TOWARDS A TRULY SMART GRID —

THE CASE FOR BROADBAND OVER POWER LINE

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Towards a Truly Smart Grid — The Case for Broadband over Power Line

Introduction

Technological change and the pressing need to concurrently address the challenges of energy security, affordability, and environmental sustainability are driving a profound renewal of the power grid. After having served us well for more than a century, grids will have to cope with a significantly higher set of expectations. Accommodating active market participation of energy consumers, resilience to attacks and disturbances, the electrification of energy use, and the integration of distributed resources are but a few examples of what will be asked of future grids.

Adapting to this new scenario, smart grids will need to handle vast amounts of information. Especially at the medium voltage (MV) and low voltage (LV) levels of the electricity networks, the need to monitor and control an ever-increasing number of devices brings about radical changes. With system complexity elevated to new levels, the importance of connectivity technologies is vital.

In this context, power line communications (PLC) and more specifically broadband over power line (BPL) are gaining momentum, offering a good balance of technical capabilities (e.g., low latency, high availability) and cost, as this technology uses existing power line wiring to transmit the signal.

This paper seeks to answer the following questions:

- How does BPL fit in the current smart grid connectivity landscape?
- What is the motivation behind BPL adoption?
- What BPL use cases is the industry creating critical mass around?

To provide answers to these questions, the PoweRline Intelligent Metering Evolution (PRIME) Alliance commissioned IDC to conduct a study on BPL and its use in smart grid applications for the purpose of identifying drivers, challenges, and opportunities related to this technology. Key findings of the study, involving a diverse set of utilities and vendors, suggest that:

- Most utilities indicate that smart grid communication is in transition from narrow to broadband and the industry is at an inflection point in the adoption of BPL technology. Out of 17 utilities interviewed, only four are using BPL today, but the majority are testing or planning to deploy it soon.
- The implementation of BPL for smart meter connectivity (or advanced metering infrastructure — AMI) and the ability to use BPL for sensoring purposes in Low Voltage Networks without any additional devices are the main use cases for BPL. In this context, the use of BPL can be seen as a first step towards the automated, decentralized management of intermittent energy and utility-operated microgrids. The BPL smart meter gateway is also an interesting use case for utilities. This is designed specifically to help

utilities manage the evolving customer-centric energy ecosystem with a high degree of IT security.

- The performance of BPL technology varies significantly depending on the communication standard used, and making the right choice of technological solution is critical for success. So far, all three utilities that have used BPL in mass rollout use the UPA standard with the same product and semiconductor vendors. However, a multivendor ecosystem based on a common standard with interoperability and certification is necessary for a comprehensive rollout of BPL in the market.
- BPL technology is being standardized for four different use cases by the PRIME Alliance through a utilities-led effort. The ITU-T G.hn series was chosen as the technology basis for the standard.
- The cost of BPL solutions will be driven down by increased performance, competition, and utilities adoption. The business case for BPL is improving significantly as the growing need for higher data throughput reduces the cost per transaction.
- Large utilities have already worked with vendors to develop complex solutions with software platforms and mature technology that they can efficiently deploy themselves. It is beneficial to learn from their experience.

New Challenges Met by a Familiar Technology

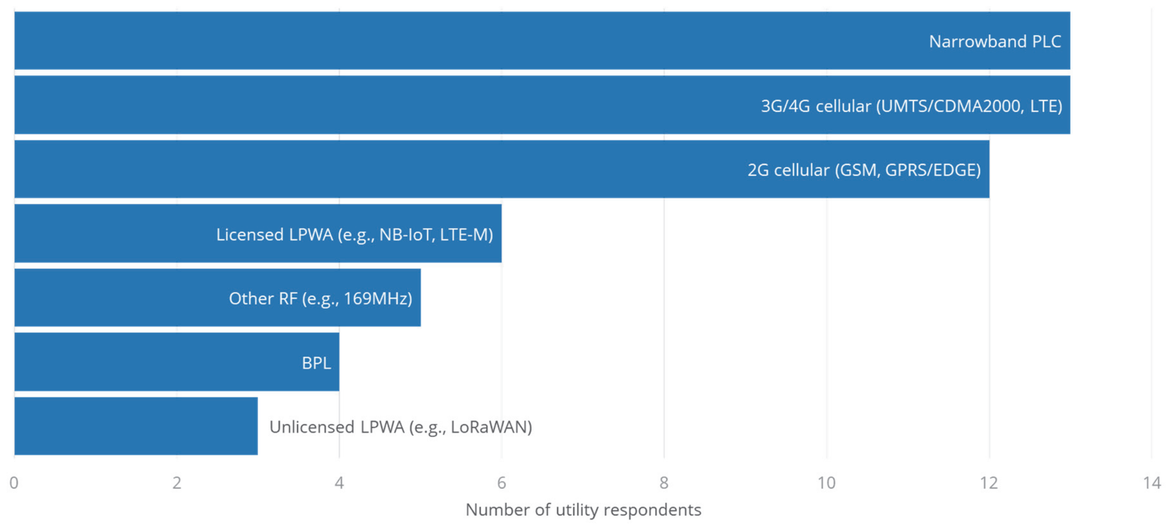
While there is no clear definition of a "smart grid," the term is commonly used to refer to a new generation power grid capable of acting as the backbone of modern energy systems. To effectively solve the previously described energy trilemma of security, affordability, and environmental sustainability, bidirectional information flowing between grid users and operators as well as locally between grid users is quintessential. And, as the system becomes more complex, this exchange should and will become more granular and as close as possible to real time.

A wide and evolving variety of technologies contribute to define the connectivity layer of a smart grid. Depending on the application and grid hierarchy, these can range from fiber optics, DSL, and PLC to public cellular, WIMAX, low-power wide-area (LPWA) mesh and short-range radio technologies over licensed and unlicensed spectrums. These technologies can broadly be divided in two large groups: wireless and wired technologies. Their use by utilities that took part in our study is found in Figure 1. The following section focuses on PLC and dives deeper into BPL, highlighting some of the advantages of this technology.

FIGURE 1

Smart Grid Connectivity Standards

Q: What smart grid connectivity technologies does your company use today?



Source: Towards a Truly Smart Grid — The Case for Broadband Over Power Line, IDC 2021 (n=17)

Digging deeper into PLC

Using bandwidth as a criterion to classify PLC technologies, Narrowband PLC (NB-PLC) refers to systems that use frequencies between 3 kHz and 500 kHz. These bands include the European CENELEC bands (3-148.5 kHz), the US FCC band (9-500 kHz), the Chinese band 3-500 kHz, and the Japanese ARIB band (10-450 kHz). Data rates of these technologies reach 500 kbps. Taking a closer look at the most used technologies:

- Open Smart Grid Protocol (OSGP) was initially promoted by Echelon and since 2014 by its spinoff Networked Energy Services Corporation. It uses single-carrier modulation, and presents its highest penetration rates in the Netherlands and Scandinavia. More than 5 million OSGP-based devices are deployed worldwide.
- Meters and More (M&M) is a technology promoted by an association with the same name, led by the Enel group. The solution uses single-carrier modulation and is widely adopted in the countries where Enel is present, predominantly in Italy and Spain. More than 50 million M&M meters are deployed worldwide.
- G3-PLC is a standard developed by EDF and Maxim. It uses OFDM to allow a more efficient use of the spectrum. The transmission speed is higher than the previously mentioned technologies. This technology is predominantly used in France where almost 30 million G3-PLC smart meters are deployed as part of the Linky project. It is also deployed in other countries, such as Austria.
- PoweRline Intelligent Metering Evolution (PRIME) is a standard promoted by the PRIME Alliance, led by Iberdrola and other European distribution system operators (DSOs) such as E.ON, E-Redes, Energa Operator, and Naturgy. As with G3-PLC, multicarrier OFDM modulation is used, and in its latest specification (PRIME Version 1.4) this technology

reaches data rates that are significantly higher (up to 1Mbps) than its previously described NB-PLC counterparts. Over 20 million PRIME smart meters are installed worldwide.

BPL, on the other hand, operates in the 2-250 MHz frequency band and its data rates range from a few Mbps to 1 Gbps. A set of different technologies exists, the following being the major ones:

- IEEE 1901 (operating between 2 MHz and 50 MHz) and ITU-T G.hn (operating between 2 and 100 MHz) are standards operating at similar frequency bands, but they have very different performances in utility applications and are not interoperable. Data rates can be as high as 500 Mbps and 2 Gbps respectively. Both have distinct variants for in-home networking and smart grid applications, the key difference being that smart grid applications require narrower bandwidth for better propagation and signal resilience. Operating frequencies for IEEE 1901 are 2-50 MHz for home networking, and 2-30 MHz for smart grid applications.
- HomePlug is another BPL technology, specified by the HomePlug Alliance industry association and fully interoperable with IEEE 1901. Its various specifications have notably different data rates that do not exceed 500 Mbps and target applications related to the IoT.
- IEEE 1901a, also known as HD-PLC, operates between 2 and 28MHz. As a modulation scheme the wavelet-OFDM modulation method is being used. In the case of HD-PLC, the Wavelet-OFDM allows it to achieve a theoretical maximum data transmission rate of 240 Mbps.

Vendor Ecosystem

While several semiconductor vendors that emerged in the past have been acquired by larger suppliers, the history of the BPL ecosystem is a testament to the industry's long-standing interest in the technology.

In the IEEE 1901 standard camp, Qualcomm and Broadcom are the two main suppliers of home networking chips, after their respective acquisitions of Atheros in 2011 and Gigle Network in 2010. ST Microelectronics also develops IEEE 1901 semiconductors for the in-home market. Only one vendor (MStar) supplies IEEE 1901 chips developed for access network applications, with PPC as a key customer. MStar obtained its IEEE 1901 and HomePlug technology via its 2011 acquisition of SPiDCOM.

In Asia, Vertexcom Technologies supplies chips for IEEE 1901.1, which is compliant with China's CGCC Q/GDW 11612 standard. An IEEE 1901-based solution is also offered by Huawei, with strong traction in China but few deployments elsewhere.

Panasonic is the major chipset manufacturer for IEEE 1901a.

In the ITU-T G.hn standard, one branch of semiconductor development originated in Spain. Diseño de Sistemas en Silicio (DS2), which developed the UPA and later the ITU-T G.hn standard, was acquired by Marvell Technology Group in 2010 and then by MaxLinear in 2017. In the same year, after several years of cooperation, Corinex acquired all the DS2 software for UPA smart grid applications from MaxLinear. A second branch of BPL development started with the 2009 acquisition of home networking system-on-chip developer CooperGate Communications by Sigma Designs (SD), which was in turn acquired by Integrated Silicon Solutions (ISSI) in 2018. ISSI has developed a chip compliant with ITU-T G.hn, thus becoming the second viable silicone vendor. The third significant semiconductor branch is represented by the High-Definition Power Line Communication (HD-PLC) Alliance, with semiconductor provider Megachip, and key product vendor Panasonic.

Over the past decade, companies in both the telecommunications and the utilities industries have invested heavily in BPL products. While the resulting vendor ecosystem is small, due to the ongoing technology challenges that are detailed in the remainder of this report, vendors like Corinex have managed to support utilities in their massive BPL deployments using UPA chips from MaxLinear.

TABLE 1
BPL Standards and Vendor Ecosystem

STANDARD	SEMICONDUCTOR PROVIDER	PRODUCT VENDOR
IEEE 1901 — ACCESS NETWORKS	MSTAR	PPC
IEEE 1901 — IN-HOME NETWORKS	QUALCOMM, BROADCOM	DEVOLO
HD-PLC	MEGACHIP	PANASONIC
UPA	MAXLINEAR	CORINEX, DEFIDEV
ITU-T G.HN	MAXLINEAR	CORINEX
ITU-T G.HN	LUMISSIL/ISSI	PPC, EFR

Why BPL?

As smart grid applications proliferate, so does the need for broadband bidirectional communication for those applications. Besides technical aspects such as reliability, data rate, latency, coverage range, and security, there are also operational aspects (e.g., integration with existing and new technologies, safety of grid operation under dynamic loads and generation) and business aspects (e.g., support of legislative requirements, new business models and operation cost) that need to be addressed carefully.

The rise of distributed energy resources (DERs) in general, and prosumers more specifically, is a great example of how different power grids are now compared to their recent past. Reliable and efficient consumption and generation measurements are a prerequisite for managing DER or enabling demand response. In a similar vein, electric vehicles (EVs) ideally need to be charged monitoring both vehicle and grid parameters to balance local loads and use power capacity efficiently.

These drivers request the sensing capabilities of the past on high voltage (HV) be brought to the MV and LV segments of the grid at a fraction of the cost. BPL technology enables utilities to collect data on voltage levels, phase angles, harmonics and temperature while providing connectivity for other applications. Further data like phase angles and harmonics are in technical development. In addition, by using existing infrastructure and enabling end-to-end control of grid communications, BPL also helps DSOs operate independently of third-party communication service providers.

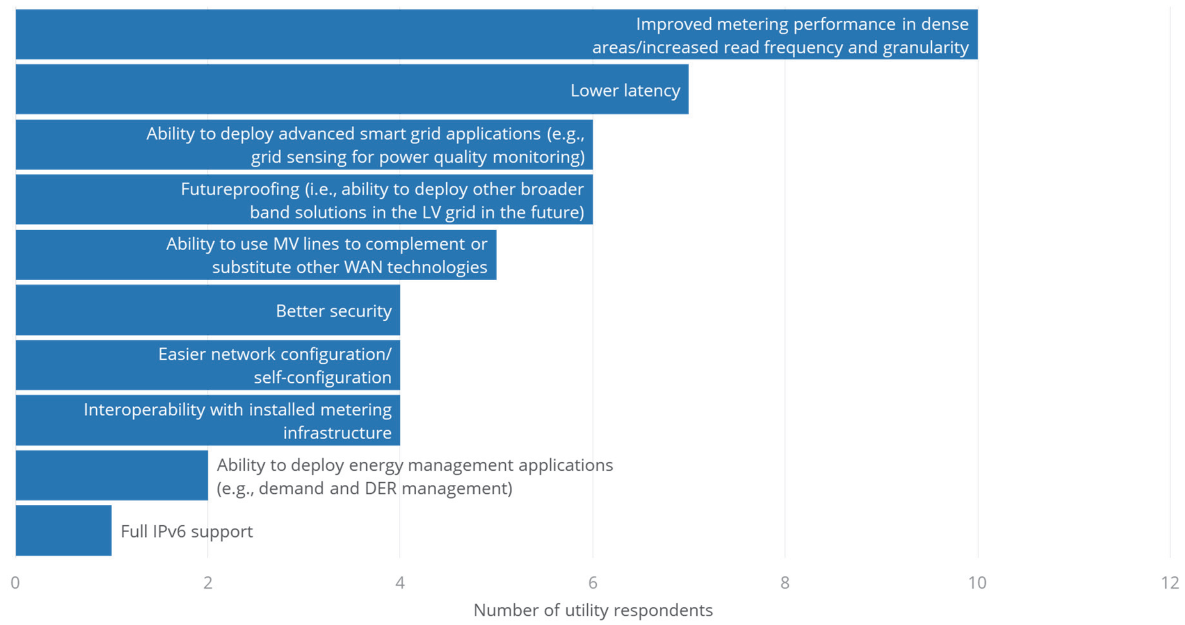
A vivid example of how the energy system is changing is provided by new legislation introduced in the EU such as Directive 2019/944 (on common rules for the internal market for electricity) or Directive 2018/2001 (on promotion of the use of energy from renewable sources) to enable broader consumer participation in the electricity market. These directives entail, for example, the right for consumers to self-generate, store, and sell excess production via power purchase agreements, suppliers, and peer-to-peer trading. They also ensure the availability of near real-time consumption data to foster participation in demand response through aggregation. BPL is well positioned to address these requirements for high-speed communication on the LV grid by implementing smart meter technology in existing or new edge computing architectures. Its higher data throughput is a growing benefit as the number of transactions increases with the participation of prosumers and growing penetration of DERs (Figures 2 and 3).

Another driver for BPL is the need to apply security protocols in the network to address growing data protection and cybersecurity requirements, such as those enshrined in the EU's General Data Protection Regulation (2016/679) and the proposed EU Network Code on Cybersecurity.

FIGURE 2

DSO Perception of BPL Benefits

Q: What are the primary benefits you expect from deploying BPL (or are already experiencing as a result of your BPL deployment)?



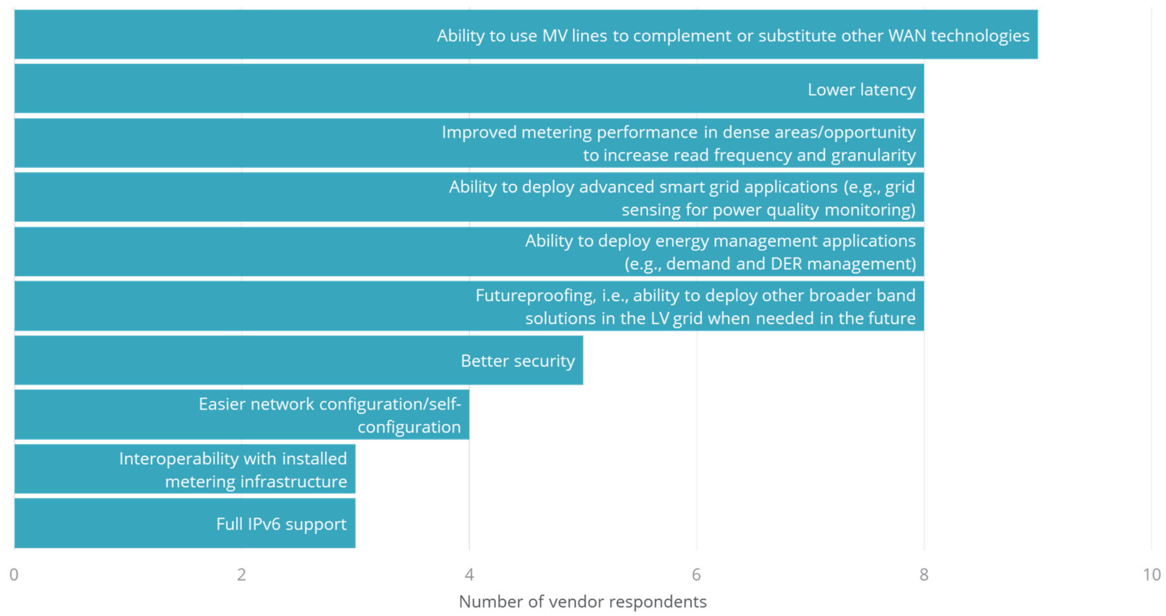
Source: Towards a Truly Smart Grid – The Case for Broadband Over Power Line, IDC 2021 (n=11)

MV lines present grid operators with interesting applications for BPL such as remote control and fault detection. Lower signal attenuation, potentially simplified network topology without branches, and fewer sources of noise make BPL a good match for MV applications. This is recognized by the vendor community, which sees great potential in the market for BPL deployments at the MV level, while utilities already feel a need to make broadband connectivity available at the LV level, especially for improving smart metering performance in dense environments.

FIGURE 3

Vendor Perception of BPL Benefits

Q: What are the primary benefits your clients expect from deploying BPL (or are already experiencing as a result of your BPL deployment)?



Source: Towards a Truly Smart Grid – The Case for Broadband Over Power Line, IDC 2021 (n=14)

The need for lower latency, but also cybersecure communication, will top the priorities list of future smart grids. BPL semiconductors have significant computational power that enables the future implementation of edge computing, AI, and even blockchain applications in BPL nodes.

As the technology continues to improve and performance requirements in the grid continue to grow, BPL will offer a better trade-off between data rate, latency, and robustness. The ongoing effort to validate and standardize the BPL solution by utilities through the PRIME Alliance will educate the industry, increase competition by improving technology transparency, and introduce real interoperability, ultimately reducing implementation risk.

Interpretation of Ongoing Challenges

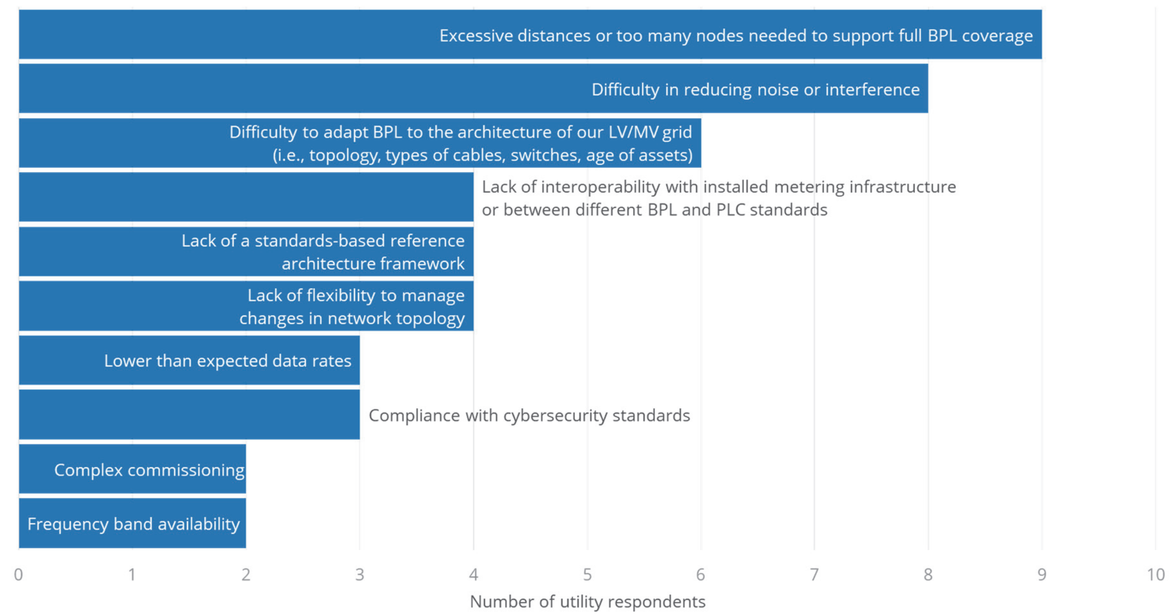
Companies in the vendor ecosystem have carried out several trials with utilities over the years and, as shown in Figure 1, four of them have now adopted BPL.

According to utilities, while one of the challenges to deploying BPL technologies is interoperability, the key obstacle seems to be a concern over the technology's performance (Figure 4). Despite this, utilities are continuing to validate the technology even before full standardization. Those that succeeded in their pilot projects and eventually moved to mass rollouts chose the same product and semiconductor vendor.

FIGURE 4

DSO Perception of BPL Challenges

Q: What are the primary challenges you expect from deploying BPL (or are experiencing as a result of your BPL deployment)?



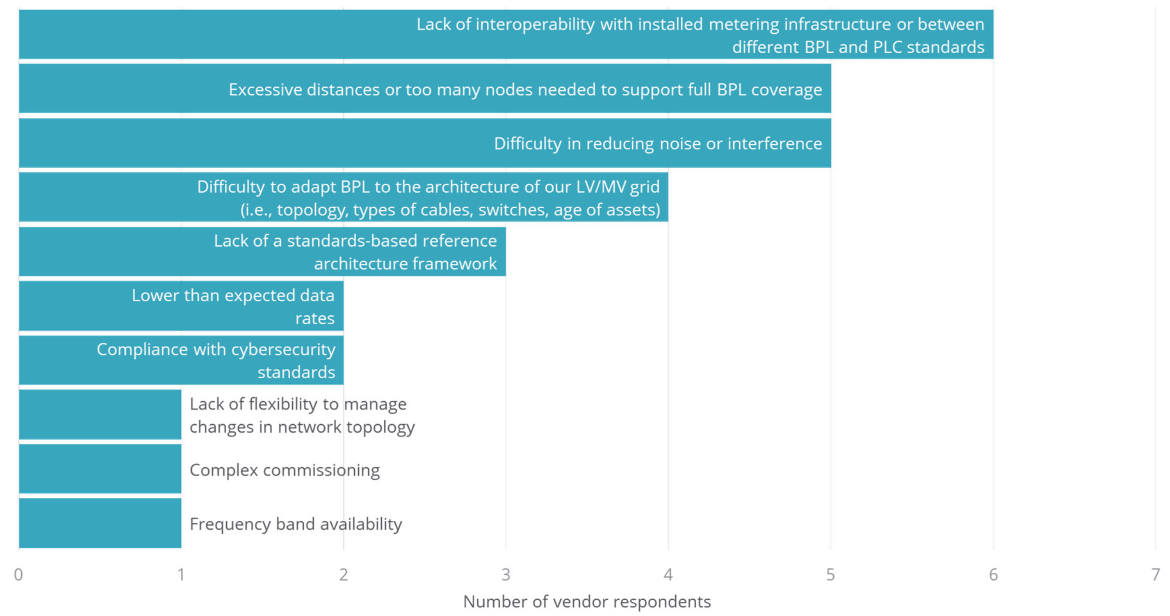
Source: Towards a Truly Smart Grid – The Case for Broadband Over Power Line, IDC 2021 (n=14)

The lack of interoperability, on the other hand, is the vendors community's primary concern when asked about the challenges of deploying BPL (Figure 5). Vendors rank performance-related issues as being less important for successful deployment. This points to a disconnect in the understanding of their utility clients' needs. The perception is that the negative attitude towards the technology's performance expressed by some utilities is linked to many vendors having failed to demonstrate success at the pilot stage.

FIGURE 5

Vendor Perception of BPL Challenges

Q: What are the primary challenges your clients expect from deploying BPL (or are already experiencing as a result of your BPL deployment)?



Source: Towards a Truly Smart Grid – The Case for Broadband Over Power Line, IDC 2021 (n=14)

The interest of utilities in using BPL and a desire to deleverage the risk associated with their investments is what led the PRIME Alliance to work on the technology. As a vendor-agnostic organization, PRIME Alliance focuses on interoperability and validation of the performance of communication technologies in the interests of utilities.

The organization decided to standardize BPL in 2018 to provide technological clarity in applications and performance for its members. To do so, it established a BPL Task Force chaired by Corinex. After evaluating the existing technologies based on the experience of its members, as an interim solution it recommended the use of products from vendors using the UPA BPL standard as validated by Iberdrola, E.ON, and CEZ. The Corinex UPA solution was used in those utilities and future deployments are open to all vendors supporting G.hn standard.

PRIME Alliance is now in the process of standardizing the next generation of the technology. As a first step, in December 2018, it standardized four use cases and set the technology's performance requirements for each of them.

- **Use Case #1**: **BPL Smart Meters with BPL Concentrator**, enabling a full BPL metering chain, including a BPL smart meter as end point and data concentrator as controller. The meter can be used for edge computing applications.
- **Use Case #2**: **Coexistence of BPL and NB-PLC**, a similar use case as number 1, enabling grid operators to use broader-band LV BPL concentrators and gateways with their installed base of NB-PLC smart meters.

- **Use Case #3**: **BPL Smart Meter Gateway** (as defined by Germany's Federal Office for Information Security BSI), enabling load management functionality beyond metering, including distribution automation and monitoring (e.g., voltage sensing) and beyond-the-meter connectivity to the home area network for demand and DER management and tariff information through low-latency broadband IP-based communication.
- **Use Case #4**: **BPL on MV Lines**, enabling grid operators to backhaul traffic from concentrators and aggregate other data communication using MV lines as a multi-service backbone to complement or substitute other smart grid wide area network (WAN) technologies.

TABLE 2

PRIME BPL Use Cases and Requirements

<table>
<tr><th></th><th>FEATURE</th><th>USE CASE 1</th><th>USE CASE 2</th><th>USE CASE 3</th><th>USE CASE 4</th></tr>
<tr><td>1</td><td>MAX # OF BPL NODES IN NETWORK</td><td>1000</td><td>50</td><td>20</td><td>100</td></tr>
<tr><td>2</td><td>MAX # OF HOPS TO HEAD-END</td><td>16</td><td>16</td><td>10</td><td>10</td></tr>
<tr><td>3</td><td>DATA RATE BETWEEN TWO NODES @ 20DB ATTENUATION</td><td colspan="4">100 MBPS</td></tr>
<tr><td>4</td><td>DATA RATE BETWEEN TWO NODES @ 70DB ATTENUATION</td><td colspan="4">50 MBPS</td></tr>
<tr><td>5</td><td>MINIMUM BANDWIDTH FOR LINK ESTABLISHMENT @ 70DB</td><td colspan="4">5 MHZ</td></tr>
<tr><td>6</td><td>MAX POWER SPECTRAL DENSITY MASK</td><td colspan="4">COMPLIANT WITH ITU G.9964</td></tr>
<tr><td>7</td><td>THROUGHPUT IN 5-HOP LINEAR TEST</td><td></td><td></td><td>5 MBPS</td><td></td></tr>
<tr><td>8</td><td>PING LATENCY IN 5-HOP LINEAR TEST</td><td></td><td></td><td>100 MS</td><td></td></tr>
<tr><td>9</td><td>THROUGHPUT IN 30-NODE NETWORK TEST</td><td></td><td></td><td></td><td>100 KBPS</td></tr>
<tr><td>10</td><td>PING LATENCY IN 30-NODE NETWORK TEST</td><td></td><td></td><td></td><td>500 MS</td></tr>
<tr><td>11</td><td>THROUGHPUT IN 50-NODE NETWORK TEST</td><td></td><td>64KBPS</td><td></td><td></td></tr>
<tr><td>12</td><td>PING LATENCY IN 50-NODE NETWORK TEST</td><td></td><td>500 MS</td><td></td><td></td></tr>
<tr><td>13</td><td>THROUGHPUT IN 1000-NODE NETWORK TEST</td><td>1 KBPS</td><td></td><td></td><td></td></tr>
<tr><td>14</td><td>THROUGHPUT IN 500-NODE NETWORK TEST</td><td>5 KBPS</td><td></td><td></td><td></td></tr>
<tr><td>15</td><td>PING LATENCY IN 1000-NODE NETWORK TEST</td><td>2500 MS</td><td></td><td></td><td></td></tr>
<tr><td>16</td><td>THROUGHPUT IN NOISE TEST</td><td colspan="4">10 MBPS</td></tr>
<tr><td>17</td><td>NETWORK SETUP TIME IN A NETWORK WITH N NODES</td><td colspan="4">120 + 5*N SECONDS</td></tr>
<tr><td>18</td><td>ENCRYPTION</td><td colspan="4">AES-128</td></tr>
<tr><td>19</td><td>QOS</td><td colspan="4">8-LEVEL</td></tr>
<tr><td>20</td><td>VLAN</td><td colspan="4">SUPPORTED</td></tr>
</table>

Source: PRIME Alliance

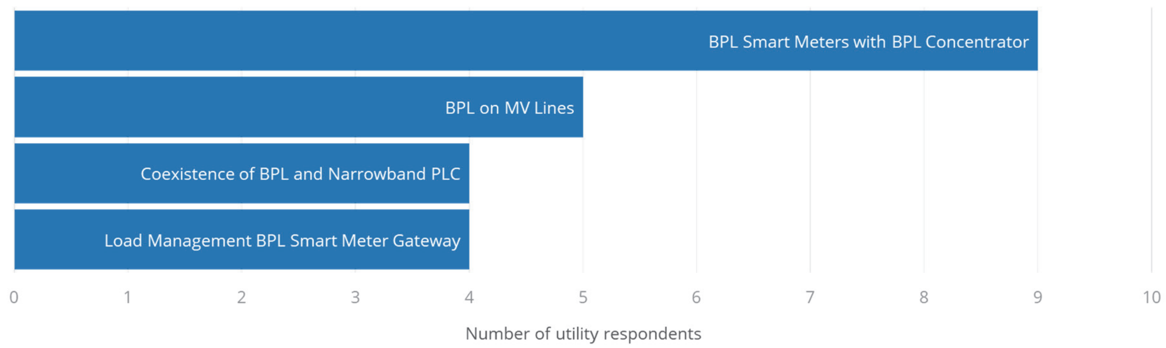
Where to Implement BPL

Mass rollouts of BPL started at the MV level, where there was a need for more bandwidth. This need is now extending to the LV level of the grid with significant demand for a full BPL smart metering chain (Figure 6) where market trends support the utilities' need for high data transfers, low latency, and requirement-based security. In fact, most utilities participating in the study expect to deploy BPL in LV projects. This represents the inflection point for the BPL industry, as metering infrastructure is the number one volume driver for technology providers.

FIGURE 6

Use Case Adoption Among DSOs

Q: Which use cases do you expect to be deploying BPL for in the future (or are already using BPL for)?



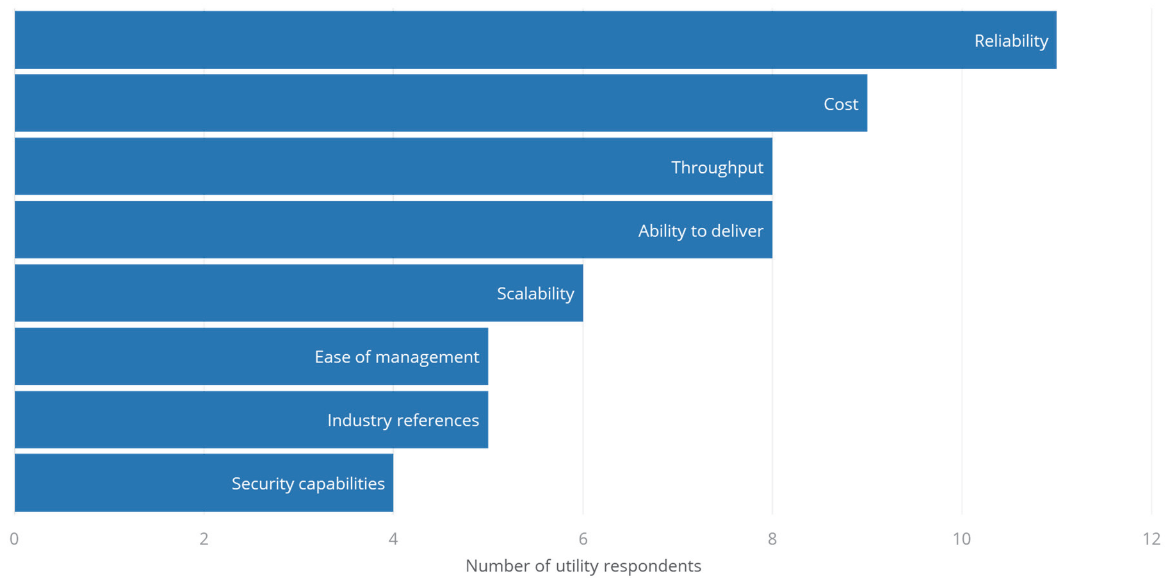
Source: Towards a Truly Smart Grid – The Case for Broadband Over Power Line, IDC 2021 (n=11)

Turning to vendor selection, most utilities consider reliability the most important criterion when evaluating potential BPL partners. Figure 7 shows that many utilities are evaluating vendors without necessarily seeking industry references. This may explain why several trials carried out by utilities independently with various vendors have had limited success. Only three utilities are carrying out mass BPL rollouts based on already available BPL systems and, after testing multiple vendors, they all chose a single product and semiconductor vendors strategy based on the UPA standard despite their interest in achieving real interoperability and coexistence of multiple vendor products in the future g.hn standard.

FIGURE 7

Criteria for Vendor Selection

Q: What will be (or have been) the most important criteria used for evaluating BPL vendors?



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Bringing Value to Smart Meter Investment

At the core of a smart grid lies the evolution towards an efficient, decentralized grid, capable of managing a massive number of devices with limited human intervention. Smart meters are integral to virtually every definition of smart grid and are universally recognized as the first step towards building one.

Twenty years have passed since Enel started deploying smart meters under the scope of the "Telegestore" project in Italy. Finland and Sweden were among the forerunners of smart metering worldwide and, together with Italy, are now deploying their second-generation devices. Similar initiatives were launched during the 2000s across North America and Australia. Driven by national mandates, several DSOs followed during the last decade in Europe, China, and Japan. As the technology evolved, what started with the main objective of reading meters remotely and reducing non-technical losses is now facilitating more complex use cases.

Despite the common wisdom regarding the benefits of smart metering, the actual drivers, key technical constraints such as the grid topology, and choice of communication technology differ widely across the globe. In Europe, the adoption of the Third Energy Package in 2009 required Member States to conduct a cost-benefit analysis for smart metering deployments and in the case of a positive outcome, set the objective to reach a penetration rate of 80% for electricity meters by 2020. Elsewhere, the motivation behind smart metering has been the need to enhance the stability of the energy system (e.g., in California) or combat energy theft.

Similarly, the architecture of the electricity system varies. While in Europe a single secondary substation may serve more than a hundred consumers, in the U.S. this figure is normally a lot lower, sometimes even in the single digits. In addition, the regulation of public band frequencies in Europe is more stringent than in the US or in Japan. All this has had a strong impact on the selection of smart metering communication technologies.

BPL Use Case #1: Combining the Power of BPL with Data Concentrators and Smart Meters

Currently, the NB-PLC technology dominates smart meter deployments, especially in Europe. The low deployment and operational cost, sufficient performance, and wide ecosystem support and device availability have led many DSOs to choose one of the PLC standards described above. However, required data rates for future use cases are on the rise. With wider consumer participation in energy markets, utilities must now start to accommodate new needs and data requirements. The use of dynamic pricing programs for demand response and peak shaving or use of vehicle-to-grid (V2G) technology to provide congestion management and voltage control services to the DSO are good examples of such new and emerging applications.

At a very basic level and in terms of communication, smart grids are hierarchically structured in area networks positioned at different voltage levels with varying degrees of data rate requirements. At the "last mile," or the so-called neighborhood area network (NAN), data in many countries is usually transmitted from several PLC meters to a data concentrator deployed at the secondary substation.

BPL's superior throughput and most importantly low latency make it an ideal candidate for the future communication requirements of such emerging use cases. The use of BPL in the data concentrator and the smart meter allows for functionality that is currently unavailable in most current PLC setups. The LV grid infrastructure would be dynamically controlled, enabling the emergence of a next-generation smart grid. Several European utilities are validating BPL's performance and robustness compared to other technologies in ongoing pilots. BPL communication also fulfills the newest data protection and cybersecurity requirements mandated by the EU, which was also validated for several use cases.

ČEZ Distribuce

ČEZ Distribuce, a major European DSO, conducted research on various aspects of BPL in smart metering applications as early as in 2011. The initial projects focused on performance relative to narrowband communication. Later more advanced projects were carried out focusing on evaluating the impact of encrypted communication on network performance in smart metering. These included verification of the technical and operational characteristics of BPL with various levels of cryptographic algorithms and estimation of possible impacts on the connectivity of electricity meters.

It was found that encryption does not have significant influence on throughput of smart meter infrastructure parameters, but time of processing can vary significantly for the highest levels of encryption.

The LODIS project was initiated to research the feasibility of energy transmission optimization in a PV production and distribution grid. This project covered multiple villages where residential PV is popular among residents. It studied the concept that actively making 24-hour forecasts of energy consumption data available could help the system reduce peak import or export of energy from the transformer station by “starving” boilers and heaters when an energy surplus is forecast. The efficiency of such a method is influenced by the accuracy of prediction of residential load curve as well as the PV production curve. Machine learning algorithms were used to predict residential loads in the future, and combined with weather data, PV production could also be accurately forecast. As a result, peak energy outputs and inputs were reduced.

Corinex conducted research projects in CEZ.

BPL Use Case #2: Bringing the Benefits of BPL to Improve the Performance of Narrow-Band Smart Metering

The different frequency bands used by NB-PLC and BPL make their coexistence possible. For the many DSOs whose NB-PLC smart meters are not yet fully amortized, the installation of BPL devices at the aggregation points of the LV grid is a viable futureproofing strategy.

A solution that was shown to increase bandwidth about 10-fold is to deploy BPL on the LV part of the network and move narrowband concentrators into buildings. This way, all access communication is carried by BPL, while narrowband PLC is used for in-building communication from gateways to meters. This solution is being tested by a major Spanish utility.

This use case offers the possibility of not deferring any deployment, while at the same time offering an evolutionary way forward that accommodates future changes in regulation, along with growing data needs and security requirements.

Moving Towards a Decentralized Energy System

With the acceleration of PV and wind deployment in residential, commercial, and industrial settings, energy generation is becoming decentralized throughout the electricity grid. This adds to new consumption loads that cause demand fluctuations as a massive number of inverters are connected to the grid along with heat pumps, EV chargers, and storage systems. On the one hand, these energy technologies help to decarbonize production and electrify consumption; on the other, they create growing challenges to the traditional energy distribution model.

For more than a century, the traditional power distribution model relied on generating energy at central plants, distributing it throughout metropolitan areas, and finally, supplying it to end users exactly when needed, with a synchronized approach. The intermittent nature of PV and wind power generation, combined with the significant jump in loads at residential and commercial premises, means the traditional centralized power model can no longer serve today's energy dynamics. With millions of EVs and new renewable sources being integrated each year, the grid is already under severe stress in many countries. This will eventually lead to increased power quality issues, more blackouts, and accelerated aging of utility assets.

Decentralized intelligent energy infrastructure is being rolled out to add grid flexibility to address the dynamics created by these changes in energy supply and demand. This creates buffers throughout the system in the form of demand flexibility and virtual distributed power plants enabled by high-speed bidirectional communications. A decentralized energy grid contributes to building the future energy network from the bottom up rather than from the top down. In such a network, each distribution layer will try to maintain supply-demand balance by shaving demand peaks and filling troughs by aggregating and utilizing local DERs such as batteries, EVs, boilers, and heat pumps. These buffers only work effectively if there is a high-speed, consistently operational network that allows this equipment to interact as demand and supply change. Together, DERs and high-speed communication technology form the backbone of the leading utilities' decarbonization and electrification strategies.

In addition to high-speed and low latency, BPL chips have a high processing power, which if implemented at LV end points can provide new functionalities such as edge computing. This allows utilities to provide smart substation services to its customers while providing the highest data security standards. For example, a utility can target the control of a particular energy load generated by multiple large home appliances and prevent overloading the substation using a high-speed BPL communication network. The response time of BPL networks, which is mere seconds, is well suited for this application.

The Case of Germany

Germany is one of the leading countries when it comes to the penetration of distributed renewable generation (wind farms, photovoltaic cells on roof tops, etc.) and flexible loads (heat pumps, electrical vehicles, etc.) that must be integrated into the larger electrical grid. This complex future distribution network, with high concentration of distributed renewable resources, will have to meet requirements addressing cybersecurity, voltage monitoring, load scheduling, demand response, and variable tariffs. In 2019, installed renewable energy resources already represented 130% of Germany's grid peak load.

Due to these developments, on August 29, 2016, the German parliament passed a law on metering point operation and data communication in intelligent energy networks (also called MsbG — the Metering Point Operation Act), which set the regulatory conditions for future distribution networks. This law brought both new regulations for the metering point operation itself (e.g., competition in metering, regulations regarding the installation, operation, maintenance of metering points, upper fee limit for metering point operation), and for data communication in general.

According to this law, these regulatory requirements must be securely integrated into the communication network for use in intelligent energy networks and fulfill state of the art data processing requirements (e.g., data protection, data security, interoperability, use of certified smart meter gateways, smart metering public key infrastructure, transport layer security encryption). Therefore, only IP-type communication is feasible (TLS over IPv6) Specifically, the requirement for the connection of a smart meter gateway (SMGw) can be divided into two WAN services from a communication point of view:

1) Requirements from the point of view of smart meter applications (essentially reading out meter values in different qualities and frequencies), and
2) Requirements from the perspective of smart grid applications (often a combination of reading out metered values with control processes).

Both applications share a common requirement for the mass suitability of the WAN technology to be used for millions of intelligent measuring systems in the complete operational range of plan, build, and operate. A noteworthy technological requirement is the need to provide fully automated and fast commissioning of the communication component modules, as well as a mass-market management system that offers high availability performance for configuration management and fault management of deployment and operations. In addition to these necessary technical functions, which are explained in more detail bellow, the system should support interoperability as is mentioned in the MsbG to be suitable for mass deployment.

Germany has more than 40 million households. The rollout of millions of measuring systems started in 2019 and will continue for more than 10 years, and the installation of the intelligent meters will largely be carried out by centrally controlled sub-service providers. Therefore, the necessary WAN networks must, and will be, set up using multivendor solutions, and the communication components used in the intelligent measuring system, and supplied by different manufacturers, must be compatible.

BPL Use Case #3: Connecting Generation, Storage, and Consumption with a Smart Meter Gateway

BPL solutions meet the above criteria and provide unique functionality for DSOs. They enable, among other things, voltage monitoring today and in the future frequency monitoring during standard network operation. Voltage sensing enables the detection of violations in voltage bands in LV networks automatically and initiates actions to maintain LV grid operations in the defined voltage bands (topology changes, transformer taps, etc.) Ultimately, it brings more intelligence to the grid and avoids higher investments in the energy infrastructure (cables, transformers, etc.) in the grid. It proactively detects outages in LV and initiates activities for fast backup supply and proactive information about end users, resulting in a better quality of service. An additional benefit is that it reduces the system's overall CO2 footprint, as it increases network utilization and enables renewable load management in the LV part of the grid.

E.ON

In 2017, E.ON, an international energy company that serves 32 million customers across multiple countries, decided to use BPL as an important technology in its communication mix in its smart grid and smart metering communication infrastructure.

After conducting an intensive field test of various system manufacturers with very good results, an RFP for the expansion of 10,000 LV local networks was launched in May 2017. After conducting an intensive field test of various system manufacturers with very good results, an RFP for the first rollout wave with 10,000 LV local networks was launched in May 2017. A powerful network management software with interfaces to higher-level config and fault management systems enables the administration of this BPL network on a carrier grade level.

In addition to the accessibility of 200,000 households for the connection of SMGW, this BPL network is also used to collect voltage values online over all 3 phases of 75,000 BPL repeaters to feed them into the grid analysis systems of the LV network of E.ON.

In the field trial mentioned above, E.ON considered several communications options including PLC (both narrowband and broadband), public mobile radio (GPRS, LTE), 450 MHz mobile radio (CDMA, LTE), and wired broadband (Docsis, xDSL, etc.). It also piloted several BPL vendors.

Derived from its technical and economic framework conditions, E.ON chose Corinex as its initial solution provider for the first rollout, which started at the end of 2019.

An important part of E.ON's implementation of BPL is also that this is the industry's first full implementation of a BPL network of over 100,000 network elements with high availability management software.

E.ON is engaged in PRIME to drive the next BPL Standard g.hn to ensure higher performance in BPL Systems and interoperability over the vendors.

"With the current BPL rollout in our LV networks, it was possible to prove that the BPL technology and the appending processes in our organization (plan, build, run) are scalable and work efficiently. With regards to the BPL technology itself, the new g.hn standard with interoperability must be available in the next rollout wave.

Elmar Peine, Expert Team Lead Process Data Technology E.ON SE

E.ON plans to expand its BPL infrastructure in the near future based on ITU-T G.hn with appropriately agreed standards and interoperability and considers BPL technology as an important key communication technology for its future smart grid and smart metering rollout.

Bringing the Benefits of BPL to Medium Voltage

As with the LV grid, the implementation of innovative applications such as interaction with energy storage systems or secondary substation automation brings about new challenges in terms of communication for the MV network. In fact, the feasibility of use cases described in the previous section (e.g., demand response and V2G) greatly depends on the MV grid's capacity to ensure reliable connectivity for millions of IoT devices in real time.

Moving towards higher voltage levels, after data is concentrated at secondary substations, it is sent towards the network operational center. Data concentrators represent a limit between the previously mentioned NAN and the WAN, where data from several NANs in larger areas are collected and transmitted back to the utility.

BPL Use Case #4: Backbone for Secondary Substations

Cellular communications or optic fiber are widely used for this backhaul interconnection. However, the installation of optical networks is time-consuming and costly and cellular communication results in third-party dependency, recurrent fees, and untransparent quality of service. On the other hand, BPL uses grid operators' infrastructure and can handle the combined traffic even if it reaches higher volumes, ensuring higher levels of cybersecurity and quality of service.

Iberdrola

Iberdrola, a large utility, started experimenting with BPL on MV in Spain in 2007, validating this technology's potential for backhauling. It considered using existing infrastructure to lay a robust communications layer on the existing electrical network. Performance measurements were taken on trial sites with very good results, and operational procedures for planning, deployment, operation, and maintenance were produced. This technology and use case was used at its large-scale smart grid and smart metering project, combining efforts to automate the MV grid, while PRIME smart meters were deployed simultaneously.

Starting with a region, representative of the whole grid footprint to a lower scale, over 25,000 BPL MV devices were deployed, covering roughly 50% of the denser secondary substations. BPL technology eventually became the second most reliable technology after optical fiber (in availability terms), and the second most widely used solution in an 11-million-meter smart metering rollout.

Iberdrola used two vendors for its MV deployment — Corinex and Ormazabal — both in significant quantities. Within the project BPL technology provides:

- Bandwidth for additional applications
- Backhauling of SCADA data
- Backhauling of data from sensors and IEDs
- Data about the line characteristics (i.e., signal-to-noise ratio and channel frequency response)

BPL's performance is influenced by various characteristics of the grid, which imposes constraints on its usage. Attenuation is a major concern, as it increases with frequency and distance. New underground MV cables would support reliable and stable throughputs at 1,000 meters. Older, paper-insulated lead-covered cables have a similar performance at roughly half the length of newer cables. BPL is an infrastructure technology, and its successful mass rollout requires planning and the consideration of distances and environmental factors, as do all other technologies.

For MV deployments, the cost for signal couplers is significant compared to those of LV BPL products. Installation of MV couplers is currently needed in both the secondary substation and in the primary substation. During the installation of MV capacitive couplers, a brief energy interruption is necessary. Installation of inductive couplers does not require this energy interruption, but the connectivity may be less reliable.

Conclusion: What Comes Next for Smart Grids?

Until not long ago, the prevalent view was that most smart grid applications required low data rates and hence NB-PLC would do the job. As sketched above, however, the pace of change has accelerated significantly. Given that the lifetime of distribution grid hardware will commonly exceed 10 or 15 years, grids using this communication technology might not be smart enough to face the challenges that lie ahead.

BPL offers a good trade-off between latency, throughput, and quality of service for many DSOs to make a critical evolutionary step towards a smarter grid. In particular:

- To address new requirements imposed by law, including new cybersecurity requirements, mass adoption of new IoT devices and consumer participation in energy markets, utilities will have to substantially upgrade the performance of their networks. For that purpose, especially on the LV part of the grid, BPL is a promising technology solution.
- The development of BPL is advancing, driven by major European utilities that are implementing it in mass rollouts and sponsoring its progress in a key industry forum: PRIME Alliance.
- The objective of PRIME Alliance is in turn to establish the next-generation BPL standard as a validated, well performing technology. This will help minimize risks to its members, avoiding the pitfalls of past standardization efforts by other organizations, whose

standardized technology did not perform optimally. PRIME Alliance's new BPL standard is slated for 2022 and will guarantee openness, interoperability, and support for a competitive vendor landscape. PRIME Alliance has evaluated all available BPL technologies on the market, as summarized at the beginning of this report (Table 1). Based on laboratory and field results, it chose the ITU-T G.hn standard as the basis for the technology.

- As of today, three vendors (Corinex, PPC, EFR) are testing solutions in the field based on the ITU-T G.hn standard with two different silicon vendors. Interviews conducted during this study indicate that several other vendors will support the technology once its maturity and market adoption have increased. They can either do this themselves or by embedding the technology of existing vendors.
- Products based on the ITU-T G.hn standard are being tested in the laboratories of European research and technological development specialist Tecnalia. Field results obtained so far demonstrate that these products can reach physical data rates in the range of 150 to 250 Mbps, depending on the channel characteristics.

The rate of installation of communal or household DERs and related interfaces and communications protocols and may vary. However, it is evident that network speed will be critical for utilities to provide flexibility and microgrid services in the future. The choice of high-speed smart metering infrastructure is critical as it protects utilities' infrastructure investment by enabling future smart grid applications. As mentioned, smart metering infrastructure investments have a life cycle of at least a decade. During this period, major changes in the grid will happen as result of its digitalization and increasing penetration of distributed generation, other DERs, and connected appliances. This wave of new grid-connected devices will require that utilities implement automated substation services acting with high speed, low latency, and cybersecure communication. BPL is an affordable technology option that meets the requirements for this decade of smart metering deployments.

Clearly, BPL will be one of several high-speed grid communication technologies that will complement each other. These include, for example, fiber connections to substations or homes in urban environments, private wireless networks in utility-specific spectrum such as the 450 MHz band in certain countries, or future 5G networks. Each of these technologies will have their respective benefits and disadvantages.

Recommendations for Utilities

Think ahead of your future needs: As utilities know all too well, large-scale infrastructure deployments require careful planning. Benefits often come from scale, which at the same time entails great financial risk. Before committing to a technology, utilities should carefully consider not only immediate needs, but also those that go beyond the current regulatory period.

Mass participation of consumers in the production of energy and marketing of energy services is only starting. As discussed, this disruptive change will result in an unprecedented need for secure broadband communication for the LV grid. The cost of BPL will be driven down by increased performance, competition, and growing order volumes. In the past few years alone, utilities have already driven down the cost of BPL solutions significantly. Likewise, the business case for BPL has evolved. In a time of intermittent electricity generation, with a need for a higher volume of more frequent energy transactions, the cost per transaction using BPL communication will be significantly lower than that of many competing technologies.

Make use-case-driven connectivity choices: Utilities need some time to understand BPL technology capabilities, deployment, and operational strategies. As performance requirements grow, it is prudent to validate BPL as a technology option to address them. Most participants in this study are doing so. This study has shown that the most compelling use of BPL technology is in smart metering and AMI applications, where BPL capabilities are embedded into the meter and data concentrator. This solution enables utilities to provide new services and offers sufficient bandwidth for the next decade of smart metering applications. It has been validated in several pilots, but it has not been deployed in mass rollouts in Europe yet. In addition:

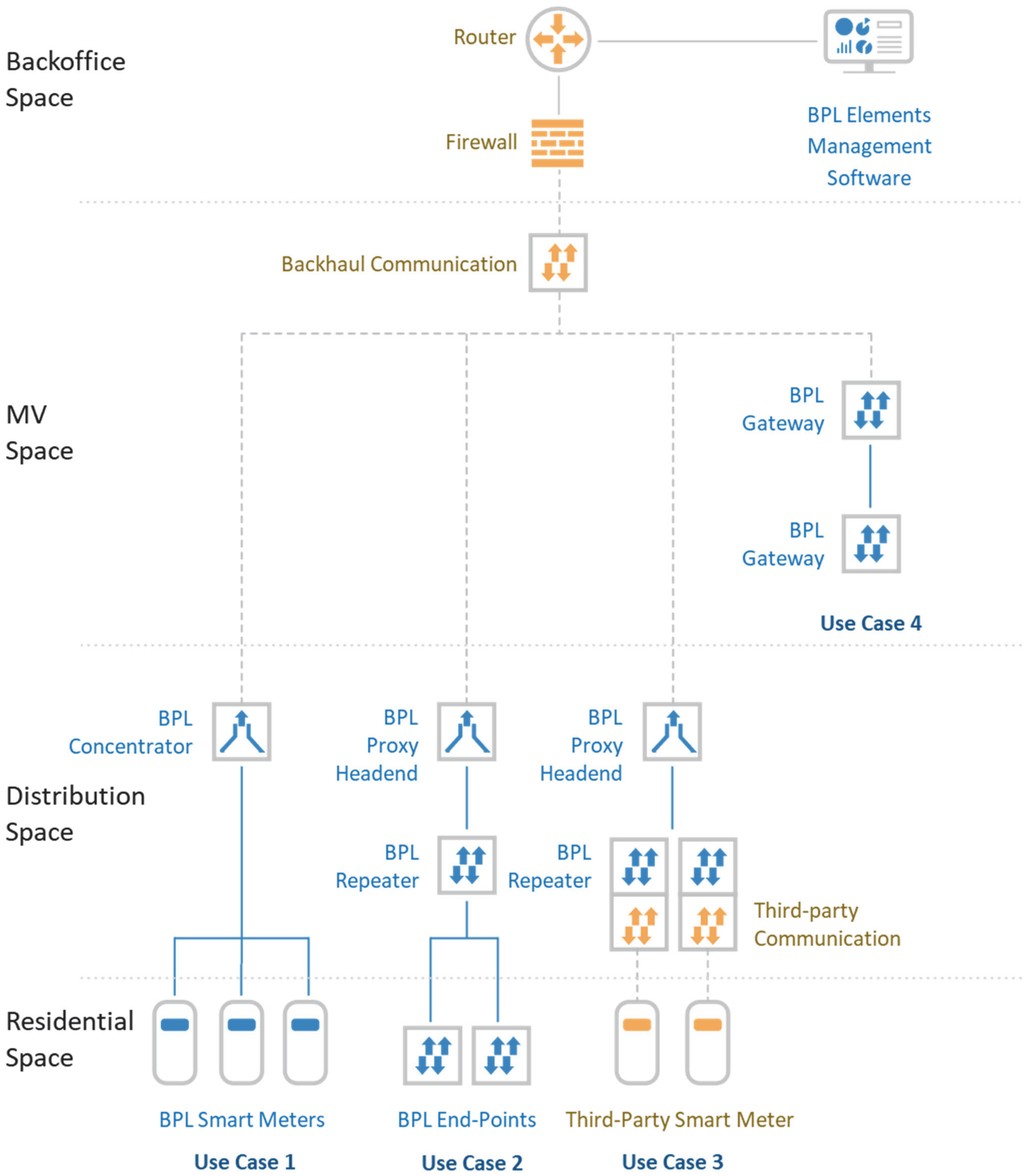
- Coexistence of BPL and NB-PLC on the LV grid helps to significantly improve network performance in cases where utilities have already deployed NB-PLC metering infrastructure.
- BPL on LV with a BSI Smart Meter Gateway is a well-established and validated solution deployed in Germany, where it is used to specifically address local energy regulation.
- BPL on MV is used to aggregate traffic from narrowband solutions and is relevant in scenarios where no mass technology changes in the grid are expected in the near future, or in geographies where a narrowband solution is satisfactory.

Select partners, not simply technology vendors: Each scenario takes time to test and validate by the utility and substantial investments by vendors. Vendors must have strong R&D capabilities, a proven track record of long-term collaboration with utilities to adapt solutions to their specific needs. The large utilities that are already using BPL have invested considerable time and money identifying the leading vendors in this space and working with them to advance their applications. In this process, complex solutions were developed, including software platforms, resulting in a mature technology that utilities can efficiently deploy themselves.

Talk to your peers, but keep in mind you are unique: Unbundled grid operators own and operate natural monopolies that do not compete directly against each other. Therefore, learning from those that have taken decisive steps forward should be uncomplicated. Still, no two grids are the same, and the same is true for their operators.

Appendix

FIGURE 8
Standardized Utility Use Cases for BPL



Source: PRIME Alliance

Methodology

This IDC White Paper presents the major findings of the 2020 IDC BPL Survey, commissioned by PRIME Alliance. The survey ran between September 2020 and March 2021 and covered 14 vendors and 17 utilities across 12 countries — Cyprus, the Czech Republic, Germany, Indonesia, Italy, Kenya, Malaysia, Poland, Portugal, Russia, Slovakia, and Spain. PRIME Alliance contributed its documents and findings, including laboratory test results. The case studies of utilities were reviewed by each utility customer, which verified the information in each case study as well as the whole white paper.

This IDC White Paper, based on the major findings of the IDC BPL Survey, focuses on recent advances in smart grid technology and presents broadband over power line along the most important use cases of this technology. Relevant regulation and the vendor roadmap are described. Finally, the study presents the reader with insights from interviews held with utilities and provides action points.

About the Analysts

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Jean-François Segalotto is the associate research director for IDC Energy Insights in Europe. In this role, he is responsible for conducting region-focused research providing full coverage of the utilities industry value chain. Segalotto leads the European Utility IT and Operational Technologies Strategies advisory service, in which he covers a wide range of industry-specific themes, including smart grids, digital asset management, e-mobility, IoT, connectivity and networks, and business systems supporting smart customer operations and digital transformation. He is based at the IDC Italy office in Milan.

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