Corinex
SmartGrid Connectivity™

Corinex BPL in Smart Meter Infrastructure White Paper Series

Contents

1. Advanced Meter Infrastructure (AMI)

The focus of this paper is to provide an overview of developments in broadband power line technologies and solutions for Advanced Meter Infrastructure (AMI). The technology, referred to as *Broadband over Power Lines (BPL)*, uses medium and low voltage power lines to provide broadband communication from residential and business customers to the utility. BPL technology is shifting to providing broadband connectivity to support the entire smart grid. BPL can be used in utility settings for several business needs including:

- Substation automation (SA)
- Distribution automation (DA)
- **Advanced Metering Infrastructure (AMI)**
- Home Area Network (HAN)

BPL has advanced significantly over the past five years and is positioned to deliver reliable communication for a variety of utility applications. There are currently several different BPL products available and it is important to match their capability to application requirements. The current generation 200 Mbps technology is being deployed on smart meter and smart grid applications and is proving to be a reliable and high performance method for deploying high performance broadband IP networks.

2. Context – Why BPL should be used for AMI communication

Corinex technology provides a real-time solution for advanced meter infrastructure. With the bandwidth made possible by employing BPL (in the Mbps range) it is possible to execute real-time applications that are not possible with slower technologies. Examples of applications include remote disconnection of meters in real-time and instantaneous meter profile readings. Another advantage for utilities is that they can leverage existing infrastructure for expanded communications and services, without the need for additional equipment purchases. Corinex's solution to achieve this is both hardware- and software-based: Corinex-designed modules (integrated into the meters), module firmware, and the Smart Grid Powerline Concentrator (SGPC) that acts as a head-end for the meters and is typically installed at the transformer or substation.

Corinex is the first company to integrate a solution for AMI using BPL communication.

3. Approach Taken

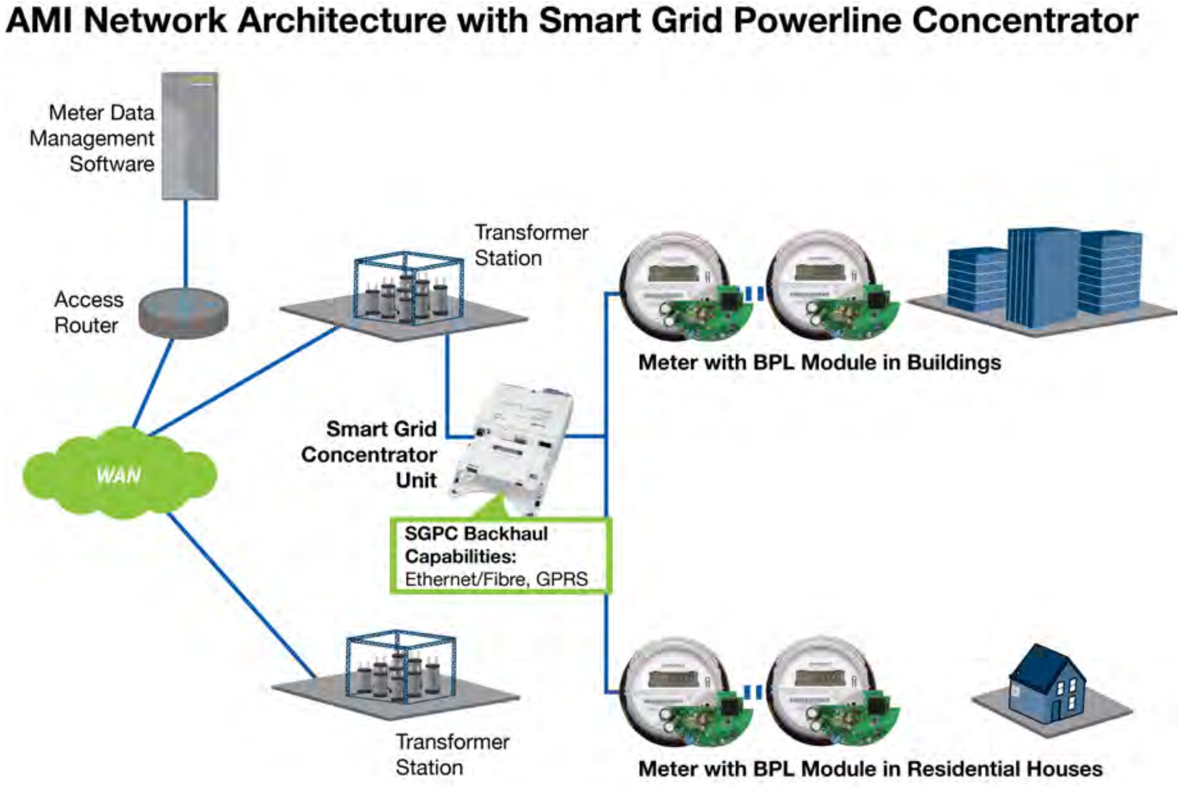


Figure 1: BPL Network for AMI

- Figure 1 shows the entire architecture for Corinex's AMI solution.
- A communication module is built directly into the meter, an industry first. Direct integration is needed in order to maximize performance.
- The SGPC is installed at the transformer or substation. This SGPC is the head-end of the network and is the gateway between the meters in the field and the MDMS installed at the NOC. A head-end can be responsible for up to 1200 meters inside its network.
- A BPL mesh network is created for reliability. All meters repeat the signal in a network, and the network topology is constructed automatically using optimized algorithms. This network is considered a 'plug-and-play' solution as the meters and concentrators just require physical installation by the operator before automatically coordinating with other devices to seek the optimal network paths to setup. This can potentially provide a meter with multiple paths to reach the head-end, therefore increasing the redundancy in the network in the event of a failure. Also, additional AMI gateways can be installed in the field to help improve the BPL signal in noisy areas.

- Meters connect to the concentrator assigned to each transformer; connectivity to meters averages 99% up-time in most settings.

- Data throughput to the concentrator averages between 10 to 40 Mbps.

- The concentrator is connected to the power lines with a USB 5+1 coupler. This option allows the concentrator to be connected to more than one feeder at a time.

- The concentrator is also connected to a router to backhaul data via the utility's wide area network (WAN). The MDM installed at the NOC must be reachable through this WAN.

- Data travels to and from the WAN via wired (Ethernet or optical fibre) or wireless (GSM/GPRS) connection.

- The concentrator polls meters individually in real-time, in 5-minute increments, as set by the utility (a typical interval is 15 minutes) for all registers in the meter (there are typically 70-90).

- Through the concentrator, the MDMS can perform online queries with response times comparable to most LANs (a typical direct meter query is 5 seconds for 80+ profiles).

4. Functionality

Corinex's comprehensive AMI solution supports the network installation process as well as the ongoing administration of the network and its performance. The SGPC establishes the IP network and monitors its health; its suite of functions for AMI include:

- Self-adapting and auto-healing mechanism
- Interoperable solution for multi-meter vendor support (meter-agnostic)
- Real-time event reporting and meter profile reading
- Security encryption support
- Advanced data integrity and validation
- Real-time demand load management
- Remote firmware upgrade (open for future needs)

For AMI, Corinex's smart grid solution is an open system architecture based on UPA/G.hn communication standards. Corinex has developed a series of communication modules that can function with either IEC- or ANSI-compliant meters.

Corinex metering software in Smart Communication Module

Corinex Broadband PLC Repeater

Corinex Smart Grid Powerline Concentrator

L&G meter

ZPA meter

Mikroelektronika meter

Figure 2: Corinex AMI solution product portfolio

Corinex BPL technology works with a variety of meters, in both single and multiphase forms. The network can be comprised of a heterogeneous mix of meter hardware from different vendors (down to the low voltage transformer) without adverse effect on overall performance, which gives utilities much more flexibility in their meter sourcing strategies. It also allows distribution operations to utilize specialized meters in different locations if required.

A BPL network that is administered through the Smart Grid Powerline Concentrator will enable utility field crews to solve difficult and time consuming issues whenever an outage occurs. The net admin functions will help isolate nested outages while field crews are still in the area. Restoration times will be enhanced significantly to the benefit of consumers.

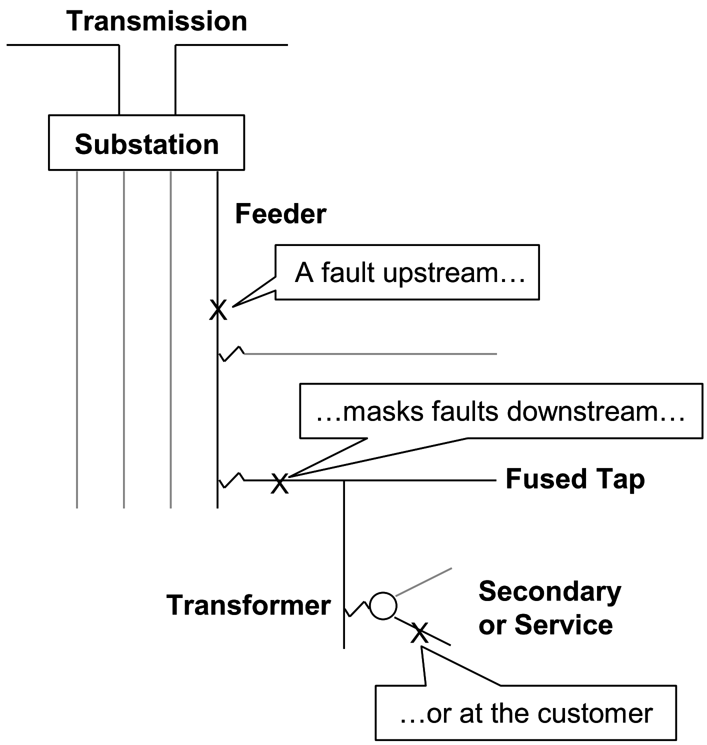


Figure 3: Example of a nested outage

The technology can be applied to identify nested outages and to provide real-time feedback during troubleshooting, to confirm which segments have been restored and which ones remain down. Since all BPL devices are IP addressable, the MDMS (through the SGPC) can regularly ping these devices to construct a topological map of the grid; when a device fails to respond, its corresponding node representation on the map is updated upon map refresh to reflect its indeterminate status, so the operator ends up with a much clearer idea on where a potential outage in the network may be occurring.

4.1. Self-Healing Network

Figure 4 shows an example of the self-healing properties of Corinex's AMI solution. Since all the meters inside of the network are repeaters, this means that for most meters there are multiple paths to reach the head-end. This is advantageous in case a meter loses connectivity to its parent node or the parent node has gone offline; the parent node going offline does not necessarily mean that the children of this node lose connectivity as well. Instead, the children nodes will actively look for other meter nodes in its vicinity to which they will reconnect.

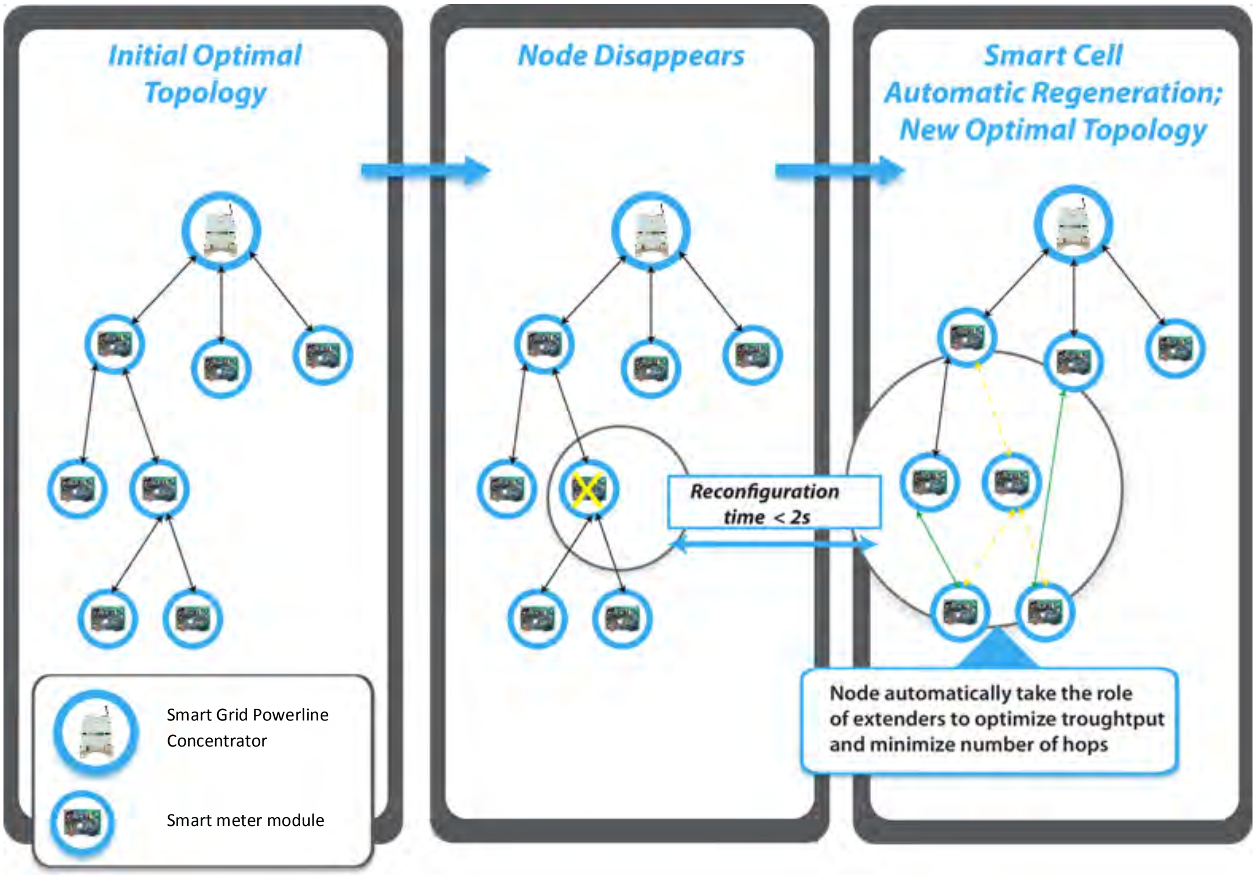


Figure 4: Example of self-healing network

4.2. Ripple Control Management

4.2.1. Application

The luxury of having high-speed connectivity is that it allows for state-of-the-art demand response capabilities similar to the ripple system used in some parts of the world. BPL enables the switching of electrical devices like heating, air conditioners, water heating, and street lights, and is designed to work in conjunction with multi-level tariffs for electricity consumption (a TOU contract can be created in the MDMS and sent to the meters if the meters support it). For example, in countries like the Czech Republic, the meters have both a main load and secondary load for devices that are energy-intensive but non-essential i.e. air conditioners. Then in times of high usage, in order to prevent brownouts, the utility can simply shut off the secondary load so that users can still receive power for their more essential needs while also maintaining overall network stability. Corinex BPL technology allows this to be done remotely and in real-time.

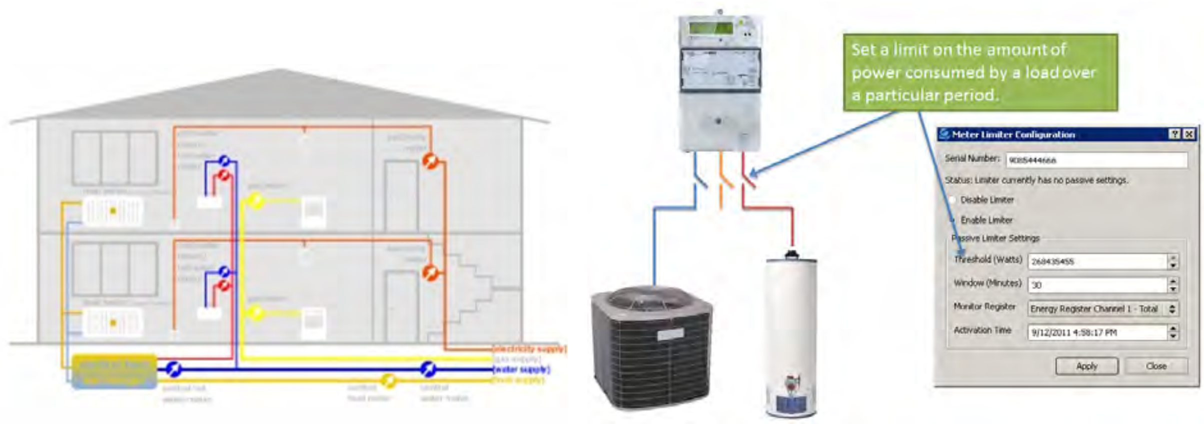


Figure 5: Advanced ripple control

With high-speed broadcast mechanisms, utilities can easily manage emergency scenarios across their networks. The MDMS can be setup to discriminate between critical and non-critical loads, by assigning different priority levels to different meters. In this way, the MDMS can intelligently inform:

- Load balancing
- Load shedding
- TOU control

During emergency situations, critical infrastructure (e.g. hospitals) remains unaffected, while (pre-planned) non-critical infrastructure can be impacted as needed to counterbalance reduced network capacity and maintain the overall health of the network.

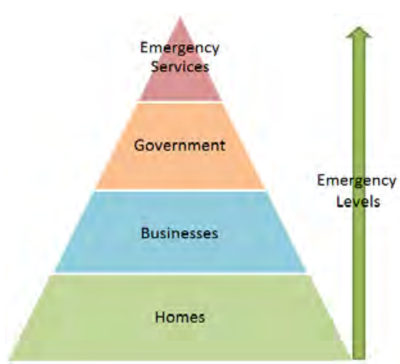


Figure 6: Example of priority levels of emergency management

4.2.2. Broadcast Mechanism

Broadcast messages are sent via the repeater and master nodes and cascade down the tree network, as shown below:

- All nodes in the network are capable of listening to the broadcast address in their subnet
- Broadcasts can be used to effect changes to tariff/output, virtual output, limiter, disconnector, TOUs, etc.
- Broadcast capabilities can also support "virtual relay" (e.g. home automation)
- Above actions can also be enabled by unicast commands to a single targeted meter

Each repeater node will broadcast the message to its children; each child node will then, in series, broadcast its message to all of its children.

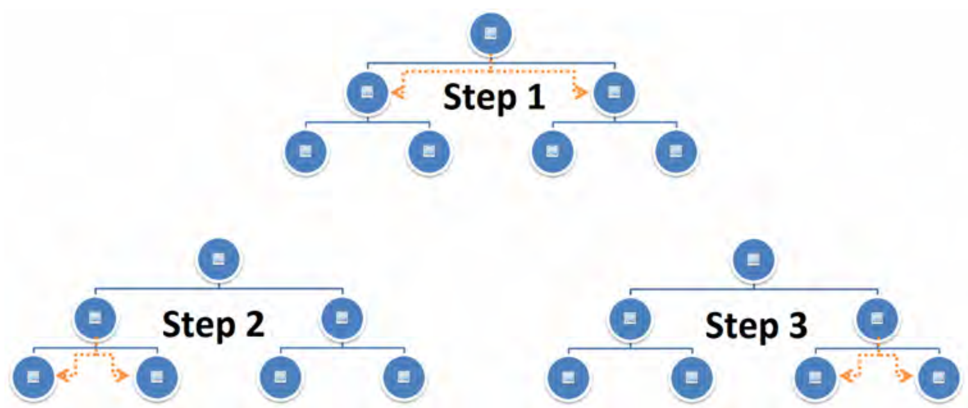


Figure 7: Broadcast in detail

The maximum time needed to execute a broadcast is a function of:

1) The topology and number of active nodes (this is described in detail in the next section)
2) The overhead of the WAN network (for GPRS this is typically less than 1 second), which is the time it takes for the request to reach the SGPC from the MDMS
3) The time the meter needs to execute the command (< 20 seconds depending on the command)

Corinex BPL meters automatically form a self-healing mesh network capable of transporting data with megabit per second speeds. As shown in Figure 8, the network topology is broken down into a master meter (blue), a number of repeater meters (green) and slave nodes (grey). In this example, there would be a total of 9 broadcasts required in the network.

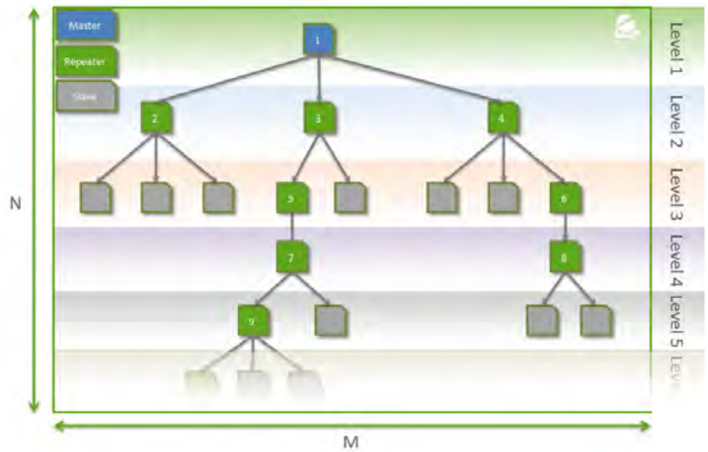


Figure 8: BPL tree topology and broadcast (indicated by numbers)

To perform functions related to load balancing, the network responds in real-time and provides feedback to system operators for requested actions that were issued across the country, in a region, a district, or even a single premise. This allows significant flexibility to manage curtailments without brownouts.

4.2.3. Broadcast example

A topology tree of 340 nodes would consist, on average, of 4 repetition levels, with the SPGC being located at L0, its children at L1, etc. In such a topology there are 85 active nodes, assuming the leaf nodes are idle. Every parent node has 4 children. In this situation there will be 4 nodes in L1, 16 in L2, 64 in L3 and 256 in L4 (340 nodes in total). For broadcasting, every node will transmit the broadcast traffic to all its children when the transmit token is received by the node. Only one node in a network can transmit at any time, so who's turn it is to transmit is determined by the transmit token (assuming every node has equal access to this transmit node). Assuming the token is given to the first node on the left of the topology picture, the last nodes to receive the broadcast packet will be the last 4 children of the relay node at the far right, at L3.

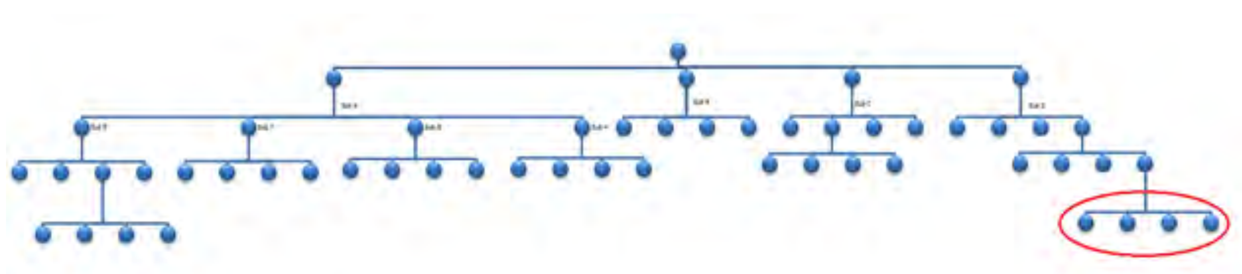


Figure 9: Broadcast example

- To calculate when the parent node of these 4 nodes will receive the token: According to the policy, the token is passed to a node whenever it needs to send from the master and then sent back when it has completed sending. The number of hops the token will travel before arriving to the 64th node of L3 is:

  6 (hops to arrive from the HE to a node of L3 and back to the HE) × 63 (nodes in L3) + 3 (hops to arrive to the 64th node of L3) = 381 hops.

- Assuming the 64 symbols of the validity are used in each transmission (the worst case) and that the symbol time for a 10 MHz mode (mode 21) is 173.6 µs, the time it takes to transmit a whole validity is 64 × 173.6 µs = 11 milliseconds. Therefore, the maximum time it will take a broadcast packet to arrive from the HE to the children nodes of node 64th at L3 is (381 + 1) × 10 milliseconds = 4.2 seconds.

Therefore:

- All broadcasts to any network size (up to 1000) can be received within 3-5 seconds
- A broadcast to each sub-tree is made in a sequential order
- Sending one broadcast in each sub-tree requires 10 milliseconds
- For approximately 300 nodes, it takes 4 seconds to receive all broadcast traffic

A meter requires 4 to 20 seconds to act after receiving the command depending on the type of commands and its security validation requirement.

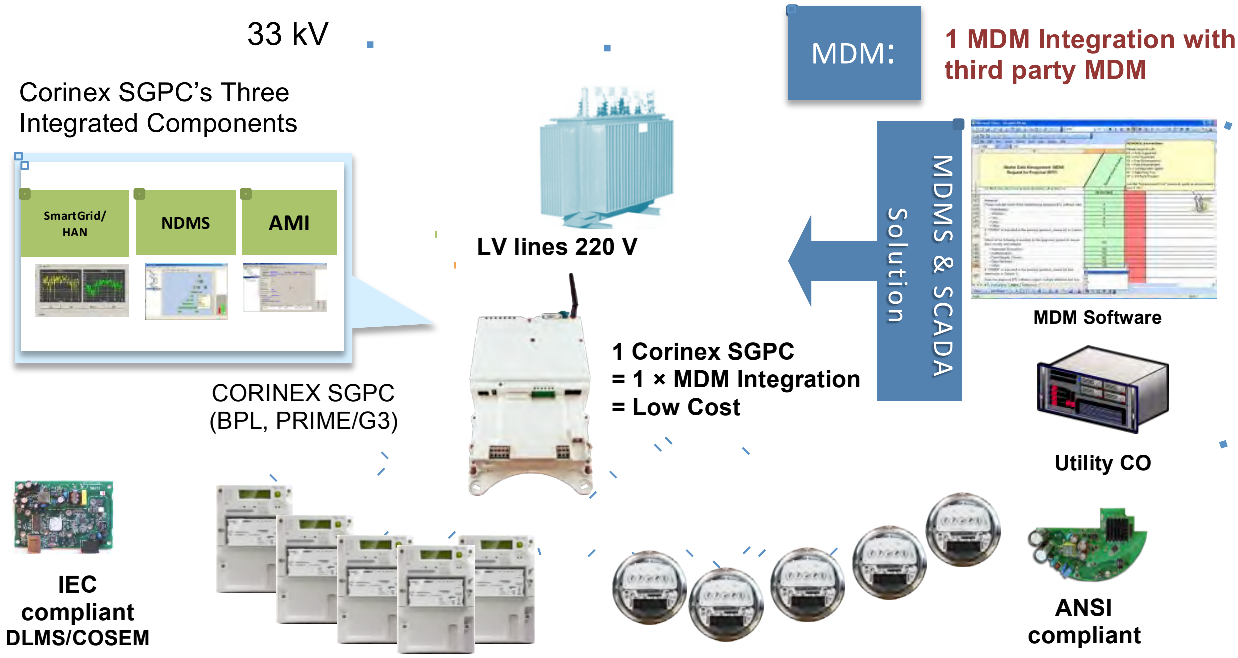
4.2.4. Drawbacks of using Other Technologies for Ripple Control Management

Corinex's BPL AMI solution is the optimal technology for ripple control management due to its reliability, real-time communications capability, and cost-efficiency.

In comparison, having GPRS installed at every meter becomes an expensive alternative. Most utilities cannot afford to have to pay a monthly GPRS subscription at every meter installed. Another drawback with using this alternate approach is that it is much more difficult to broadcast information to all the meters (all meters have public dynamic IP addresses which makes it harder to track the meters). Corinex's Smart Grid Powerline Concentrator provides a fixed address for all meters. All meters in the same low voltage circuit are on the same subnet, so it is much easier to broadcast information to a group of meters. Additionally, GPRS is far less reliable, as it is not guaranteed that all meters will be online at all times. The latency is much higher, as instead of the broadcast procedure mentioned above, each meter needs to be contacted one by one.

Narrowband powerline communications (PLC) is also not ideal for ripple control management, due to its unreliability; it is not possible, using narrowband PLC, to reach all meters on the network as reliably as with BPL, since the network will be flooded with re-transmissions of ripple control management requests. When a broadcast is sent, it cannot be ascertained which devices actually received the message, which further complicates the matter. Most critically, emergency situations can prove potentially disastrous if the pertinent meters cannot be reliably accessed at such times to execute appropriate actions.

5. Integrated Solution



- Corinex communication technology complies with multiple standards and specifications (BPL, PRIME/G3) and thus compatible with multiple vendors
- Corinex BPL technology is validated through third-party certification processes

Figure 10: Corinex Integrated LV solution

6. AMI Benefits

AMI infrastructure using Corinex BPL technology will support advanced capabilities in customer service, as well as provide a foundation for new smart grid applications that will follow, given the excess bandwidth capacity made available.

The benefits specific to metering include:

- Operating efficiencies—More efficient use of distribution assets (distribution substation MV and LV) and streamlining of business processes, reducing operating and future capital expenses;

- Energy savings—Lower electricity use through improved system control (for supply and demand management), operational efficiencies and providing customers with new options to conserve energy or better manage their electricity consumption;
- Revenue protection—Includes both recovery of revenue through more accurate billing for higher overall customer satisfaction. It also includes the detection and prevention of future potential revenue losses (e.g. reduced energy siphoning and theft); and
- Capacity Savings—Reduction in generation requirements by lowering electricity use at peak periods, which reduces peak generation strain on resources to help resolve capacity constraints.

Utilities are turning to Corinex to provide BPL as their principle last-mile communications backbone, to support communications to meters and intelligent end devices (IEDs). Progressive utilities are developing real-time single IP networks to move large amounts of data, streamlining operations and eliminating the need for redundant networks that operate independently.

Corinex provides the only proven BPL network solution for smart grid that can be used to simultaneously support AMI, distribution automation, and integration of distributed energy resources on the grid.

7. Performance

7.1. Speed

BPL has the speed and capacity to enable the next generation smart grid networks. Utilities can plan ahead, knowing they can obtain critical data in a timely manner and share it amongst operations and customer care systems.

Table 1: Sample distances and performances at various transformer stations

		Bandwidth	Bandwidth		
Transformer	**Distance between SGPC and Meter [m]**	**RX [Mbps]**	**TX [Mbps]**	**Peak SNR [dB]**	**Peak CFR [dB]**
A	172	19	27	39	5
A	182	11	26	38	5
B	141	26	41	42	2
C	82	21	45	44	5
D	44	33	45	46	3
E	77	30	41	45	2
F	132	17	32	39	5
G	72	11	24	46	-1
H	69	11	28	41	5

As shown in table 1, achievable data rates exceed concurrent wireless and PLC technologies by a large margin. Utilities can deploy smart grid networks to obtain reliable data transfer for mission-critical information. Customer service representatives can work with this information in real-time in order to satisfy customer queries. Meter information, such as voltage and reactive power, can be regularly referenced numerous times per hour to improve grid performance.

The capacity of the BPL network is sufficiently generous such that retrieving larger volumes of data being does not adversely affect application response times. Figure 11 and table 2 shows that increasing the number of running threads on the SGPC software can further reduce the time required to read all the meters in the network. For example, based on an average meter with 83 registers, each meter returns 8.3 MB of profile data to the NOC every day.

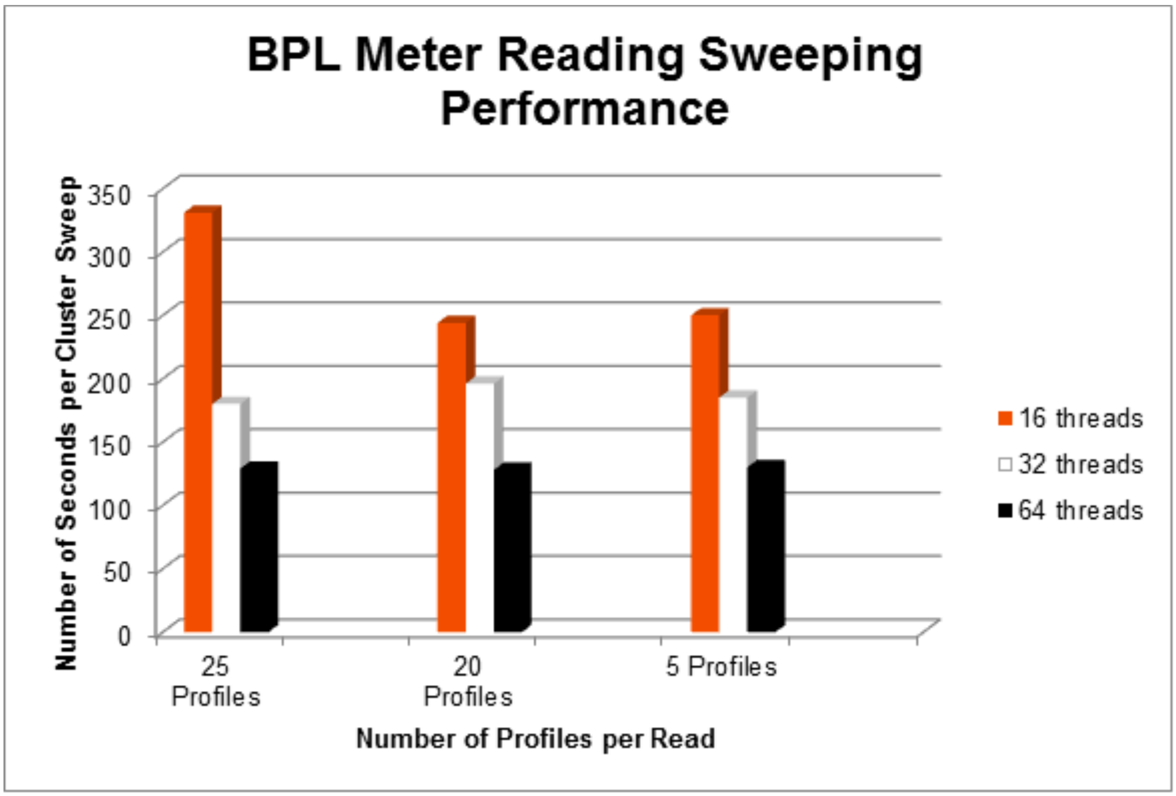


Figure 11: Variable data retrieval over BPL

Table 2: Polling times vs. number of profiles vs. number of threads

Number of Meter Profiles	16 Threads	32 Threads	64 Threads
25 profiles (140 bytes per profile)	219 nodes in 331 s	226 nodes in 180 s	223 nodes in 129 s
20 profiles (120 bytes per profile)	227 nodes in 244 s	223 nodes in 196 s	223 nodes in 128 s
5 profiles (60 bytes per profile)	225 nodes in 250 s	224 nodes in 185 s	226 nodes in 130 s

All devices are fully addressable IP nodes. The utility has full knowledge of the operational statuses of these devices. Data transfers are executed with AES-128 encryption.

7.2. Reliability

In a recent trial, a major Eastern European utility deployed the Corinex AMI solution and compared its performance to both wireless and narrowband PLC solutions. The objective was to verify multiple technologies using an open, multi-meter vendor architecture using BPL and other network communication schemes. In total, five meter vendors and three data centres were fully integrated. Their goal was to create an operating environment that accurately simulated a live one, to evaluate complex system operations within the network and test network control. This utility was seeking a powerline solution because the cost and reliability of G3 and GPRS would have made the AMI solution prohibitively expensive for mass rollout.

The utility compared the performance of the Corinex AMI solution with narrowband PLC technology and the results far exceeded their expectations.

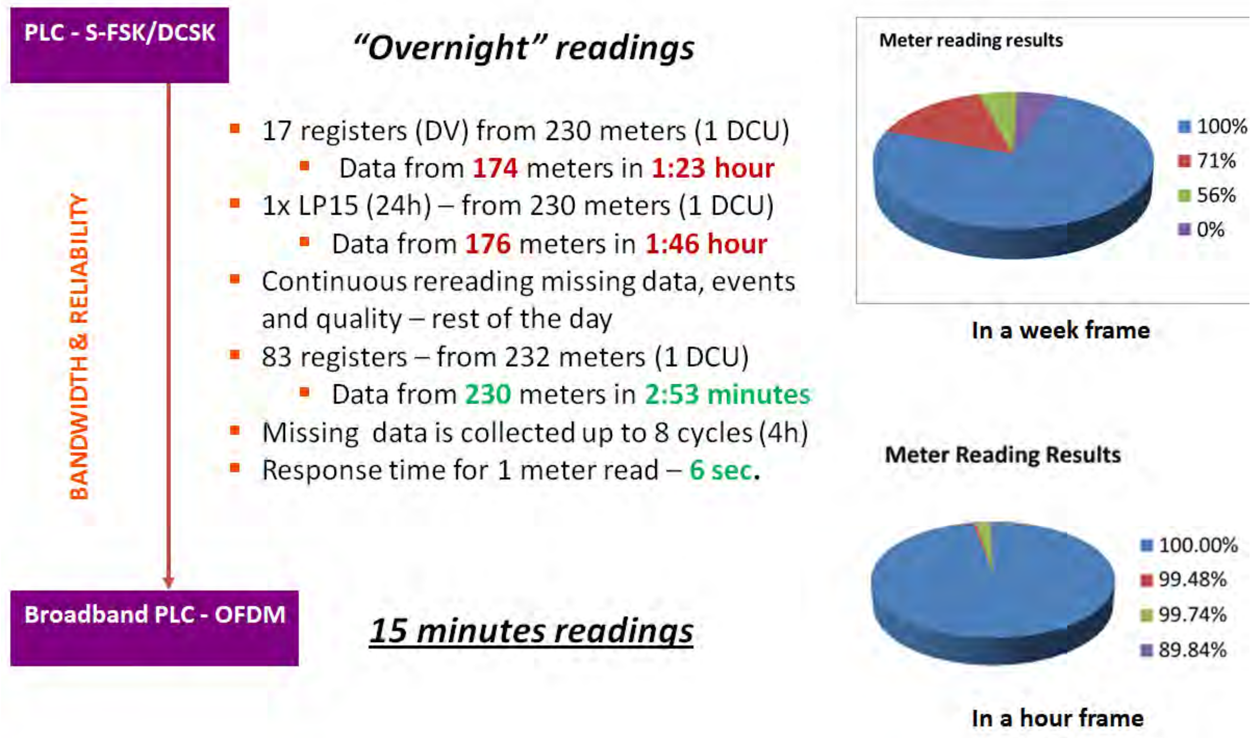


Figure 12: Comparison of Corinex AMI solution with a narrowband PLC solution

The BPL real-time network demonstrated significantly better performance in meter profile collection. For instance, BPL profile collection (with 83 registers) from 230 meters was completed in 2 minutes, 53 seconds; in contrast, during a less demanding scenario, the narrowband solution was tasked with collecting profiles containing only 17 registers and took 1 hour and 23 minutes to complete—worse yet, approximately 25% of the meters remained unresponsive during this timeframe.

Another key performance differentiator is connectivity. The Corinex AMI solution is deployed by connecting meter modules to a gateway at each transformer. In the most recent deployment, Corinex BPL technology was able to achieve over 99% connectivity up-time across all meters, with significant bandwidth being made available to each meter; much higher than what would be possible using narrowband PLC.

In a 2012 deployment in Eastern Europe involving 1220 meters, the average meter reading success rate was 99.705% *without the benefit of additional repeater gateways installed*.

To achieve this, the following approach was taken:

1. **Planning and Hardware Installation** - Completed by the utility without assistance from Corinex.
2. **Network Optimization -** Accomplished by Corinex in less than 2 days:
    - Only 1.6% meters failed to report in

3. **Clean up and 100% connectivity** – Connected all remaining meters in the following month

This result sets the benchmark for levels of connectivity that has remained out of reach for other industry players, made all the more impressive as it was achieved without any additional repeaters.

Figures 13 and 14 show the performance of the meters for one transformer. Figure 13 shows the average speed of all the meters in the network. From the figure, you can see that the vast majority of meters have a speed of at least 10 Mbps, which is substantial for meter profile collection. With this excess unutilized bandwidth, it is possible to add additional applications to the network in the future.

Figure 14 illustrates the network topology of all the meters in the network that act as repeaters for other meters. The diagram shows that the majority of these meters have a speed of at least 10 Mbps, which is crucial as they form the network backbone.

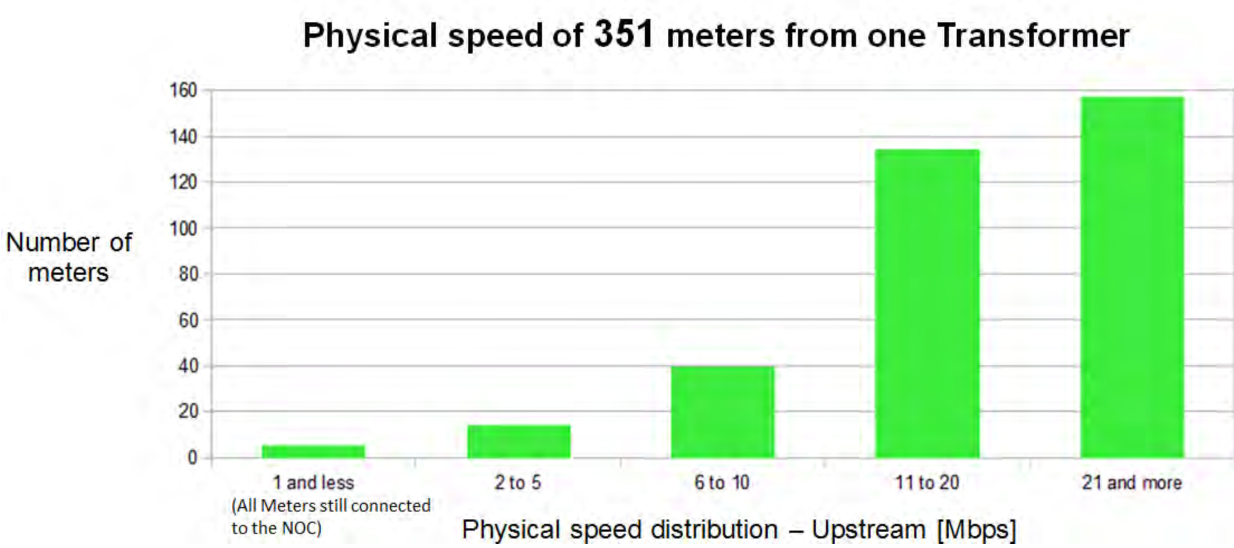


Figure 13: Distribution of meter speed for a given transformer

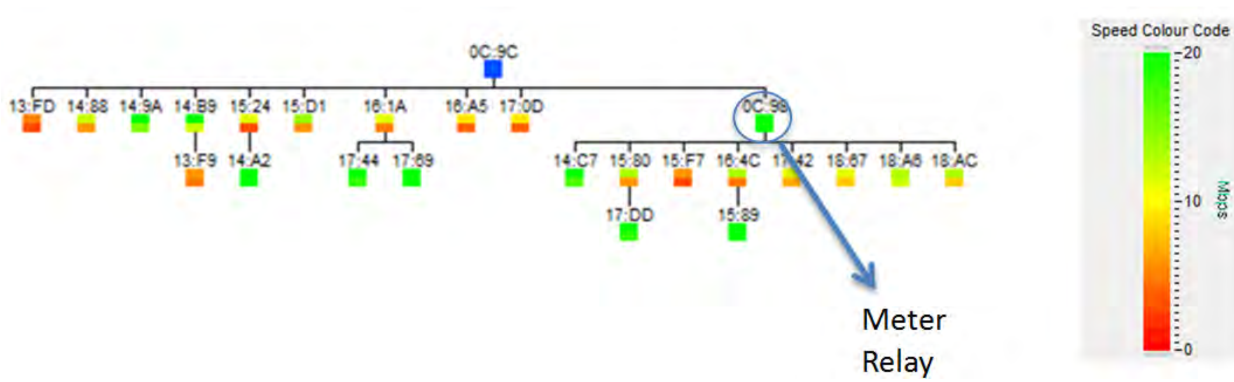


Figure 14: Generated tree topology

7.3. Distances Achieved

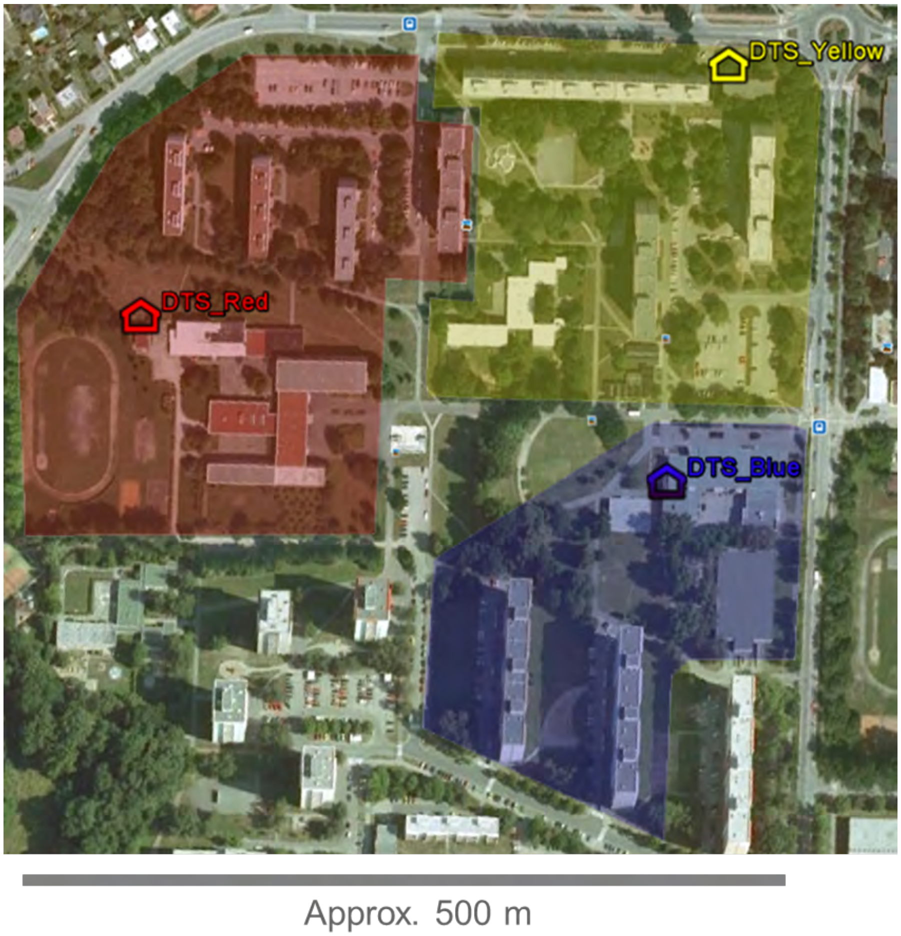


Figure 15: Three substations where Corinex AMI solution was deployed. The three shaded areas (in red, yellow and blue) show the coverage of each substation.

Figure 15 shows the geographical area where the Corinex AMI solution was deployed in Eastern Europe. There are three substations in this area and an SPGC was installed at each substation. Table 3 shows that meters can be installed up to 470 meters from the substation and still have connectivity. The Corinex BPL AMI solution is ideal for these types of network topologies where there are multiple dwelling units (MDUs) with clusters of meters in close proximity. Since the meters are in close proximity to each other, there's a greater chance of the meters being able to find another path to the head-end if their primary link becomes unreachable; therefore, the network is more robust. Also, with this many meters installed in the network, there is a higher probability for meters to act as repeaters the further away one travels from the substation.

Table 3: Statistics (re: figure 15)

	Yellow_Substation	Red_Substation	Blue_Substation
Most Remote Meter Installed from the Substation (m)	470	352	310
Number of Meters Installed	451	390	348

8. Benefits of Corinex BPL

Corinex's BPL AMI solution enables smart grid communication with the best price and performance over existing PLC and wireless technologies.

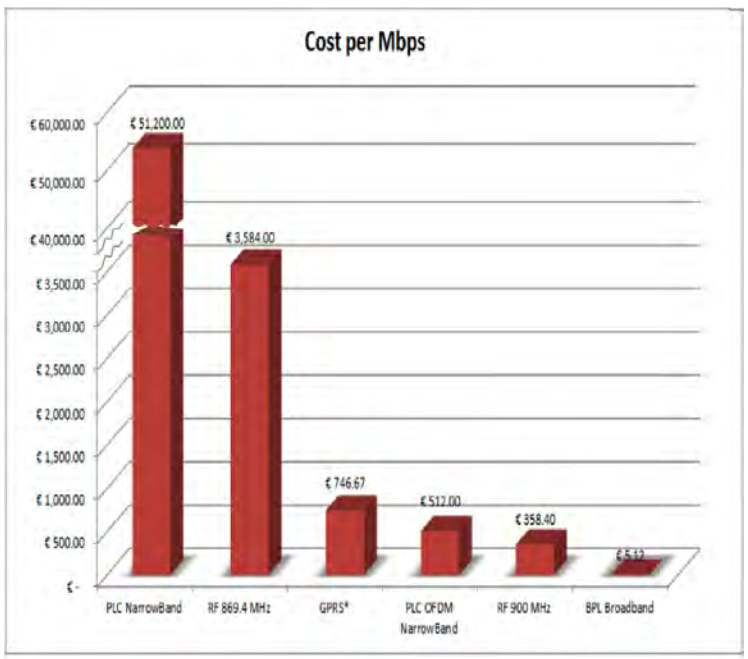


Figure 16: Cost per Mbps for different technologies

BPL can achieve the following benefits:

- Reliable high-speed communication in difficult, high-noise environments.
- Reduced labour costs for installation and outages – in-house utility field crews can be used for deployment. Outage times can be shortened, as precise fault locations can be better predicted i.e. the utility does not have to wait for customer feedback or have a field crew searching the streets.

- Additional bandwidth can be exploited for value-added services such as VoIP and system alarms.
- Reduced maintenance costs for networking systems.
- Technology can easily be scaled up to larger facilities.
- Connect a variety of devices using IP for interoperability (gateways can be connected to IEDs to further expand the smart grid network).

9. Challenges of using Other Technologies (Wireless Mesh & Narrowband PLC)

Early lifecycle wireless mesh technologies and narrowband PLC were selectively deployed in some areas of the world. Several issues were found with these deployments (2007-2011):

- High RF noise environments made wireless communication impossible.
- Workarounds have been expensive to connect 'orphaned meters' and significantly impacted the business case.
- Capacity for applications other than AMI (including demand response) were very limited, as meter data consumed the majority of the available bandwidth.
- Reliance on telcos for wireless capacity in their GPRS or G3 networks was undependable and very expensive.
- Installation planning was significant; ongoing troubleshooting required additional network expertise sometimes had to be brought in from outside the utility.
- Communication speeds in the kbps were common, with no real-time communication capability; real-time metering requests sometimes took several minutes or even hours to complete. Also, the information that could be retrieved from the meter was limited.
- Communication inside buildings proved difficult, and demand response was both very difficult and unproven.
- The topology of the area was a critical factor affecting the performance of wireless networks e.g. uneven terrain could make the wireless signal harder to propagate or severely limit its range.

11. Conclusion

Corinex's AMI BPL solution is an innovative new offering providing superior value for AMI and smart grid networks. Corinex would be pleased to offer this groundbreaking, patent-pending technology as a foundation for your future smart grid network. No other last-mile solution on the market offers comparable speeds, reliability and longevity as our next-generation smart grid solution.