operation of the Power system [26]. Sensors which are installed across the network would help in measuring the various characteristics such as voltage, temperature etc. This improved monitoring gives also a better visibility of real-time power quality that is being delivered to consumers. The smart meters are able to calculate the average value of RMS voltage over a period which can be configured, can record the value calculated, be able to detect when the value calculated is above or below the threshold values and send an alert signal to HAN interface. Based on the local voltage deviation detections, smart meters can trigger events to alert the local grid operator. These events could either generate a request to automatically increase the sampling rate in the affected area or be forwarded to a grid operator for manual decision making. Thereby ICTs can not only help in improving the quality of power being supplied, it also offers greater potential for early problem identification and preventive maintenance [5].

Power quality measurements can also be used to identify the fault related conditions such as high impedance faults and developing faults. With the help of Smart Grid, power quality measurements (Voltage and current) can be taken. Process involves trending of the power quality data. This is one way of tracking developing faults due to insulation breakdown. Further, this data can also be used for tracking sources of harmonic distortions [25].
With the implementation of Telegestore project, Enel has gained approximately €500 million in year savings, with a 5 year payback period, and a 16% internal rate of return. The minutes of interruption per year has decreased from 128 min (2001) to 42 min (2011) [30].

6.2.8. Distribution Customer storage application

This can address the operational challenges faced by utility by providing power, energy and fast response to a distribution network allowing an efficient integration of renewable energy resources. These storage applications include the use of storage devices installed along distribution feeder circuits for peak load shaving, voltage support, power quality, demand control, and interruption protection. Typical data size is 25 bytes for a charge / discharge command from a Distribution Application Controller (DAC) to a distribution customer storage, and the data latency requirement is less than 5 s [2].

6.2.9. Energy Storage

Integration of large scale renewable energy projects has posed various operational challenges. The main challenge is intermittent generation from renewable energy projects which necessitates the operator to switch the generation schedule rapidly. This issue could be resolved by managing the power flow between grid and electric car. The schemes like G2V (Grid to Vehicle), V2G (Vehicle to Grid) and V2H (Vehicle to Home) rely on ICT for managing and controlling the power flow. These schemes also require an end user interface (at consumer location), through which the system operator can give signals to vehicles (consumers) to absorb the power when the system generation is high (renewable energy penetration is more) [1] [5].

A Vehicle-to-Grid (V2G) demonstration project executed by AC Propulsion, Inc was launched in California, USA. A VolksWagen Beetle car has been utilized in the study. The vehicle was equipped with a wireless modem which allows remote dispatch of V2G functions through internet. It is expected that a huge number of electric vehicles would be connected to the grid in near future, due to which it would not be possible for the grid operator to interact with individual vehicle. Hence Aggregator is introduced which would appear to be a large source of rapidly controllable generation or load and would manage the interactions between the grid operator and the connected vehicles. Architecture of Vehicle based grid regulation system is pictorially shown in Figure 7 [2] [23].

The aggregator would contract with the grid operator through day ahead and hour ahead markets to provide the regulation capacity. The grid operator would send the regulation
commands to the aggregator and based on that, aggregator would allocate the required regulation to the connected vehicles. Aggregator uses GPS to keep track of the vehicles and gets the location information which is required to identify area in which the vehicle is connected [2] [23].

Control commands can be sent through Wireless communication to vehicle based on the power requirement and knowledge of vehicle battery current state-of-charge (SOC). Wireless link between the vehicle and the aggregator server is always on TCP/IP connection. The aggregator would be an intermediary entity which provides service to grid operator and would be paid for its service. Aggregator would share the value created with the connected vehicles. A typical payload is 100–255 bytes for electric transportation applications, and the data latency requirement is less than 15 s [2] [23].

![Vehicle based grid regulation system](image)

**Figure 7**: Vehicle based grid regulation system [23]

### 6.2.10. Protection

Protective relays are basic requirement for any power system to provide quality and reliable power supply. The transition of protection relays from electro-mechanical to programmable relays took place in most of the places and now majority of the relays are programmable. The characteristics of protection relaying such as Selectivity, Sensitivity and Speed can be enhanced with availability of advanced communication technologies. Some of the relaying applications which can make use of the Smart Grid communication infrastructure are given below [25].
Protection relay settings are based on the static configuration of the network. Relays are set such that it will be sensitive and selective under any operating conditions. Modern relays will have settings groups which can be selected based on defined set of conditions. New setting will increase the sensitivity while maintaining its selectivity. Smart Grid can help in determining the setting group scenarios and drive when to dynamically change the settings as per operating condition.

Auto-reclosure settings are static and cannot be adjusted based on the operating scenario. By receiving real-time data, it is now possible to adjust the settings in real-time.

Some of the protective relaying such as differential protection has its elements geographically apart and requires sample synchronization for proper decisions. Smart Grid infrastructure can provide accurate time for these protection relays.

As the penetration of distributed generation connected to a radial feeder increases, then Smart Grid infrastructure with the help of SIPS (System Integrity Protection Schemes) has to initiate targeted and coordinated control actions such as generation rejection, reactive power control, system separation etc.

Changes to Conservation Voltage Reduction settings based on real-time operating conditions.

Locating the fault by gathering the information through various devices such as relay, reclosure, smart switch control, line faulted circuit indicators (FCIs), smart meters, SCADA, fault recorders and substations controllers.

In the LV network, the protection systems are required to act in less than 100ms. Considering this aspect and based on the data rate of the different communication technologies [3] the applicable technologies to LV networks include PLC, WiMax, and public cellular data services. WiFi is also applicable if the system is cyber secured and is technically achievable through highly developed telecommunication networks.

The protection system in MV network has to act in the possible minimum time and a data rate of minimum 1Mbps is required for this. Hence, copper pair and Fiber optic from the wired technologies and WiMax and public cellular data services from wireless group are among the suitable communication technologies in MV network. VHF /UHF can be used for the distances close to the control center located in the substation. However, IEC61850 is emerging as communication standard for the different purposes in distribution systems and it is expected that in future all distribution IEDs will be compatible to this standard.
6.2.11. Remote monitoring and Control of irrigation pumps

A large-scale pilot project was carried out by Siemens and Amperion for the Public Power Corporation (PPC) Greece, aiming to provide remote monitoring and control of irrigation pumps. The main objective of the project was to reduce the electricity consumption during peak hours and to detect the power outages and availability of the network in rural area of Central Greece. Siemens and Amperion designed and implemented the embedded telecommunications on the medium voltage lines with a span of 107 km, which was based on Broadband Power Lines (BPL) technology. BPL units were organized into cells to allow network scalability [2] [24].

A hybrid Wireless- Broadband Power line (W-BPL) solution, which combines the power distribution grid with Wi-Fi is also deployed which enables point to point connections to neighboring BPL cells. The W-BPL network is further connected to Network Operating center which is installed inside substations and provides the connection to utilities remote operating center via Virtual Private Network. The applications delivered in this project include [2] [24]:

- Load management (remote control switches that controls agricultural loads within milliseconds)
- AMI
- RF Noise level measurements (Fault prediction)
- Wireless Cameras Surveillance
- Measurement of the LV grid (Voltage, Current and Temperature)
- Telecom applications (VoIP, Internet)

6.3. Wide Area Network Applications

Wide Area Network supports the real-time monitoring, control and protection applications corresponding to the wider area i.e. utility, which can help prevent cascading outages with real-time information related to the state of the power grid. These wide area applications offers higher data resolution and shorter response time than SCADA and EMS systems. Wide area monitoring, control and protection provide high resolution data of 60 samples per second. The preferred communication technologies for WAN applications are Fibre Optic in Wireline category and WiMax and Cellular communication in Wireless communication category [2].

The above explained Smart grid applications are summarized in Table 6.
Table 6: Summary of Smart grid applications [2]

<table>
<thead>
<tr>
<th>Application</th>
<th>Typical data size (bytes)</th>
<th>Typical data sampling requirement</th>
<th>Latency</th>
<th>Communication technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Premises Area Network</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Home automation</td>
<td>10-100</td>
<td>Once every configurable period</td>
<td>Seconds</td>
<td>Wireline: PLC, Ethernet; Wireless: Z-Wave, Bluetooth, ZigBee, WiFi</td>
</tr>
<tr>
<td>2) Building automation</td>
<td>&gt;100</td>
<td>Once every configurable period</td>
<td>Seconds</td>
<td>Wireline: PLC, Ethernet; Wireless: ZigBee, WiFi, Wireless mesh</td>
</tr>
<tr>
<td><strong>Neighborhood Area Network</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a) Meter reading – (on-demand (from meters to utility)</td>
<td>100</td>
<td>As needed (7 am–10 pm)</td>
<td>&lt; 15 s</td>
<td>Wireline: DSL, Coaxial cable, PLC, Ethernet; Wireless: ZigBee, Wireless Mesh, WiFi, WiMax, Cellular</td>
</tr>
<tr>
<td>1b) Meter reading – scheduled interval (from meters to AMI head end)</td>
<td>1600–2400</td>
<td>4–6 times per residential meter per day (24 x 7) 12 - 24 times per commercial/industrial meter per day</td>
<td>&lt; 4 h</td>
<td></td>
</tr>
<tr>
<td>1c) Meter reading – bulk transfer from AMI head end to utility</td>
<td>x per day for a group of meters (6 am–6 pm)</td>
<td>&lt; 1 h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a) Pricing-TOU (from utility to meters)</td>
<td>100</td>
<td>1 per device per price data broadcast event 4 per year (24X7)</td>
<td>&lt; 1 min</td>
<td></td>
</tr>
<tr>
<td>2b) Pricing-RTP (from utility to meters)</td>
<td>100</td>
<td>1 per device per price data broadcast event 6 per year (24X7)</td>
<td>&lt; 1 min</td>
<td></td>
</tr>
<tr>
<td>2c) Pricing-CPP (from utility to meters)</td>
<td>100</td>
<td>1 per device per price data broadcast event 2 per year (24X7)</td>
<td>&lt; 1 min</td>
<td></td>
</tr>
<tr>
<td>3) Electric service prepayment (from utility to customers)</td>
<td>50-150</td>
<td>25 times per prepay meter per month (7 am–10 pm)</td>
<td>&lt;30s</td>
<td></td>
</tr>
<tr>
<td>4) Demand response – DLC (from utility to customer devices)</td>
<td>100</td>
<td>1 per device per broadcast request event (24 x 7)</td>
<td>&lt; 1 min</td>
<td></td>
</tr>
<tr>
<td>5) Service switch operation (from utility to meters)</td>
<td>25</td>
<td>1–2 per 1000 electric meters per day (8 am–8 pm)</td>
<td>&lt; 1 min</td>
<td></td>
</tr>
<tr>
<td>6a) Distribution automation – (distribution system monitoring and maintenance data from field devices to DMS)</td>
<td>100 - 1000</td>
<td>CBC: 1 per device per hour (24 x 7) Feeder fault detector: 1 per device per week (24 x 7) Recloser: 1 per device per 12 h (24 X 7) Switch: 1 per device per 12 h (24 X 7) VR: 1 per device per hour (24 X 7)</td>
<td>&lt; 5 s</td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>Typical data size (bytes)</td>
<td>Typical data sampling requirement</td>
<td>Latency</td>
<td>Communication technologies</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
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<td>---------------------------</td>
</tr>
</tbody>
</table>
| 6b) Distribution automation – Volt/VAR control (command from DMS to field devices) | 150-250                   | Open/close CBC: 1 per device per 12 h (24 x 7)  
Open/close Switch: 1 per device per week (24 x 7)  
Step up/down VR: 1 per device per 2 h (24 x 7) | < 5 s   |                           |
| 6c) Distribution automation – distribution system demand response (DSDR) (command from DMS to field devices) | 150-250                   | Open/close CBC: 1 per device per 5 min  
Open/close switch: 1 per device per 12 h  
Step up/down VR: 1 per device per 5 min (1–6 h duration, 4–8 times a year) | < 4 s   |                           |
| 6d) Distribution automation – FLISR (command from DMS to field devices)     | 25                         | 1 per device per isolation/reconfiguration event (<5 s, within <1.5 min of fault event)            | < 5 s   |                           |
| 7) Outage and Restoration Management (ORM) (from meters to OMS)              | 25                         | 1 per meter per power lost/ power returned event (24 x 7)                                         | < 20 s  |                           |
| 8) Distribution customer storage (charge/discharge command from DAC to the storage) | 25                         | 2–6 per dispatch period per day (discharge: 5 am–9 am or 3 pm–7 pm; charge: 10 pm–5 am)          | < 5 s   |                           |
| 9a) Electric transportation (utility sends price info to PHEV)               | 255                        | 1 per PHEV per 2–4 day (7 am–10 pm)                                                              | < 15 s  |                           |
| 9b) Electric transportation (utility interrogates PHEV charge status)         | 100                        | 2–4 per PHEV per day (7 am–10 pm)                                                                | < 15 s  |                           |
| 10) Premises network administration (from utility to customer devices)       | 25                         | As needed (24 x 7)                                                                               | < 20 s  |                           |
7. Conclusion

This report was prepared with the intention of addressing the New Zealand’s current ICT infrastructure. In this regard, a brief introduction of Smart Grid architecture was discussed. This architecture has three major components as Premises Area Network, Neighborhood Area Network and Wide Area Network. Further different communication technologies available for developing the Smart Grid infrastructure were discussed. Available Wired communication links are Fibre-optic, PLC, DSL etc. Similarly, wireless communication links available are WiMax, ZigBee, Z-Wave, cellular communication and Radio mesh networks. With the brief introduction to these Smart Grid solutions, current ICT infrastructure in NZ and other countries were discussed. At the end of the report, Smart Grid applications were presented. Most of the applications are presented with the help of already executed projects / pilot projects across the world.

This report would provide a brief idea about the smart grid communication requirements and its applications. Further, the communications used in HAN, NAN/ FAN in New Zealand was compared with the practices followed by the rest of the world with an emphasis of NAN / FAN applications, which would be useful for NZ distribution utilities.

It was noted that, PLC is the preferred communication technology for NAN / FAN in most of the European countries except UK. UK has used GPRS during pilots and prefers either Radio Frequency mesh or GPRS for complete roll out. Wireless communication technologies like RF Mesh network are preferred communication links for NAN / FAN in USA. WiMax has widely been deployed in Victoria Australia by SP Ausnet. Long Term Evolution (LTE) is in limited deployment in private utility networks including Ausgrid and a partnership between Green Mountain Power and Vermont Telephone Company in USA; however it is gaining traction as the first global cellular standard because of its performance characteristics and support for IP. Fibre optic is the commonly chosen technology for WAN, since it is reliable and offers high performance.

Compared to the worldwide practice, it was noted that, Radio mesh network and GPRS are the main communication technologies that are being implemented / preferred in New Zealand distribution networks. It was also observed that the Radio mesh is preferred by most of the NZ distribution companies whereas GPRS is used by rest of the companies.
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