Smart Grid Communication Assessment Criteria among RF Mesh, PLC, and Cellular Technology

WHITE PAPER

Trilliant helps leading utilities and energy retailers achieve their smart grid visions through the Trilliant Communications Platform, the only communications platform purpose-built for the energy industry that integrates disparate systems of systems into a unified whole. The Trilliant Platform is deployed with more than 200 utilities worldwide to enhance energy efficiency, improve grid reliability, lower operating costs, integrate renewable energy resources and electric vehicles, and empower consumers to better manage their energy consumption.

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Executive summary

With multiple smart grid communication technology available, utilities are facing difficulties in choosing the right technology communications platform that can address not only the AMI needs it may have today, but also other smart grid applications tomorrow. Utilities in various places have different strategies, market characteristics and environments. Understanding these elements is important to define the best communication solution for each different utility company.

This document will help utilities to map their different situation/deployment scenarios across the important assessment criteria, and to define the implications of this assessment in choosing the right communication technology. This white paper focuses on three smart grid communication technologies: RF Mesh, PLC, and cellular, and is organized into three remaining sections, followed by a brief conclusion and next steps. The first section, *The Smart Grid Communication Assessment Criteria,* identifies assessment/selection criteria of smart grid communication technologies. It also provides concise description on the criteria definition, potential scenario and how each scenario influences the communication technology decision. The second section, *The Technology Family*, describes each of the smart grid communication technology characteristics, especially on those that further explain how each technology suits or does not suit certain criteria in the previous section. The third section, *Examples Network Choice,* provides three past examples of utility companies that deployed each of the three technologies. This section describes the assessment criteria results of the companies, and how those lead into the decision of smart grid network technology that they have made. The *Conclusion and Next Steps* section synthesizes output of this white paper, describes what it means to utility companies, and suggests next steps for implementation. This white paper also occasionally touches upon analysis towards different regions in the world, specifically in the US, UK/Europe, and Asia.

Table 1: Snapshot summary of smart grid communication assessment criteria results

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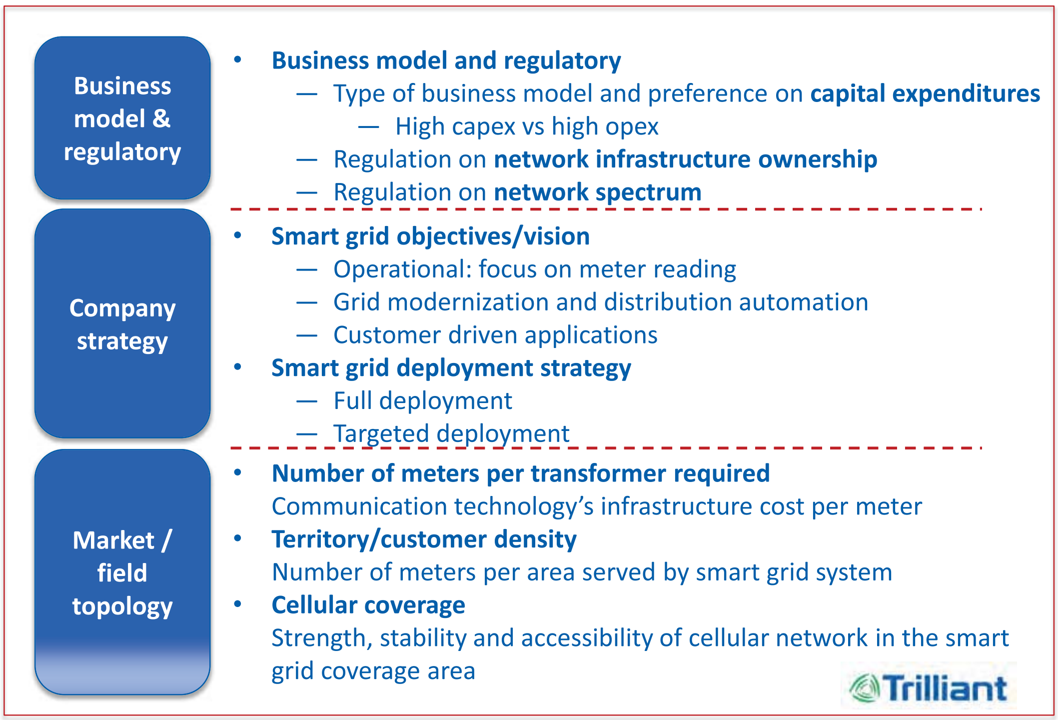
The Smart Grid Communication Assessment Criteria

Utility company has to assess its deployment scenario or situation that largely defines communication network design/architecture. This scenario consists of several elements or (assessment) criteria. Assessment criteria described in this white paper represent basic and fundamental elements of strategic decisions and external factors that affect the degree of suitability between each communication technology and the utility company. The assessment result of these criteria can also help identify necessary adjustments that need to be taken for each smart grid communication technology.

Figure 1: Smart grid communication technology assessment criteria



Business Model and Regulatory

Utility's resources and its business model as well as external regulatory supports are very influential in determining network technology for utility's smart grid system:

Business model and its impact on utility's preference on capital expenditure

Municipal and cooperative utility companies usually are small in size and may not have a lot of resources to manage smart grid projects. It also tends to have a very high cost of capital, which means it will be very expensive to spend cash upfront for investment. Hence low capex-high opex project would be preferable. Investor Owned Utility (IOU) on the other hand, will need to submit smart grid project proposal to utilities commission for approval. This proposal requires IOU to present certain rate-of-return case. Cost of capital of large IOU will definitely be lower compared to municipal's or cooperative's, hence it has more incentives to spend capital and create return. IOU also has enough human resources to manage their network system. These situations lead to preference for capex. State-owned enterprise (SOE) is a common business model for utility companies in Asia. There is no mainstream preference on capex vs opex in this business model.

Regulations on network infrastructure ownership

In some country, the electricity producers are not necessarily the same with the sellers. When a market adapts retailer market like this, applying high-capex smart grid solutions has a high risk, because customers can easily change their electricity suppliers in short time. The similar situation applies whether utility owns power line or not. If it does, then it makes sense to develop high-capex project with PLC technology or hybrid. If it does not, then high-opex project is preferable or a fee-based PLC project as an alternative.

Regulations on network spectrum accessibility

In the U.S., Federal Communication Commission's (FCC) has flexible regulations regarding the use of public, unlicensed radio bands. While in Europe, these bands are heavily regulated. In most part of Asia, the 900 MHz RF spectrum bands are regulated and pre-allocated mostly for telecommunication. All these regulations on network accessibility will strongly affect utility's selection of smart grid network technology

Smart Grid Objectives/Vision

The communication infrastructure in smart grid must support its desired functionalities and performance requirements not only for today, but also in the next 5, 10, 15 or 20 years depending on the utility company's vision. Utilities need to think about what the drivers or objectives of deploying smart grid are.

Operational: Focus on Meter Reading

If the long-term objective is mainly to have a better meter reading function, then all smart grid network communication technology will be capable in achieving such objective. If utility wants to apply more advanced smart-metering applications over time, then several network technologies would be more suitable than another.

Grid Modernization and Distribution Automation

Utility should think of its long-term, 5, 10 or 15 years smart grid objectives. If immediately, or within the short future utility wants to apply grid modernization and distribution automation (DA) function, then utility will need a high speed, high bandwidth, and low latency smart grid communication technology to be installed since the beginning. This will reduce required cost over the smart grid life cycle. Not only cheaper by million dollars, but deploying smart distribution/DA applications early will also help customer education process for future smart grid development.

Customer Driven Applications

Customer driven applications such as demand response (load management), distributed storage, solar integration, electric vehicle integration, etc., would have the highest requirement on network technology. High bandwidth, high speed, and low latency communication technology could support these functions, however further developments are still required.

Table 2: Smart grid communication technology performance on advanced applications

No	Applications	Smart grid communication technology			Notes
		RF Mesh 2.4 GHz	PLC	Cellular	
1	Distribution automation	Yes*	No**	Yes	*Especially on WAN **PLC only supports up to substation
2	Multi-interval meter reading	Yes	Yes	Yes*	*If cellular carrier provides head end software and is able to support this application, or if the AMI network provider can support this application
3	On-demand meter reading	Yes	No*	Yes**	*Can read meter on-demand but manually **If cellular carier provides head end software, or if the AMI network provider can support this application
4	Firmware/progress updates	Automatic*	Manual	Depends**	*Can upgrade on the air, down to the meter automatically **Need to upgrade at NMS
5	Service switch	Yes/No*	No	Yes/No**	*Depends on the provider **Depends if cellular carrier provides head end software and is able to support this application, or if the AMI network provider can support this application
6	Demand response - direct load control	Yes	No	Yes*	*If cellular carrier provides head end software and is able to support this application, or if the AMI network provider can support this application
7	Real-time pricing	Yes	Yes	Yes*	
8	Provisioning	Automatic	Manual	Automatic*	
9	Outage management	Yes	Yes	Yes*	

Smart Grid Deployment Strategy

If utility companies have support from regulator and influencer stakeholder, then the question is what deployment strategy that the utility and its stakeholder want to implement. There are two possibilities: Mass/blanket/full deployment, or targeted deployment.

Full deployment

Utility will do full deployment when the smart grid solution is installed to cover all of company's customers area. This deployment scene is also called mass deployment or blanket deployment. All network communication technologies for smart grid are capable of doing this.

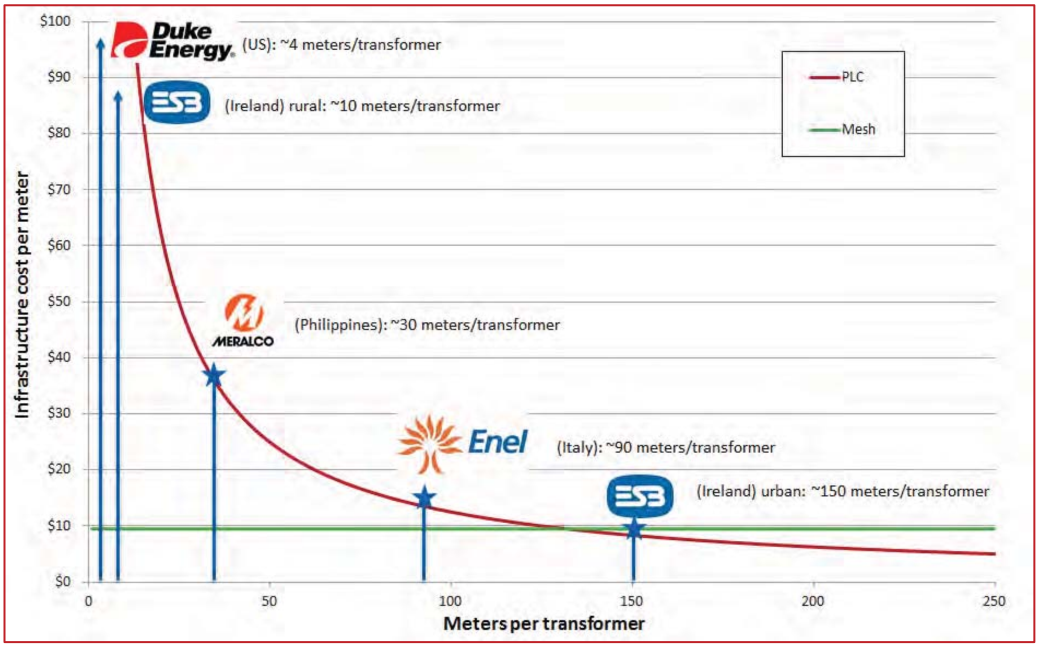
Targeted deployment

If utility companies will only do targeted deployment, which means smart grid deployment on specific customers/meters within the whole customer area, there is only one communication technology that can support. There are several types of targeted deployment: (i) High-value customers based. This is a smart grid deployment to monitor, increase efficiency and service to high value customers; (ii) Opt in.When a municipal/cooperative/state does not approve a smart grid or smart grid project, however some of their customers voluntarily request for smart grid installment, that is when opt in deployment happens; (iii) Gap filler. There are also situations where a utility company already has a smart grid system installed; however there are still some gaps in the system (e.g. system can only read in average 96% of customers' data). The company then needs another mechanism to read and install new smart grid system to these unreadable customers.

Numbers of meter per transformer required

The result of this assessment criterion is driven by region. In the U.S number of meter/transformer is on average less than 10. In Europe, the number of meter/transformer is on average more than 100. In Asia, the number of meter per transformer is around 60-70. The numbers of meter per transformer will determine infrastructure cost per meter for certain communication technology, hence this criterion becomes one of the smart grid project's cost efficiency indicators. The decision on which communication technology is the best for utilities will however also depends on other assessment criteria.

Figure 2: Analysis on infrastructure cost per meter



Territory/Customer Density

Measured by #meter/square mile, this criterion analyze whether the market is an urban or rural environment. This will have different impact on different technology, hence it is important to be analyzed. Having said this, sometimes hybrid solutions can be the best answers for utility companies, especially those that are large and serve diverse territories. It is also important to identify whether the area served by utility company is flat or non-flat (foliage, hilly, trees), in order to determine what type of adjustment required to optimize the chosen communication technology's functionalities. Terrain and land cover might require extra repeaters in place for some communication technology. Distributions of meter location identifies whether there are high concentration on meters located in basements. Usually the more urban/dense the area is, the higher likelihood of basements-located-meters is. This characteristic will also determine whether there are some adjustments required to optimize the chosen technology performance.

Cellular Coverage

Utilities that strongly considers cellular for their communication technology should ensure that there is strong, reliable, and accessible cellar signal on the smart grid area (NAN and/or WAN). It is critical to know not only that there is some available cellular spectrum for smart grid applications, but also that the quality of the cellular network is good (strong, high speed) and reliable. This criterion is a basic requirement for cellular technology decision making.

Smart Grid Communication Technology Family

PLC tends to be more economical compared to wireless network technology due to the ubiquity of power lines. However, there are some challenges that PLC technology faces. Since power lines are not designed to transfer data, there will be noise over the transmission, with intensity depending on the quality of the existing infrastructure. PLC technology also has limitation in supporting some non-metering smart grid applications, hence if utility has a long-term smart grid vision that involves advanced applications, using PLC could be a challenge. PLC is a capex heavy project due to the installment of network, meters, and modem. PLC's infrastructure cost per meter would be competitive with the other technologies when there are >100 meters per transformer in the area served by smart grid. If it is less, e.g. in the U.S., then the infrastructure cost per meter would not be competitive compared to other technologies. In low-density areas such as suburban or rural territories, PLC will be cost-effective since feeders serving meters tend to be lengthy[1].

Figure 3: Pros and cons of smart grid communication technologies

	Pros	Cons
Power line carrier	Potentially the more economical technology for operational function: meter reading	Not high enough bandwidth and speed as well as low enough latency to support grid modernization and several advanced applications (especially narrowband)
	Private network; full control ownership by utility	Significant upfront investment is required for targeted deployment
	Competitive infrastructure cost per meter for market with >100 meters per transformer	High infrastructure cost per meter for market with <50 meters per transformer
	Independent of terrain/land cover; Able to reach meters at architecturally-challenging positions (e.g. basement)	Performance is dependent on power line (single point of failure), hence the quality of distribution line (e.g. high noise / unstable) really affect smart grid performance
RF Mesh	Has higher bandwidth and speed than PLC to support grid modernization, customer applications, and other advanced smart grid functions	Not suitable for targeted deployment
	Infrastructure cost per meter is independent of #meters per transformer, hence it is more cost-competitive than PLC for market with <50 meters per transformer	Terrain and land cover could affect the performance, hence some adjustments would be required to be optimum
	Cost-effective in high-density/urban areas	Could be costly as the density falls
	Private network; full control ownership by utility	Significant upfront investment is required for targeted deployment
	Redundancy and self-healing function increases reliability (no single point of failure)	
Cellular	Low latency, higher bandwidth (compared to PLC), and has ability to aggregate very complex data (e.g. from industrial and commercial customers)	Generally the most expensive smart grid communication technology (*however, cellular carriers are recently working on lower cost for utilities' smart grid projects*)
	The most effective communication technology that is able to support targeted deployment at this point of time	Public network; Utility does not have ownership/control over the network
		High risk of obsolescence (short technology evolution)

Wireless mesh has high capacity as it has scalable high-band width capacity that accommodates network of thousands devices. The mesh network mechanism allows a wide range of possible routes, ensuring redundancy and self-healing capacity. It also supports more smart grid applications compared to PLC. RF mesh is a heavy-capex project with high upfront installment of network, comm module and meters (including the design). It has the high bandwidth, speed, and low latency required to deploy grid modernization and customer applications, on top of smart metering advanced applications. There are currently two major types of RF Mesh for smart grid available in the market: RF Mesh 900 MHz and 2.4 GHz. There are available 2.4 GHz spectrums available globally, while not necessarily the case for 900 MHz that is often unavailable or only has very limited spectrum (especially outside the U.S. and Ausstralia). The difference between both types of RF Mesh network can be found in Table 4.

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[1] ELP, AMI Communication Technology, http://www.elp.com/articles/powergrid_international/print/volume-14/issue-8/features/ami-communications-technology.html, accessed June 1st, 2013

Most of the time cellular technology is used for Wide Area Network (WAN) communications or at the backhaul of the system, to transfer data from end points in at the Neighborhood Area Network (NAN) to the head-end. Recently there are some developments that allows cellular as an end-to-end standalone solution, similar with RF Mesh, which can connect cellular technology directly to meters or directly to neighborhood connection. One of the biggest challenges that cellular technology has is its public network. Network is owned by the cellular telecommunication providers, who are also decision makers on a lot of network-operations issues. The rapid development of cellular technology also makes it has less long-term sustainability compared to RF Mesh and PLC. In the early days, cellular technology is very expensive, however recently cellular providers has adapt their price for smart grid customers to be much more competitive with the other two communication technologies.

More detailed comparison on PLC, RF Mesh, and cellular technology for smart grid communication systems can be seen in Table 4.

Assessment Criteria Results on Each Communication Technology

Each communication technology fits with different situation. The suitability of each network technology towards different scenario for each of the assessment criteria is explained in Table 3.

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In general, PLC is going to potentially be the best solution for utility that prefers heavy-capex project, owns power lines (backbone infrastructure), aims for mainly meter-reading function even in the measurable future (e.g. in the next 5, 10, 15 years), conducts full deployment, has #meters per transformer > 100, and has low-density market/coverage area.

RF Mesh is going to be the perfect solution for utility that prefers heavy-capex project, has sufficient spectrum availability, aspires to have apply advanced smart grid function including grid modernization (DA) and customers based application, conducts full deployment, and has high-density market/coverage area. RF meshes 2.4 GHz and 900 MHz, however, have further quality differentiation. Utility should further investigate which spectrum best fit its requirement, situation, and provide better performance.

Table 4: Smart grid communication technology comparison

No	Characteristics/Performance Metrics	Smart grid communication technology				Notes
		RF Mesh 900 MHz	RF Mesh 2.4 GHz	PLC	Cellular	
1	Network type	Utility deployed and operated (private)		Utility deployed and operated (private)	Operator managed WAN (public)	
2	Spectrum type	Unlicensed		Power line	Licensed	
3	Topology	Star, tree, and mesh		Power line	Cellular	
4	Typical data rate/throughput	NAN: ≤ 300 Kbps; WAN: Depends on the technology. Trilliant applies 54 Mbps (based on 5.8 GHz)		NAN: 1.2 - 128.6 Kbps (Narrowband PLC); 33.4 Kbps (G3 PLC); 128.6 Kbps (Prime PLC)*; WAN: PLC doesn't support WAN	500 Kbps - 9 MB; However, usually ≤ 1 Mb	*Only applies outside of the U.S., because in the U.S. there is no policy support to apply PLC technology
5	Message delivery latency	NAN: < 20 ms per hop*; WAN: <10 ms per hop **		>> 1 seconds per hop***	< 1 second	*RF Mesh and PLC transfer data through hops. For RF Mesh NAN, assume average of 10 hops per transfer (Trilliant technology can support up to 59 hops) ** For RF Mesh WAN, assume average of 6 hops per transfer *** Because data rate under PLC is low
6	Coverage	<10 km	NAN: < 35 km (without repeater); WAN: 10 - 16 km	1.6 - 2.5 km*	As long as there is access. Depends on how much utility pays to telco carrier	*Power decrease through distance; It needs repeater(s) up to substation
7	Security	Most vendors comply with AES 128 Bit; Trilliant additionally complies with NERC CIP S002 - S009		Most vendors comply with AES 128 Bit	AES 128 or 256 bit, depending on carrier. However, since it is a public network, user will always share bandwidth with others	
8	Ease of deployment and operations	Easy		Hard; Need to shutdown distribution network in order to install system	Easy	
9	Lifetime	~20 years		~20 years	As long as utility pays to telco carrier; As long as technology is still valid	
10	Interference with other networks	High interference; GSM bandwidth still use 900 Mhz	Free from interference; ~100 billion devices globally, all coexist	Quite high interference; PLC affects other equipment	Depends on the quality of the network	
11	Applicability	Depends country by country	Global	Global (except US and Canada)	Global	
12	Availability	99.50%	99.90%	98.50%	99.999%	
13	Regulatory	Depends country by country	No regulatory, as long as meeting transfer level transmit power to local preference	No regulatory, utility owns the power line	As long as meeting requirement from telco provider	
14	Provisioning	Automatic		Manual	Automatic*	*Function is provided by AMI network provider
15	Interoperability	Yes, depends on whether provider complies with ANSI C12.22		No regulatory, utility owns the power line	Yes, depends on whether carrier complies with ANSI C12.22	Interoperability between headend systems

Cellular is so far the most effective option for a targeted smart grid deployment. As long as the targeted locations have strong and stable cellular coverage, utility should choose cellular as its network technology

Utilities should carefully assess their situation based on these assessment criteria, then together with consideration on cost, choose the most-suitable network technology.

Example of Network Choices

Iberdrola USA

Iberdrola USA, specifically Central Maine Power (CMP), one of the U.S.' largest utilities, serves more than 600,000 customer accounts with a service area that includes 78 percent of Maine's population and major commercial and manufacturing centers. CMP has a broad, long-term vision for its smart grid, which will require the wide and neighborhood area networks to support applications beyond advanced metering infrastructure (AMI), including smart consumer applications and smart distribution where reliability and real-time performance are mission-critical. To satisfy these demanding requirements while keeping the total cost of ownership low, CMP chose to implement a private, multi-tiered network in the unlicensed wireless spectrum.

Figure 4: Examples of network choices based on the assessment criteria

Key drivers (highlighted)

	IBERDROLA USA		British Gas		Enel	
	Scenario	Technology	Scenario	Technology	Scenario	Technology
Business model and regulatory	Capex	Mesh, PLC	Opex	Cellular, fee based	Capex	Mesh, PLC
	Own power line	All	Does not own power line	Mesh, Cellular	Own power line	All
Smart grid objectives/vision	Grid moderniza-tion;Customer apps	Mesh, Cellular	Customer apps	Mesh, Cellular	Meter reading	All
Smart grid deployment strategy	Full deployment	Mesh, PLC	Targeted deployment	Celllular	Full deployment	Mesh, PLC
#meters / transformer	<50	Mesh, Cellular	n.a.	All	90	PLC
Territory/customer density	Rural to urban	All	Rural to urban	All	Rural to urban	All
Cellular coverage	Coverage holes	Mesh, PLC	Good	All	Good	All
	RF Mesh 2.4. GHz		Cellular		PLC	

British Gas

British Gas, part of Centrica PLC, is the United Kingdom's leading energy supplier. The utility serves 12 million consumers in Britain – nearly half of the country's homes – as well as providing energy to one million UK businesses. As the largest energy retailer in the UK, they are an aggressive first mover who is leading the UK smart meter rollout – 400,000 already deployed. They have the vision to lead the standards and become the first energy retailer to roll out standards-based solutions in volume/scale. They are also consumer-focused: they view smart metering as an enabler for value-added services to customers. BG's deployment is massive: 16 MM+ meters, 3-4 devices each (electricity, gas, in-home displays, and comms hub). Full UK rollout is planned be complete by 2019: 27m homes to be connected with smart gas and electricity meters before then. Unlike in the US, the UK energy market is highly deregulated and as such, energy retailers have to compete for customers. Hence BG will need smart grid system that can cover their spread customers. BG chose to use cellular as its network technology.

Enel

Enel is the main operator in Italy. It manages 39,813 MW of installed capacity and produces 79 TWh per year. Its contribution is crucial to meet the energy needs and national development, serving over 31 million customers. ENEL installed power line based smart meters for over 27 million customers. It was the first deployment of a nationwide smart grid.

Conclusion and Next Steps

Choosing the right smart grid communication technology is very critical to define the success of smart grid objectives/vision of each utility company. It is a long term decision that requires a thorough consideration across all assessment criteria. There is no one-size-fits-all solution. Each technology has its own strength and weakness, and it can be the best solution for different problem. Trilliant Inc. can provide further and more detailed assistance on choosing the right solution for each utility's situation based on these assessment criteria, since Trilliant Inc. believes in a comprehensive solutions platform of all smart grid communication technologies.

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