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Communications for smarter energy systems

**Energy and utilities
Smart grid**

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Executive Summary

Two distinct but related developments are having a transformative effect on power grid infrastructure and the way it is managed. The first is a greater reliance on renewable but volatile energy sources; the second is the inclusion in the distribution domain of non-grid assets, such as microgeneration capabilities, roof-top photovoltaics, battery storage, electric vehicles, combined heat and power (CHP), and other types of distributed energy resources (DER).

Whereas utilities and system operators have complete control over their traditional grid assets, these newer, non-grid assets are in effect controlled by the owners of the premises on which they are installed. This presents a challenge to utilities attempting to balance load effectively and support real and reactive power while enabling dynamic renewable injection into the grid.

Smart devices, such as inverters and gateways, help address this problem. These technologies make active and effective grid management possible, by enabling communication between newer, distributed non-grid assets and the existing, traditional grid assets.

This is an example of the Internet of Things (IoT) in action and, as with all examples of the IoT, the introduction of smart, data-driven devices requires both the equipment and the communication it carries to be protected. Quality of Service (QoS) also comes into play, for example to ensure that control messages sent to solar photovoltaic installations are sent and received with the immediacy needed to ensure effective grid management. A robust, secure, and flexible communication infrastructure is therefore essential.

This paper looks at the connectivity options needed at various points within an increasingly smart power grid and discusses the challenges and potential solutions for three distinct use cases. It also looks at future communication and networking technologies that can deliver significant benefit to utilities, distribution service operators (DSOs), aggregators, and service providers.

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Distribution, decentralization, and digitization

Utiltities and system operators face the challenge of expanding grid capacity to meet growing demand with aging assets. DER tends to be less expensive to build and offers a shorter time to operation than monolithic power plants and high-voltage transmission lines. It has the potential to lower energy costs, improve service reliability, augment power quality, and increase energy efficiency. It also makes a significant contribution to the decarbonization agenda by facilitating the integration of renewable sources.

However, to optimize both energy management and grid planning in this new decentralized infrastructure, smarter systems for distributed generation and load management (including reactive power management and line sensing) are essential. To interconnect both the software and hardware elements of these diverse systems, smart technologies with integrated communications and security capabilities are required.

To date, in domains such as generation, transmission, and distribution, field bus protocols like Modbus*, which are sent over serial ports, have been used. However, in the low-voltage

(LV) distribution domain – where communication has traditionally been less well developed – the smart grid requires more advanced IP-based communication technologies to be deployed to gain access to the distributed, non-grid assets.

One of the challenges that utilities and DSOs have faced is that legacy process systems, such as SCADA, use proprietary data formats that serve a very closely prescribed purpose and are primarily reactive. Integrating these at the LV field level would be a costly and cumbersome method of sending real-time command controls to grid assets and, now, non-grid assets. This is where a robust IoT[1] platform plays a vital role. Enabling the convergence of operational technology (OT) – of which SCADA is a prime example – and information technology (IT), it connects smart systems with grid and non-grid assets at lower cost and lower risk and will create more efficient operations in the future.

The advance of the IoT will be further aided by the IPv6 protocol, which greatly extends both the number of IP addresses that can be allocated to previously unconnected devices and the routing capabilities of the communication network.

DATA RATE AND LATENCIES FOR VARIOUS USE CASES[2]

USE CASE DESCRIPTION	DATA RATE PER DEVICE	LATENCY (ROUND TRIP TIME)	LATENCY CLASS
Regulation of reactive power	5-100 kbps	0.5-5s	Medium
Synchrophasor power management unit (PMU)	> 5 kbps	<10 ms	Low
Smart metering, including demand response and DER integration (see following **use case 1**)	1 kbps	1 s-15 mn	High
Injection of energy into grid from distributed generation (see following **use case 2**)	1-5 kbps	5-60 s	High
Secondary substation as last-mile data hub (see following **use case 3**)	2-100 kbps	50-100 ms	Medium

Utilities and DSOs face important decisions. There is a large choice of communication technologies and protocols, including radio frequency (RF) mesh, power line communication (PLC) and fiber. More recently, this choice has been expanded by various flavors of LTE, or Long-Term Evolution, the standard for wireless communication of high-speed data. As the IoT drives commoditization of solutions, the architecture for the smart grid needs to be based on open standards at each stage from field devices to data centers.

Communication challenges, requirements, and solutions

Network resilience and QoS are both fundamental requirements at each stage of the network. In addition, end-to-end security is an operational requirement. It is also essential to comply with local, national, and international legislation and regulation.

There are also more specific challenges, which vary according to the particular use case under consideration. As Table 1 shows, different grid functions or use cases, across different domains, require varying rates of data transfer and latency.

As detailed in the representative use cases below, these requirements will often determine which technologies can be deployed in each case.

Use case 1: Smart metering, demand response, and DER integration

Smart meters are the source of essential consumption data from a variety of commercial and residential premises. In the future, meters will also have additonal functions to enable the control of non-grid assets to facilitate active grid management.

However, these vital components are located on customer premises and therefore present a particular set of communication challenges. Data must be gathered from meters installed in both congested urban environments and distant rural locations. It must also be aggregated so that data indexes can be read many times each day. Different countries have also specified different types of connectivity for their meters, which raises the question of interoperability in the future. The smart meters and associated communication technology need to be both upgradable and resilient: even allowing for upgrades, smart metering systems need to work perfectly for 15 to 20 years.

The most basic requirement, therefore, is that the smart metering system supports easy remote management. It should also support remote updates to devices and to a variety of sensor connections – such as Modbus, WMBUS or, in North America, DNP 3.0. Where national regulators allow, the communication system should also provide a way to easily integrate smart-metering information with the wider smart power grid that enables both demand response and remote home automation when these are required.

The transmitted data also has to be made available at an affordable price, including network subscriptions. The smart grid must, therefore, be able to transmit only the necessary data and locally store the remainder of the data set. The differing data transmission requirements for meters and solar PV generation illustrate the point. Metering indexes are read only at 15-minute intervals either for accurate billing of electricity consumption or to calculate feed-in payments from renewable injection. In contrast, data relating to solar PV generation is tracked on a second-by-second basis in order to optimize grid balance.

Finally, it is important that end users can connect to their data through a fully secured portal and that the integrity of their data is protected from theft or modification. End-to-end data security from the sensor to the data center is therefore imperative.

Solutions
There are a number of possible solutions that can address the requirements at the smart metering level, including narrowband or broadband PLC, RF, and LTE.

- Currently, the simplest option is to attach smart meters to a wireless sensor network (WSN) within an RF mesh that includes meters connected via GPRS to cellular stations. However, it is worth noting that RF mesh technologies are proprietary and do not offer the open standardization of LTE.

- Where bi-directional communication is needed between a demand response management system (DRMS) and a personal area network (PAN) or building

A more sophisticated solution for aggregation of meter data is to use Intel® IoT Gateway based on the Intel® Atom™ platform, which enables connectivity from meters to the Gateway through either PLC or LTE. This solution makes it possible to carry out edge analytics on local storage and thus minimize data traffic coming from the gateway. It also enables a mix of connectivity technologies to be deployed, with the gateway relaying data from one technology to the other. In this model, a secondary substation can play the role of a data hub.
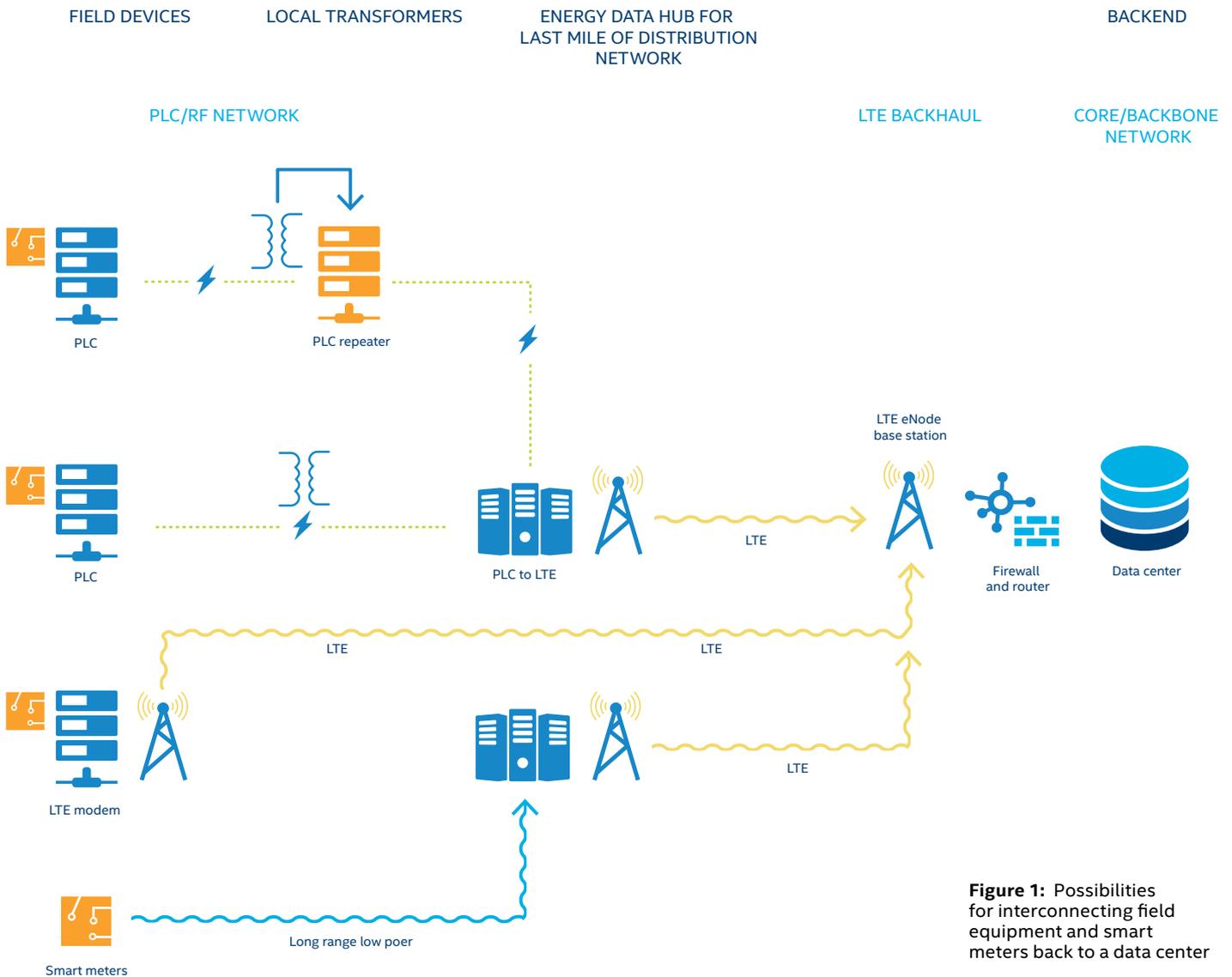
FIELD DEVICES LOCAL TRANSFORMERS ENERGY DATA HUB FOR LAST MILE OF DISTRIBUTION NETWORK BACKEND

PLC/RF NETWORK LTE BACKHAUL CORE/BACKBONE NETWORK

PLC

PLC repeater

LTE eNode base station

PLC

PLC to LTE

LTE

Firewall and router

Data center

LTE modem

LTE

LTE

LTE

Smart meters

Long range low poer

Figure 1: Possibilities for interconnecting field equipment and smart meters back to a data center

area network (BAN), protocols like MQ Telemetry Transport (MQTT) and OpenADR can be used. MQTT is designed to connect remote locations which require a 'lightweight' protocol suited for limited network bandwidth. In the future, these will be available using LTE-NB low-power devices on the existing LTE infrastructure. Security and updates can also be pushed over LTE using over-the-air (OTA) technology.

• As shown in Figure 1, a flexible and interoperable gateway to connect and bridge the various technologies is likely to be needed. For high-band communication,

such a gateway acts as a concentrator between PLC and a 3G or 4G LTE network. For medium-traffic requirements, the technologies to be connected are likely to be LTE Category 4 to LTE Category 6. In low-traffic networks, LTN ETSI M2M, LORA, SIGFOX, LTE-NB, or LTE Category 0 can all currently be found. LTE Category 1 may be used in low-traffic networks in the future.

The proposed data usage will determine requirements for speed, bandwidth, and latency, as well as physical media and communication protocols. In cases where demand for big data and analytics is greater, these choices will be more

limited. As both field metering and DER devices themselves consume energy, which DSOs will have to pay for, the most energy efficient chips and connectivity features will play a role in minimizing the energy envelope of the deployed solution in the grid.

Use case 2: Microgrids and energy injection from distributed generation

A microgrid can be defined as a self-sufficient energy entity serving a relatively small community, such as a village or small town, that can disconnect from and reconnect to the main grid when needed.

The main challenge in this case is the coordination and exchange of data between various devices and equipment, such as batteries, solar PV panels, generators, and even substations, within a strict timeframe set by the grid code. This is made more complicated by the variety of device manufacturers involved. At the same time, the voltage and frequency of the load have to be stabilized along the electrical copper cables.

Voltage and phase data at both the substation and the DER installation therefore need to be time stamped – using network time protocol (NTP) and, in the case of electric vehicles, GPS coordinates – to determine whether the DER and the wider power grid are synchronized. The accurate time stamp should make the method independent of small time delays in the communication channel.

Finally, because equipment may be dispersed over a wide geographic area in locations that are often hard to access, remote monitoring of the gateway and IT devices are a key feature

of a smart and self-healing grid. Secure communication ensures that data can be transmitted and data persistency maintained in real time, even when a device is disconnected. This in turn means that nodes need to be managed in real time.

Solutions

- The use of standard protocols and data models addresses a number of these difficulties, notably the IEC 61850 standard for data exchange between the various systems and the IEC 62056 standard for exchanging electricity metering data.[3]

- The inclusion of high-performant multi-agent based autonomous control systems can be used to exchange load and generation forecast (and support energy price trading).[4]

- A data distribution system (DDS) can be used for real-time data when latency needs to be less than one second.[5] As DDS is based on the user datagram protocol (UDP),

it avoids many of the problems related to the use of transmission control protocol (TCP).[6]

Here the advantages of LTE come to the fore. Providing both low latency and high bandwidth, LTE is a promising solution for interconnecting the various devices and equipment in a smart microgrid.[7] LTE can be used in cases where RF mesh is not ideal. This includes backhaul, access to remote areas, or when sub-second latency is required. As Table 2 shows, there are different flavors of LTE that can be used in these circumstances.

Both data rates and latency are highly dependent on the rate of path loss. They can also be strongly affected in extreme coverage scenarios. For example, LTE category M and LTE-NB can withstand much higher path loss but they will decrease data rates and increase latency as a result. Power usage depends on the cycle of stand-by, hibernation, and working of the application and the platform.

CURRENT AND FUTURE LTE SOLUTIONS COMPARED TO OTHER WIRELESS TECHNOLOGIES[8]

CATEGORY	DATA RATE (UP /DOWN)	BEST LATENCY (RTT)	POWER TECHNOLOGY
LTE-NB	200 kbps	Low during normal coverage, but high in extreme coverage	1 to 20 years on battery (depending on use case)
Cat M LTE	1/1 Mbps	Low during normal coverage, but high in extreme coverage	1 to 20 years on battery (depending on use case)
Cat 0 LTE	1/1 Mbps	Low	Not yet estimated
Cat 1 LTE	5/10 Mbps	Low	Not yet estimated
Cat 4 LTE	50/150 Mbps	Low (10 ms)	On battery if use case allows
Cat 6 LTE	50/300 Mbps	Low (10 ms)	On battery if use case allows
3G	Up to 700 kbps	Medium (200 ms)	n/a
EDGE	Up to 384 kbps	High	n/a
GPRS	Up to 140 kbps	High (600 ms)	n/a
GSM data	Up to 14 kbps	High (600 ms)	n/a
Long-range low-power network (LORA)	<10 kbps	Duty cycle	Up to 20 years on battery

Use case 3: Secondary substation as last-mile data hub

The combination of the two use cases outlined above creates an opportunity to build a 'super smart' solution at the distribution domain level by bringing together grid and metering functionality at the same location. In this use case, a secondary substation can be optimized to host the bridge between all communication standards and protocols and to create an intelligent node for gathering, processing and analyzing data. This can enhance both energy management and active grid management capabilities and improve operations for both transmission service operators (TSOs) and DSOs.

Fixed, LTE wireless, or optical fiber can all form the basis of a communication network that uses IEC 61850, the global standard for communication in substations. End-to-end data security is required to protect the connections between various sensors and embedded devices within the substation. It also needs to protect communication between the substation and the operation center. Cyber security solutions to protect critical infrastructure are also essential.

One of the advantages of the intelligent substation is that QoS levels can be adjusted for different circumstances and uses. The substation-as-data-hub model also requires the ability to isolate any of the various applications running on the same platform. Edge analytics with log capabilities on field devices are therefore needed.

Solutions

- Encrypted communication between mutually authenticated systems and substations, based on security analytics are required so that interconnections can be

To facilitate the convergence of gateways and base station and to support edge analytics, an embedded system that enables Intel® Security Critical Infrastructure Protection (Intel® Security CIP) can be used.[10] Based on the Intel® Core™ processor or the Intel® Atom™ platform, Intel Security CIP provides a real-time, deterministic, and virtualized platform that enables the safe processing of data in different application virtual machines. It provides some network function, such as Network Functions Virtualization (NFV), and allows analytics to be protected by enhanced security features inherent in Intel Security CIP.

The Intel Security – Data Exchange Layer (DXL) provides real-time context sharing and orchestration, while the Intel Security Information and Event Management (SIEM) brings best-in-class security event and network traffic analysis for the distribution domain. Finally, device identity can be assured through Intel® Enhanced Privacy ID (Intel® EPID), which provides a trust anchor in hardware. Intel EPID keys are distributed in Intel® Xeon™ processors, Intel Core processors, and Intel Atom processors.[11]

operated, monitored and remotely managed in zones, enabling appropriate action to be taken when necessary.

- Real-time context sharing and orchestration, as well as collective threat intelligence and adaptive threat prevention techniques are also required. They should be suitable for scalable networks such as the smart electricity grid.[9]

- A Security Information and Event Management (SIEM) system can be used to analyze and correlate security events and network traffic on a distribution grid network. It brings together event, threat, and risk data to provide strong security intelligence, rapid incident response, seamless log management, and extensible compliance reporting.

- Devices like smart meters and gateways that multicast data to the communication network should also be authenticated.

The future of smart grid communication

As technology continues to evolve, new opportunities for utilities and DSOs will emerge. The following developments present new possibilities for managing communication networks in the future.

Optimizing data flow between field devices and data centers

It is often necessary to control the volume of data to be transferred back to the core communication network, either by limiting data sent to the backhaul network or by optimizing pre-processed data on the gateways. Figure 2 shows the various possibilities for connecting equipment to the data center and the use of intelligent gateways to locally pre-process data in order to reduce traffic and save bandwidth. This structure has the ability to identify which data is to be sent from the hub or gateway to the data center. It also determines which parts of the network are to be private and which are to be public.
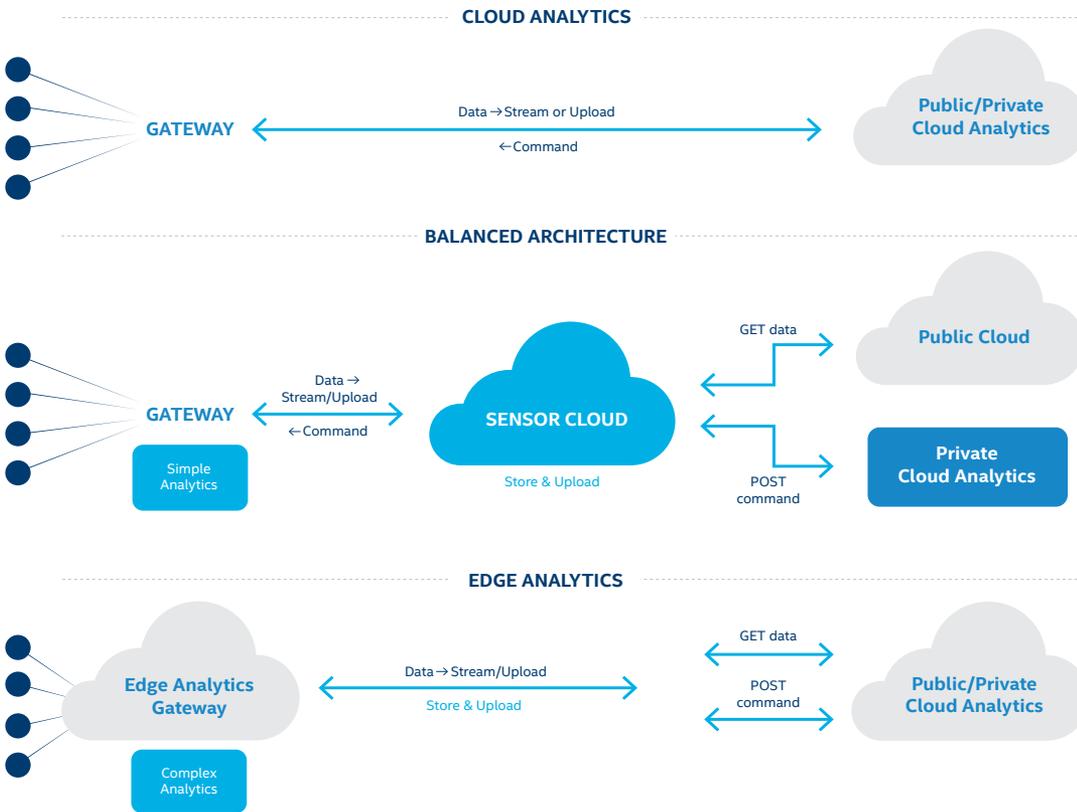
CLOUD ANALYTICS

GATEWAY

Data → Stream or Upload

← Command

Public/Private Cloud Analytics

BALANCED ARCHITECTURE

GATEWAY

Simple Analytics

Data → Stream/Upload

← Command

SENSOR CLOUD

Store & Upload

GET data

POST command

Public Cloud

Private Cloud Analytics

EDGE ANALYTICS

Edge Analytics Gateway

Complex Analytics

Data → Stream/Upload

Store & Upload

GET data

POST command

Public/Private Cloud Analytics

Figure 2: Connectivity options for smart bandwidth use

This is an area that demonstrates the importance of IPv6. Because IPv6 greatly expands the address space available, it enables greater flexibility when it comes to address configuration. This makes it possible to create sub-networks that can be dedicated to distributed generation and storage or electric vehicle charging stations, for example. In addition, IPv6 expands and simplifies multicast addressing, which enables system operators to target precisely the subdomains they need to communicate with. This has the potential to reduce network traffic, improve the use of bandwidth, and further optimize the delivery of services. The design of the IPv6 protocol also takes into account the general need for more device mobility, configuration, and security, including authentication and encryption.

Optimizing data flow also requires the use of field-message buses with communication nodes that can separate non-critical data from data which needs to be processed in real time. This can be achieved by using DDS for real-time data. DDS provides a brokerless solution for data persistency that can be adjusted to meet various required QoS levels.

With data taking a central role in the smart energy grid, data management and storage solutions are increasingly important. An Apache Hadoop* cluster gives utilities an open-source, time-series database that can store structured and semi-structured data sets from all sources in a single place. The Hadoop cluster can process smart meter data, SCADA exports, phase readings, geographic information, and digitized customer calls. It also

differentiates and prioritizes them according to QoS requirements.

The processed data can also be further analyzed by new and existing applications, such as business intelligence, deep learning, and machine learning. These applications can support interactive queries and other advanced business needs. Intel® Analytics Toolkit for Apache Hadoop* software makes it easy to transform and analyze these diverse data types using familiar interfaces.[12]

Simulation of a communication network

DER can disrupt the balance of power flows at both the transmission and distribution levels of the power grid. Any failure due to packet loss or congestion from excess latency on the

communication network is likely to lead to electrical instability. The ability to reconfigure communication networks in the event of data congestion is therefore an essential feature of a smart grid. The communication network should also be scalable in order to integrate new renewable energy sources as they come online.

As illustrated in Figure 3, a solar PV farm, a microgrid, or other elements within a distributed infrastructure, can be described as small smart-grid cells within a cellular network macrocell. Some elements in the field also act as local aggregators for these smart-grid cells. Early estimates of LTE traffic in a macrocell have found that the optimal traffic rate is between three and five

Mbps per cell.[13] This is the rate that best enables the smart grid to deliver the operational needs of TSOs and DSOs. In regions where the penetration of DER is greater than assumed in this estimation, the figures can be updated through further simulations.[14]

Simulation technologies help utilities predict and optimize the performance and cost of the system. For example, simulation models can be used to predict the impact of different network topologies on CapEx or OpEx budgets. Alternatively, simulation can be used to assess the robustness of grid networks in the event of a failing element in the field system or communication network.

Solutions like Mosaik*, a co-simulation framework, enables grid operators to integrate distributed intelligent agents that are active on power flow controllers (PFC) to create large-scale smart grid scenarios. When used in conjunction with the Intel® CoFluent™ studio, it enables utilities to co-simulate the behavior, timing requirements, architecture, and performance estimates of field devices and other components in various communication topologies. This ensures ongoing grid resilience.[15]
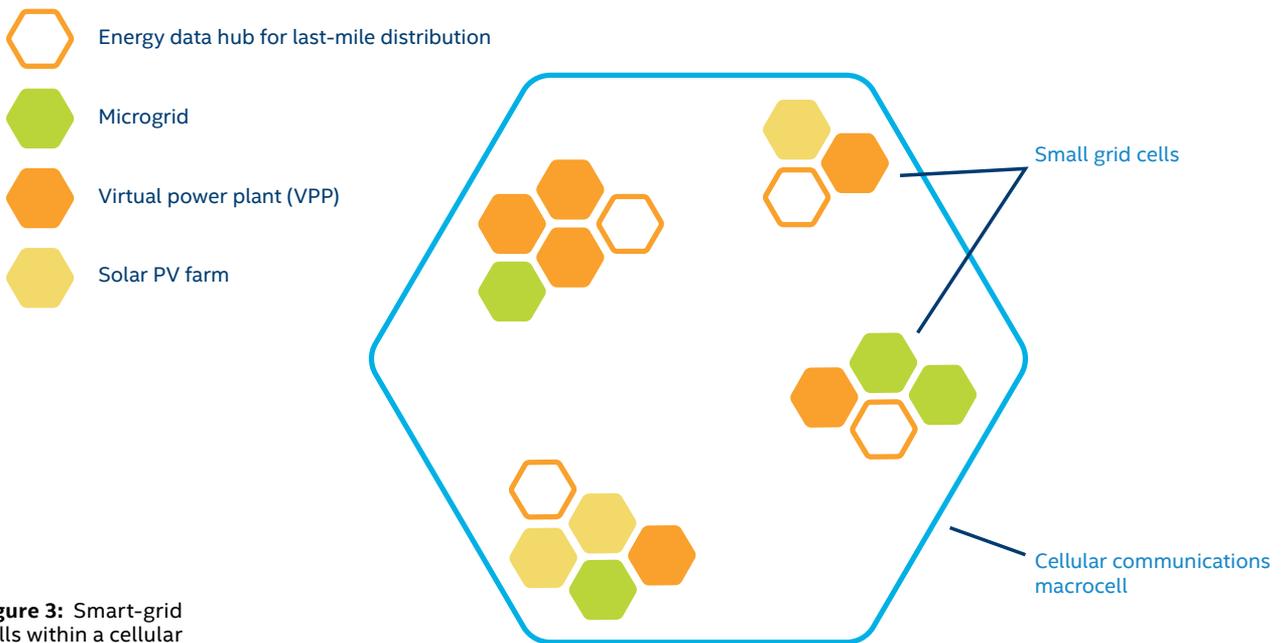

- ⬡ Energy data hub for last-mile distribution
- ⬢ Microgrid
- ⬢ Virtual power plant (VPP)
- ⬢ Solar PV farm

Small grid cells

Cellular communications macrocell

Figure 3: Smart-grid cells within a cellular network macrocell

Conclusion

The smart grid addresses a number of challenges facing today's utilities, grid operators, and their customers. But it will only do so if its communication network can support a number of vital features, notably a distributed architecture, heterogeneous networks, full end-to-end security, selective transmission of data, and local and distant data processing. The technologies deployed must be stable, secure, interoperable, and standards-based. This helps to protect investment through a modular approach and to lower the total cost of ownership.

As this paper explains, both IPv6 and LTE meet these requirements. Because IPv6 makes it possible to multicast data, available bandwidth can be used in more intelligent ways. As an IP-based technology, LTE enables the high performance and low latency

necessary for the use cases outlined here and those of the future. LTE also offers the advantage of ultra-low power consumption, enhancing it suitability for smart-grid deployments.[16]

Grid operators are starting to deploy smart technologies based on flavors of LTE that are currently available. As LTE evolves, and more advanced flavors come to market in the next few years, smart grid deployments will start to make greater use of IoT technologies that enable zero-touch, machine-to-machine communication.

Many of the technologies discussed in this paper are already widely used in the telecommunication sector. They are also transforming and streamlining network and data centers operations in various industries by enabling virtualization techniques. Adopting IP-based communication in each domain of the smart grid

network brings the benefits seen in these networks to the communication infrastructure of the smart grid. For example, the virtualization behind Software Defined Networks (SDN) would make reconfiguring and orchestrating a network of field devices relatively straightforward.[17] The techniques behind Network Function Virtualization (NFV) could also be enabled. This would make it easy to add analytics and security functionality to virtual machines at secondary substations or even onto LTE eNode base stations. This would bring new capabilities and services to the smart grid network.

With these emerging and evolving technologies, telecom service providers, grid operators, and power utilities are able to put in place the necessary foundations for a network that enables technical, operational, and energy efficiencies throughout the grid.

For more information about Intel® and the Smart Grid, visit **http://www.intel. com/content/www/us/en/energy/ energy-overview.html**

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