# Communication Network Solutions for Smart Grids

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8 Communication Network Solutions for Smart Grids

8.1 Introduction

A secure, reliable and economic power supply is closely linked to a fast, efficient and dependable communication infrastructure. Planning and implementation of communication networks require the same attention as the installation of the power supply systems themselves (fig. 8.1-1).

Telecommunication for utilities has a long history in the transmission level of the power supply system and Siemens was one of the first suppliers of communication systems for power utilities. Since the early 1930s Siemens has delivered power line carrier equipment for high-voltage systems. In today’s transmission systems, almost all substations are monitored and controlled online by Energy Management Systems (EMS). The main transmission lines are usually equipped with fiber-optic cables, mostly integrated in the earth (ground) wires (OPGW: Optical Ground Wire) and the substations are accessible via broadband communication systems. The two proven and optimal communication technologies for application-specific needs are Synchronous Digital Hierarchy (SDH) and MPLS-TP solutions. Fiber-optic cables are used whenever it is cost-efficient. In the remote ends of the power transmission system, however, where the installation of fiber-optic cables or wireless solutions is not economical, substations are connected via digital high-voltage power line carrier systems.

The situation in the distribution grid is quite different. Whereas subtransmission and primary substations are equipped with digital communication as well, the communication infrastructure at lower distribution levels is very weak. In most countries, less than 10% of transformer substations and ring-main units (RMU) are monitored and controlled from remote.

The rapid increase in distributed energy resources today is impairing the power quality of the distribution network. That is why system operators need to be able to respond quickly in critical situations. A prerequisite for this is the integration of the key ring-main units as well as the volatile decentralized wind and solar generation into the energy management system, and

Fig. 8.1-1: Siemens offers complete communication network solutions to build a Smart Grid for power utilities
thus into the communication network of the power utilities. Because the local environment differs widely, it is crucial that the right mix of the various communication technologies is deployed. This mix will need to be exactly tailored to the utilities’ needs and the availability of the necessary infrastructure and resources (e.g., availability of fiber-optic cables, frequency spectrum for wireless technologies, or quality and length of the power cables for broadband power line carrier).

In the consumer access area, the communication needs are rising rapidly as well. The following Smart Grid applications request a bidirectional communication infrastructure down to consumer premises.

- Exchange of conventional meters with smart meters, which provide bidirectional communications connections between the consumer and energy applications (e.g., meter data management, marketplace, etc.)
- Management of consumers’ energy consumption, using price signals as a response to the steadily changing energy supply of large distributed producers
- If a large number of small energy resources are involved, the power quality of the low-voltage system must be monitored, because the flow of current can change directions when feed conditions are favorable.

The selection of a communication solution depends on the customer’s requirements. If only meter data and price signals are to be transmitted, narrowband systems such as narrowband power line carriers or GPRS modems are sufficient. For smart homes in which power generation and controllable loads (e.g., appliances) or e-car charging stations are to be managed, broadband communication systems such as fiber-optic cables, power line carriers or wireless solutions are necessary.

For these complex communication requirements, Siemens offers tailored ruggedized communication network solutions for fiber optic, power line or wireless infrastructures, based on the standards of the Energy Industry. Naturally, this also includes a full range of services, from communication analysis to the operation of the entire solution (fig. 8.1-2).

8.2 Communication Network Solutions for Transmission Grids (Communication Backbone)

8.2.1 Smart Grid Fiber-Optic Communications on its Way to Carrier and Utility Grade Packet Transport Networks

**Today – Synchronous Digital Hierarchy (SDH) plus PDH (Plesiochronous Digital Hierarchy) Access Multiplexer Solutions**

Today, SDH solutions in combination with PDH Access Multiplexer are used mostly by utilities for the communication requirements in high-voltage networks. Siemens offers for these demands the latest generation of SDH equipment, commonly referred to as NG (Next Generation) SDH systems or Multi-Service Provisioning Platforms (MSPP).

NG SDH technology combines a number of benefits that makes it still well-suited to the needs of power utilities. Among those benefits are high availability, comprehensive manageability, and monitoring features. Ethernet-over-SDH provides the capacity to transport packet-based traffic over the SDH backbone with high reliability and low latencies. State-of-the-art NG SDH systems are highly integrated, providing the requested capabilities for utilities in a single device.

At the subscriber side there is still a need to operate a number of different systems with conventional communication interfaces in today’s substations (e.g., FXS, FXO, E&M, V.24, X.21, etc.). For this purpose, so-called PDH access multiplexers are used, which provide the requested interfaces, bundle the communication signals, and pass them on to the NG-SDH systems.

Fig 8.2-1 shows a typical NG-SDH solution with connected PDH Access Multiplexer.

**Migration to highly available (carrier and utility grade) MPLS-TP (Multi-Protocol Label Switching – Transport Profile) networks**

The SDH technology, combined with PDH multiplexer, is a well-proven solution for the manifold communication requirements of the transmission utilities.

But meanwhile new requirements arise, which clearly identify the limits of the SDH/PDH technology. Especially the demand for further cost savings, above all the OPEX part, is the main challenge for the communication departments of the utilities. At the same time, the portion of packet-based data (Ethernet and IP) in

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![Diagram](image-url)  
**Fig. 8.2-1: Typical Next Generation SDH solution for transmission grids**
the wide area networks, caused by new Ethernet- and IP-based systems (e.g., new RTUs, IEC61850 protection systems, sensors, IP telephony, IP CCTV, etc.) is increasing dramatically.

In order to follow the general trend of the telecom industry and the roadmaps of the network manufacturers, the existing traditional communication networks need to be migrated into highly available, packet-based hybrid systems with low latency.

However, these packet-based optical networks need to meet the specific communication requirements of the transmission network operators. The most important requests are:

- Cost-optimized installation and operation of the network
- Low latency and the possibility of circuit switching
- Use for critical Smart Grid applications (e.g., distance and differential protection)
- Easy network extension
- Support of conventional communication interfaces.

In order to meet these requirements, we recommend a stepwise migration of the installed SDH/PDH communication infrastructure to a packet-based, highly available (carrier and utility grade) and standardized MPLS-TP transport network, which integrates, besides Ethernet, also conventional interfaces.

This means that MPLS-TP systems offer the integration of voice, data and protection signals into one system. This allows the operation of older systems during a transition period.

Fig. 8.2-2 shows a typical MPLS-TP communication network.

In a final stage, Ethernet would be the single communication interface, which will be used in the backbone as well as in the access network.

Based on this easy network structure in combination with a powerful Network Management System (NMS) and intelligent network functions, daily network configuration tasks and other service work can be performed fast and straightforward. This is the basis for further OPEX reductions.

Benefits of a MPLS-TP communication network

- Exceptionally cost-efficient operation of the network
- Supports all latency critical Smart Grid applications
- SDH-like look-and-feel (e.g., central NMS, fixed communication paths)
- Efficient use of the available transmission bandwidth, etc.)
- Supports the conventional interfaces, and is therefore perfectly applicable for a stepwise migration from SDH to an Ethernet- and IP-based Next Generation network.

Siemens offers a wide range of end-to-end solutions for utility grade telecommunication networks, and supports with its Smart Grid knowledge a smooth migration from today’s TDM-based networks towards IP-based networks.

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**Fig. 8.2-2: MPLS-TP communication solution for transmission grids**
8.2.2 PowerLink – Power Line Carrier for High-Voltage Lines

The digital power line carrier system PowerLink from Siemens (fig. 8.2-3) uses the high-voltage line between substations as a communication channel for data, protection signals and voice transmission. This technology, which has been applied over decades, adapted to the latest standards, and has two main application areas:

- As a communication link between substations where a fiber-optic connection does not exist or would not be economically viable
- As backup system for transmitting the protection signals, in parallel to a fiber-optic link.

Fig. 8.2-4 shows the typical connection of the PowerLink system to the high-voltage line via the coupling unit AKE 100, coupling capacitor.

Fig. 8.2-3: PowerLink system

Fig. 8.2-4: PowerLink high-voltage line communication
Flexibility – the most important aspect of PowerLink
Versatility is one of the great strengths of the PowerLink system. PowerLink can be matched flexibly to your infrastructure (table 8.2-1).

Multi-service device
PowerLink offers the necessary flexibility for transmitting every service the customer might want in the available band. All services can be combined in any way within the available bandwidth/bit rate framework.

Bridge to IP
IP functionality is best suited for the migration from TDM to packet-switched networks. PowerLink offers electrical and optical Ethernet interfaces, including an integrated L2 switch, extending the IP network to remote substations with a bit rate up to 320 kbps.

Optimal data throughput under changing environmental conditions
PowerLink adapts the data rate to changes in ambient conditions, thus guaranteeing maximum data throughput. Thanks to PowerLink’s integral prioritization function, which can be configured for each channel, routing of the most important channels is assured even in poor weather conditions.

Variable transmission power
The transmission power can be configured via software in two ranges (20 – 50 W or 40 – 100 W), based on the requirements of the transmission path. This makes it easy to comply with national regulations and to enable optimized frequency planning.

Maximum efficiency – the integrated, versatile multiplexer (vMUX)
A large number of conventional communication interfaces today (e.g., ab telephone, V.24, X.21, etc.) and in the foreseeable future must be operated in a switching station. For this purpose, PowerLink uses an integrated versatile multiplexer that bundles these communication forms together and transmits them by PLC. The vMUX is a statistical multiplexer with priority control. Asynchronous data channels can be transmitted in “guaranteed” or “best effort” modes, to guarantee optimum utilization of available transmission capacity. The priority control ensures reliable transmission of the most important asynchronous and synchronous data channels and voice channels even under poor transmission conditions. Naturally, the vMUX is integrated in the management system of PowerLink, and is perfectly equipped for the power line communication requirements of the future with extended options for transmitting digital voice and data signals.

### Features

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<thead>
<tr>
<th>Features</th>
<th>Digital PLC system</th>
<th>Analog PLC system</th>
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<tbody>
<tr>
<td>Universally applicable in analog, digital, or mixed operation</td>
<td>■</td>
<td>■</td>
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<tr>
<td>Frequency range 24 kHz – 1,000 kHz</td>
<td>■</td>
<td>■</td>
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<tr>
<td>Bandwidth selectable 2 kHz – 32 kHz</td>
<td>■</td>
<td>■</td>
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<tr>
<td>Data rate up to 320 Kbps @ 32 kHz</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Transmission power 20/50/100 W, fine adjustment through software</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Operation with or without frequency band spacing with automatic cross talk canceller</td>
<td>■</td>
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**Digital interface**
- Synchronous X.21 (max. 2 channels)
- Asynchronous RS 232 (max. 8 channels)
- TCPIIP (1 x electrical, 1 x optical for user data; 1 x electrical for service)
- E1 (2 Mbps) for voice compression
- G703.1 (64 Kbps)

**Analog interface**
- VF (VFM, VFO, VFS), max. 8 channels for voice, data and protection
- Asynchronous RS232 (max. 4) via FSK

**Miscellaneous**
- Adaptive dynamic data rate adjustment
- TCP/IP layer 2 bridge
- Integrated versatile multiplexer for voice and data
- Max. 5 compressed voice channels via VF interface
- Max. 8 voice channels via E1 interface
- StationLink bus for the cross-connection of max. 4 PLC transmission routes (data and compressed voice; compressed voice routed without compression on repeater)
- Reverse FSK analog RTU/modem data via dPLC (2 x)

**Protection signal transmission system SWT 3000**
- Integration of two devices in PowerLink
- Remote operation via cable or fiber-optic cable identical to the integrated version
- Single-purpose or multi-purpose/alternate multi-purpose mode
- Element manager, based on a graphical user interface for the control and monitoring of PLC and teleprotection systems
- Command interface binary and in accordance with IEC 61850

**Remote access to PowerLink**
- Via TCPIIP connection
- Via in-band service channel
- SNMP compatibility for integrating NMS
- Event memory with time stamp
- Simple feature upgrade through software

Table 8.2-1: Overview of features
Voice compression
Voice compression is indispensable for the efficient utilization of networks. Naturally, quality must not suffer, which is why PowerLink offers comprehensive options for adapting the data rate to individual requirements. PowerLink offers different compression stages between 5.3 and 8 kbit/s. To prevent any impairment of voice quality, the compressed voice band is routed transparently to PowerLink stations connected in line, without any further compression or decompression.

Protection signal transmission system SWT 3000
A maximum of two independent SWT 3000 systems can be integrated into PowerLink. Every integrated teleprotection system can transmit up to four protection commands. The command interface type for distance protection devices can be either standard binary or compliant with IEC 61850. Even a combination of both command interface types is supported. For highest availability, an alternate transmission path via a digital communication link can be connected in PowerLink. SWT 3000 systems are also fully integrated into the user interface of the PowerLink administration tool.

One administration system for all applications
PowerLink not only simplifies your communications, but also makes communications cost-efficient. The PowerSys software administers all integrated applications of PowerLink under a standard user interface. This ensures higher operating security while cutting training times and costs to the minimum.

Integration of PowerLink in network management systems via SNMP
PowerLink systems can also be integrated in higher level management systems via the IP access by means of the SNMP protocol (Simple Network Management Protocol). System and network state data are transferred, for example, to an alarm, inventory or performance management system.
8.2.3 SWT 3000 – Teleprotection for High-Voltage Lines

The SWT 3000 (fig. 8.2-5) is an highly secure and reliable system for transmitting time-critical distance protection commands via analog and digital transmission channels (fig. 8.2-6). This enables faults in the high-voltage grid to be isolated selectively as quickly as possible. The SWT 3000 system can be integrated in the PowerLink system or be operated as a stand-alone system.

Security, reliability and speed of protection signal transmission is one of the central factors in the operation of high-voltage grids. For maximum operating reliability, SWT 3000 can be configured with two separately fed power supplies. If possible, protection signals should be transmitted over two alternative communication paths to safeguard maximum transmission security. Fig. 8.2-7 shows the different analog and digital transmission paths between SWT 3000 systems.

The SWT 3000 also demonstrates its high degree of flexibility when existing substations are migrated to protection devices via the IEC 61850 communication standard. The SWT 3000 has all necessary command interfaces – both as binary interfaces and as GOOSE. This always keeps investment costs economically manageable, because the substations can be updated step by step for a new network age.

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**Fig. 8.2-5: SWT 3000 teleprotection system**

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**Application**
Transmission of protection signals to quickly identify, isolate and resolve problems in the transmission network of a utility

**Advantages**
- Keeps downtimes to an absolute minimum
- Supports IEC 61850 interfaces as well as conventional binary interfaces
- Flexible integration into various customer communication networks
- Path protection via two different transmission routes for increased reliability

* not applicable in combination with IEC 61850

**Fig. 8.2-6: SWT 3000 teleprotection system – wide range of Command and Line interface**
Pilot cable connections
For operation via pilot cable, two SWT 3000 devices can be linked directly through the analog interfaces (CLE).

Power line carrier connections
The analog link (CLE) between two SWT 3000 devices can also be a PLC link. Depending on device configuration, SWT 3000 can be used with PowerLink in alternate multi-purpose, simultaneous multi-purpose, or single-purpose mode.

Fiber-optic connections between SWT 3000 and PowerLink
A short-distance connection between an SWT 3000 and Siemens’ PowerLink PLC terminal can be realized via an integrated fiber-optic modem. In this case, an SWT 3000 stand-alone system provides the same advanced functionality as the version integrated into PowerLink. Each PowerLink can be connected to two SWT 3000 devices via optical fibers.

SWT 3000 digital connections
The digital interface (DLE) permits protection signals to be transmitted over a PDH or SDH network.

SWT 300 Ethernet connections
The ETH line interface (EN 100) supports transmission via packet based networks.

Alternative transmission routes
SWT 300 enables transmission of protection signals via two different routes. Both routes are constantly transmitting. In the event that one route fails, the second route still bears the signal.

Direct fiber-optic connection without repeater
SWT 3000 protection signaling incorporates an internal fiber-optic modem for long-distance transmission. The maximum distance between two SWT 3000 devices is 150 kilometers.

Fiber-optic connection between SWT 3000 and a multiplexer
A short-distance connection of up to two kilometers between SWT 3000 and a multiplexer can be realized via the integrated fiber-optic modem according to IEEE C37.94. Alternately, the multiplexer is connected via FOBox, converting the optical signal to an electrical signal in case the MUX does not support C37.94.

SWT 3000 integration into the PowerLink – PLC system
The SWT 3000 system can be integrated into the PowerLink equipment. Either the analog interface or a combination of the analog and the digital interfaces can be used.

Fig. 8.2-7: SWT 3000 transmission paths
## SWT 3000 integration into the PowerLink –

### 1. Direct fiber-optic connection without repeater

- **SWT 3000**: Fiber-optic connections with PowerLink equipment. Interface EN 100 enables transmission of protection signaling incorporates an internal fiber-optic modem for long-distance transmission. The maximum distance between SWT 3000 and PowerLink via an integrated fiber-optic modem is 150 kilometers.

### 2. Alternate transmission routes

- SWT 3000 can be integrated into the PLC system as a pilot cable connection or a combination of the analog and the digital PowerLink equipment. Either the analog interface or the digital interface (DLE) can be used. SWT 3000 digital connections can be used for operation via pilot cable, two SWT 3000 devices can be linked directly through the analog link (CLE) between two SWT 3000 devices.

### 3. Pilot cable connections

- SWT 3000 enables transmission of protection signals via packet based networks. An external or internal fiber-optic modem can be used for transmission. The ETH line interface (EN 100) supports transmission via an integrated fiber-optic modem. In this case, an SWT 3000 stand-alone system provides multi-purpose, or single-purpose mode. PowerLink in alternate multi-purpose, simultaneous device configuration, SWT 3000 can be used with Siemens' PowerLink PLC terminal can be realized via optical fibers.

### 4. Analog transmission

<table>
<thead>
<tr>
<th>SWT 3000</th>
<th>EN 100</th>
<th>Interface IEC 61850/Ethernet line</th>
</tr>
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<tbody>
<tr>
<td>PowerLink</td>
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</table>

### 5. Digital transmission

<table>
<thead>
<tr>
<th>SWT 3000</th>
<th>EN 100</th>
<th>SDH/PDH Fiber</th>
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</thead>
<tbody>
<tr>
<td>PowerLink</td>
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### 6. Analog & Digital transmission

<table>
<thead>
<tr>
<th>SWT 3000</th>
<th>EN 100</th>
<th>MUX</th>
<th>SDH/PDH</th>
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<tr>
<td>PowerLink</td>
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### Integrated into PowerLink

<table>
<thead>
<tr>
<th>PowerLink</th>
<th>EN 100</th>
<th>PowerLink</th>
<th>EN 100</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SDH/PDH</td>
</tr>
</tbody>
</table>

### Definitions

- **PDH**: Plesiochronous Digital Hierarchy
- **CLE**: Copper Line Equipment
- **FOBox**: Fiber-Optic Box
- **FO**: Fiber-Optic Module
- **MUX**: Multiplexer
- **EN 100**: Interface IEC 61850/Ethernet line
- **IP Network**: Digital network
- **Ethernet network**: Ethernet network
- **SDH**: Synchronous Digital Hierarchy
- **DLE**: Digital Line Equipment
- **CLE**: Copper Line Equipment
- **FO**: Fiber-Optic Module
- **MUX**: Multiplexer
8.2.4 Coupling Unit AKE 100

The PLC terminals are connected to the power line via coupling capacitors, or via capacitive voltage transformers and the coupling unit. In order to prevent the PLC currents from flowing to the power switchgear or in other undesired directions (e.g., tapped lines), traps (coils) are used, which are rated for the operating and short-circuit currents of the power installation and involve no significant loss for the power distribution system.

The AKE 100 coupling unit from Siemens described here, together with a high-voltage coupling capacitor, forms a high-pass filter for the required carrier frequencies, whose lower cut-off frequency is determined by the rating of the coupling capacitor and the chosen matching ratio.

The AKE 100 coupling unit is supplied in two versions and is used for:
- Phase-to-earth coupling to overhead power lines
- Phase-to-phase coupling to overhead power lines
- Phase-to-earth coupling to power cables
- Phase-to-phase coupling to power cables
- Intersystem coupling with two phase-to-earth coupling units.

The coupling units for phase-to-phase coupling are adaptable for use as phase-to-earth coupling units. The versions for phase-to-earth coupling can be retrofitted for phase-to-phase coupling, or can as well be used for intersystem coupling.

8.2.5 Voice Communication with PowerLink

The TCP/IP protocol is gaining increasing acceptance in the voice communication area. However, considerably higher bandwidth requirements must be taken into account in network planning with VoIP compared with analog voice links. Table 8.2-2 shows the bandwidth requirement for a voice link via TCP/IP as a function of the codec used for voice compression.

In the office area today, the LAN infrastructure is usually sufficiently generously dimensioned to make VoIP communication possible without any restrictions. The situation is distinctly different if it is necessary to connect distant substations to the utility’s voice network. If these locations are not integrated in the corporate backbone network, power line carrier connections must be installed. Fig. 8.2-8 shows the basic alternatives for voice communication via PowerLink.

<table>
<thead>
<tr>
<th>Codec</th>
<th>Net bit rate</th>
<th>Gross bit rate</th>
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<tbody>
<tr>
<td>G.711</td>
<td>64 kbit/s</td>
<td>87.2 kbit/s</td>
</tr>
<tr>
<td>G.726</td>
<td>32 kbit/s</td>
<td>55.2 kbit/s</td>
</tr>
<tr>
<td>G.728</td>
<td>16 kbit/s</td>
<td>31.5 kbit/s</td>
</tr>
<tr>
<td>G.729</td>
<td>8 kbit/s</td>
<td>31.2 kbit/s</td>
</tr>
<tr>
<td>G.723.1</td>
<td>5.3 kbit/s</td>
<td>20.8 kbit/s</td>
</tr>
</tbody>
</table>

Table 8.2-2: Bandwidth requirement for VoIP

Fig. 8.2-8: Basic options of voice communication via PowerLink
Communication Network Solutions for Smart Grids

8.2 Communication Network Solutions for Transmission Grids (Communication Backbone)

Analog connection
The telephone system is connected to the PowerLink via the analog E&M interface. A telephone system or an individual analog telephone can also participate in a PowerLink system at a different location. The bandwidth requirement can be reduced to about 6 kbit/s (including overhead) per voice link by means of voice compression in the PowerLink.

Digital connection
With digital connection, the telephone system is connected to PowerLink via the digital E1 interface. Because of the restricted bandwidth, up to 8 of the 30 voice channels (Fractional E1) can be used. This alternative is only suitable for communication between telephone systems. Individual telephones must be connected locally to the particular telephone system. The bandwidth requirement is made up of the user data per voice channel (e.g., 5.3 kbit/s) and the D-channel overhead for the entire E1 link (approximately 2.4 kbits/s), (i.e., for a voice channel less than 10 kbit/s).

In the case of series connected locations with both analog and digital connection, multiple compression/decompression of the voice channel is prevented by the unique PowerLink function “StationLink”.

TCP/IP connection
The telephone system, voice terminals and the PowerLink system are connected directly to the TCP/IP network. Voice communication is conducted directly between the terminals. Only control information is transmitted to the telephone system. Use of the TCP/IP protocol results in a broadband requirement per voice channel of at least 21 kbit/s (5.3 kbit/s voice plus TCP/IP overhead).
8.3 Control Center Communication

Redundant control center communication
A control center for power supply systems such as Spectrum Power (fig. 8.3-1) is typically configured with full redundancy to achieve high availability. This includes communications. Depending on the system operator’s requirements, various mechanisms are supported to achieve this goal for communication. This includes:
- Automatic failover of communication servers
- Configurable load sharing between two or more communication servers
- Automatic failover of communication lines
- Supervision of standby communication line, including telegram buffering.

Process communication to substations and power plants
Process communication to the substations and to Remote Terminal Units (RTUs), e.g., in power plants or power supply systems, is implemented via serial interfaces or by means of TCP/IP-based network communication with a Communication Front End. The Communication Front End includes data-pre-processing functionality like:
- Routine for data reduction, e.g., old/new comparison, threshold check
- Data conversion
- Scaling and smoothing of measured values
- Integrity checks for incoming data
- Data completeness checks and cycle monitoring
- Statistical acquisition of the data traffic with the RTU.

All kinds of different protocols are used for historical reasons. However, as a result of international standardization there is also a market trend here towards standardized protocols like IEC 60870-5-104, DNP3i protocol or IEC-61850.

The more recent protocol standards all rely on TCP/IP-based communication. However, it must be possible today and in the near future to continue connecting conventional telecontrol devices (already installed RTUs) via serial interfaces.

Interface for industry automation/third-party applications
OPC (OLE for process control) and OPC UA provide a group of defined interfaces. OPC in general enables the overall data exchange between automation and control applications, field systems/field devices, as well as business and office applications.

OPC is based on OLE/COM and DCOM technology. OPC UA (Unified Architecture) is a continuation and further innovation of OPC. OPC UA is based on native TCP/IP and is available for multiple operating system platforms, including embedded devices.

Communication between control centers
The communication between control centers is provided via the communication protocols ICCP or ELCOM, and is based on TCP/IP.

The Inter Control Center Communication Protocol (ICCP) is an open and standardized protocol based on IEC 60870-6 and Telecontrol Application Service Element Two (TASE.2).

The exchanged data is primarily real-time system information like analog values, digital values and accumulator values, along with supervisory control commands.

Remote workstations/office communication
Remote workstations can communicate with the control center via the office LAN or an Internet connection. System and data integrity has to be ensured by the system security configuration for:
- Protection against external attacks
- Protection against unauthorized usage
- Protection against data loss.

Fig. 8.3-1: Typical communication interfaces and communication partners of a control center using the example of Spectrum Power™ (SCADA, Applications)
8.4 Communication Network Solutions for Distribution Grids (Backhaul/Access Communication)

8.4.1 Introduction

In the past, electricity was mainly produced by bulk generation at central locations, and distributed to consumers via the distribution systems. Energy peaks (e.g., at midday) were well-known and balanced out by reserve capacity of central power plants. It was therefore usually not necessary to specifically control the lower-level distribution networks, or even to integrate the consumers into the grid monitoring system.

Ever since renewable energy has been significantly expanded, electricity is being fed into both the medium-voltage and low-voltage systems, depending on changing external conditions (e.g., weather, time of day, etc.). These fluctuating energy resources can severely impair the stability of the distribution grids.

Buildings account for 40% of the world’s energy consumption and 20% of total CO₂ emissions. Therefore, smart buildings also play a central role in the Smart Grid as they provide a huge potential for energy efficiency. Actively influencing their consumption and generation, smart buildings support the system stability and allow generators to consider other options before adding new generation facilities.

Communications infrastructure
- Fiber optics/SHD/MPLS-TP
- PLC
- WIMAX
- Wireless mesh
- GSM/UMTS/LTE
- Router, switch

Applications
- Control Center (EMS/DMS)
- Virtual Power Plant
- Micro Grid Controller
- Distribution Automation
- Condition Monitoring
- Marketplace
- Demand Response Management System
- Asset Management
- Meter Data Management
- Billing/Call Center
- E-Car Operation Center
- etc.

One of the key challenges of a Smart Grid therefore is quickly balancing out the energy supply and energy consumption in the distribution system (fig. 8.4-1).

A prerequisite for implementing a solution for this demand is monitoring and managing as many components of a power supply system as possible all the way to the consumer. The basis for this is a reliable communication infrastructure. For medium voltage, at least the following system components must be integrated into a Smart Grid and managed:
- The key ring-main units
- All large distributed producers (solar/wind farms, biogas/hydroelectric power plants, etc.)
- Large buildings, campuses, refrigerated warehouses, etc.

For low voltage, primarily households and small producers of renewable energy are involved.

With respect to their role in the power supply system, consumers can be divided into two groups:
- “Standard consumers”, who have smart meters and optimize their electricity costs via ongoing price signals depending on supply and demand
- “Prosumers” (producer + consumer), who can feed surplus energy into the power grid – such as solar power or energy generated by combined heat and power systems (CHP); many can also intermediate store energy using possibilities such as night storage heaters or e-cars.

While the communication requirements for standard consumers are concentrated on smart metering including price signals, time-critical control signals and power quality data must also be transmitted for prosumers. Therefore, in addition to smart meters, prosumers have energy gateways, which process and forward these control signals accordingly.

Fig. 8.4-1: Typical power distribution network integrating ring-main units, consumers, prosumers, distributed energy resources, etc.
The young history of Smart Grids has already shown that utilities do not implement it as a whole from the scratch. They usually start with smart metering projects with later extensions of Smart Grid applications.

Already with the first roll-out, the design of the communication infrastructure has to consider the growing requirements for these extensions. After a large deployment of metering infrastructure in the first step, it is not acceptable to replace the communication network a few years later because the requirements for the next subsets of Smart Grid applications cannot be met anymore.

Communications infrastructures for all conditions
The communication infrastructure in the medium-voltage and low-voltage distribution systems is usually heterogeneous, and the suitable technologies depend to a large extent on the local topology (large city, rural region, distances, etc.). It must therefore be specifically tailored for each customer.

In general, the following communication technologies are available:
- Fiber-optic or copper cables are the best option, if present
- Power line carrier systems for medium-voltage and low-voltage networks
- Setup of own private wireless networks (e.g., wireless mesh, private WiMAX), when spectrum is available at reasonable prices or local regulations allow for it
- Public wireless networks, depending on the installation for narrowband communication in the kbps range (e.g., GPRS), or in the future in the Mbps range (LTE, WiMAX providers). Attractive machine-to-machine (M2M) data tariffs and robust communication in case of power outages are key ingredients to make this communication channel a viable option.

Depending on the applications being installed inside the RMU, an Ethernet switch/router might be needed in order to concentrate the flow of communications. These data concentrators can be implemented as customized solutions or integrated, for example, in the RTU (remote terminal unit). To meet these requirements, Siemens offers a full range of all above-mentioned communication technologies including rugged switches and routers that comply with energy industry standards.

8.4.2 Communication Infrastructures for Backhaul and Access Networks

Optical fibers

The best choice for all communication needs
Optical fibers is the best transmission medium for medium-voltage and low-voltage applications because it is robust and not susceptible to electromagnetic disturbances or capacity constraints. That is why system operators who choose this technology will be well-prepared when their communication needs multiply in the future.

Fiber-optic cables are laid underground to connect individual substations. This work is associated with heavy civil works, and therefore with great expense. However, when new power cables are installed, the cost-benefit analysis paints a clear picture. Fiber-optic cables should generally be the first choice in this case.

Benefits in detail
- At the core of a variety of communication systems, from passive optical networks (PON) to Ethernet and SDH
- Durable, insusceptible to electromagnetic disturbances
- Practically unlimited transmission capacity.

Medium-voltage power line carrier solutions
Standards-based power line carrier solutions provide an attractive communication channel for all applications in medium-voltage and low-voltage Smart Grid scenarios. They use the utility-owned infrastructure in the distribution network, and provide a reliable and affordable communications channel. Therefore, PLC solutions are especially useful for connecting elements in grids, where no other reliable communication channel is available. They transform the DSOs assets into a highly capable Smart Grid communication infrastructure. With its throughput, low latency and high reliability, PLC solutions serve for distribution automation applications as well as for backhauling data from metering applications in the medium-voltage grid.

Combining IEEE 1901 broadband power line products with IEEE 1901.2 high-speed power line products, the resulting power line communication solutions allow the DSO to equip the entire MV grid with a single family of communication technology.

The resulting PLC network forms a transparent layer 2 bridge, and can therefore be used flexibly for all Smart Grid applications.
Fig. 8.4-3 shows the typical deployment of power line carrier solutions in distribution networks. As with every communication technology, the transmission range and bandwidth provided by the PLC solution depends on the quality of the used transmission medium. In case of the transmission over power lines, type and age of the power cable as well as the number of joints have an impact on the achievable results. Consequently, a PLC network needs to be engineered and planned correctly to provide maximum performance. The unique combination of broadband power line using the frequency range between 2 and 30 MHz and high-speed power line using the range between 9 and 500 kHz allows the DSO to equip all MV lines with a single family of communication technologies. Combined with a coupling unit that spans both frequency ranges, this provides maximum freedom in choosing the right technology on each link without changing the coupling units.

Benefits of power line communication solutions:
- They transform the utility-owned infrastructure into a highly capable communication network
- They are especially useful for connecting all elements in the grid where there are no other reliable communications media available
- They provide a communication solution for all MV power grids.

WiMAX
The main application area for WiMAX is backhauling of RMUs, data concentrators or Distributed Energy Resources (DER). Single prosumers could technically be served, but this is economically reasonable only in selected cases.

Fig. 8.4-4 shows the typical deployment of WiMAX solutions in distribution networks.

WiMAX (Worldwide Interoperability for Microwave Access) is a standards-based telecommunications protocol (IEEE 802.16 series) that provides both fixed and mobile broadband connectivity. The advanced point-to-multipoint technology is field-proven and deployed globally. In the recent past, certain manufacturers have evolved the system for the requirements of specific vertical markets such as oil & gas or power utilities. Differing from telecommunication-carrier-oriented systems, these implementations support special features such as asymmetric prioritization of uplink traffic, layer-2-based traffic (multicast/IEC 61850 GOOSE), redundancy options, as well as economic system scaling fitting also for smaller, privately owned regional or local networks.

Besides the application requirements, it is important to assess regional conditions like area topology and availability of radio spectrum. Professional radio network planning and network engineering are mandatory when setting up WiMAX networks.

Basic technical data
- Data rates: up to 15 Mbps (uplink, 10 MHz channel, IEEE 802.16e system)
- Coverage:
  - up to 10 km in non-line-of-sight (e.g., urban) and
  - up to 30 km in line-of-sight conditions (with range extension)
- Implementations for radio spectrum in licensed or license-exempt frequency bands available.

Benefits
The WiMAX technology is field-proven, globally deployed, and continues to evolve. WiMAX networks can be scaled from small to large, which allows for privately owned networks even on regional and local levels.
Wireless mesh
In general, wireless mesh networks are composed of cooperating radio nodes that are organized in a mesh topology (fig. 8.4-5). The link communication technology from one hop to another can be standardized (e.g., IEEE 802.11 series [WiFi] or IEEE 802.15.4 [LoWPAN, Low-rate Wireless Personal Area Network]) or proprietary (e.g., FHSS, OFDM technologies). The mesh protocols and corresponding forwarding algorithms are on the other hand more recent developments and therefore still predominantly proprietary. Thanks to their mesh properties along with self-setup and self-healing mechanisms, mesh networks inherently offer ease of operation and redundancy for fixed applications. The system performance can be characterized by the hops’ throughput capacity, the average reach of a hop-to-hop link, and the max. number of hops on a single path.

Detailed requirements as well as specific regional conditions must be carefully assessed in order to select the best-suited technology.

There are two major categories of wireless mesh networks:

**Broadband wireless mesh for RMU / DER backhaul**
Broadband wireless mesh systems have sufficient transport capacity to backhaul a high amount of data, that is to say aggregated data of various RMUs / DER plants, with multiple RTU devices or data concentrators / access gateways.

**Basic technical data**
- Maximum throughput (gateway capacity): ~ 20 Mbps (shared among the nodes connected to the gateway)
- Coverage: hop-to-hop reach 100m ~ 1 km depending on system, frequency band and applicable power limit; meshing among up to 10 ~ 20 hops per path depending on the deployed system
- Radio spectrum primarily in license-exempt frequency bands, e.g., 5.8 GHz.

**Narrowband radio frequency (RF) mesh for access / metering**
We use the term “RF mesh system” to denominate narrowband wireless mesh technologies. Their capacity suffices to connect individual devices with moderate data transmission requirements, such as meters, grid sensors, measuring transformers, etc. The single RF mesh nodes communicate via each other towards an access gateway, which serves as take-out point into other WAN/backhaul communication networks.

**Basic technical data**
- Average throughput per node: 50 ~ 100 kbps
- Coverage: hop-to-hop reach 100m ~ 1 km depending on system, frequency band and applicable power limit; meshing among up to ~ 10 hops per path depending on the deployed system
- Radio spectrum primarily in license-exempt frequency bands, e.g., 868/915 MHz.

**Benefits**
Thanks to their mesh properties along with self-setup and self-healing mechanisms, mesh networks inherently offer ease of operation and redundancy for fixed applications.

**Public cellular networks**

*For the extension of private communication networks*
The main application areas for public mobile radio networks in the Smart Grid context are meter reading and energy grid monitoring functions (fig. 8.4-6).

In contrast to constructing new, proprietary networks for Smart Grid communication, there is also the option of using existing cellular radio networks owned by communication service providers. These networks are standards-based, deployed worldwide, and continuously upgraded and expanded. Activities like acquiring spectrum licenses, building, operating and maintaining the network as well as assuring sufficient coverage and bandwidth on a nationwide scale are naturally managed by the communication service providers. Data rates normally available range from 50 kbps (GPRS), over 10 Mbps (HSPA), to over 50 Mbps (upcoming LTE). Attractive data tariffs and the availability of the network are key to use public cellular networks for Smart Grid applications.
8.5 IT Security

Increased networking of systems, standardization of communication protocols and operating systems – simplifying processes ensures efficient operation. But the other side of the coin is that these trends also make our networks vulnerable.

What can effectively protect our energy supply from attack? A solution which takes security into account at every stage of the development process. And which, at the end, contains exactly the security features that are needed. Looking at security as an integral component is important for a secure infrastructure – during both network planning and the design process.

Siemens offers well-thought-out products, systems and solutions to ensure the security of the energy automation infrastructure.

8.5.1 Integral Approach

The graphical display of the security network or network blueprint, as it is called, forms the infrastructure and architecture of a system. It is the basis for a clear segmentation with which the risk for every link in the automation chain can be analyzed precisely – while still keeping an eye on the impact on the system as a whole.

The network is therefore divided up into manageable zones in order to equip them with precisely the IT security that is necessary and worthwhile in order to protect the data in this zone, as well as ensuring smooth operation of the system at the same time (fig. 8.5-1).

The zones are protected at network level by a SCADA firewall that controls data traffic between the zones and blocks dangerous packets.

**Fig. 8.5-1: Zoned IT security concept**
The architecture is the most visible part of the comprehensive IT security approach. The energy automation IT security approach contains the following process measures:

- Organizational preparedness
- Secure development
- Secure integration and service
- Vulnerability and incident handling as well as technical measures
- Secure system architecture
- System hardening
- Access control and account management
- Security logging/monitoring
- Security patching
- Malware protection
- Backup and restore
- Secure remote access
- Data protection and integrity
- Privacy.

All computer systems are equipped with virus scanners in order to withstand the permanent threat due to malware. The remote administration and connection of other networks is effected by VPN tunnels that guarantee access protection at the highest level.

The complete infrastructure also undergoes system hardening in order to match up to the consistently high security requirements for the system as a whole.

8.5.2 Secure throughout from Interface to Interface

With the advent of the Internet and increasing networking within the systems, every interface represents a potential risk. These risks must be easy to estimate in the system. With Integrated Energy Automation, Siemens therefore applies the philosophy of IT security offering simple protection. For this reason, Siemens attaches greatest importance to homogenization by means of standardized and reproducible processes for authentication, authorization, malware protection, effective patch management also for third-party components, standard logging and continuous security tests.

8.5.3 Continuous Hardening of Applications

Reliable products are an essential basis for a secure network. Siemens therefore continuously hardens its products to protect them against attacks and weak points. Individual risk analyses and regular tests – also specially for third-party components – with a defined combination of IT security test programs for detecting weak points (test suite) are used for this.

8.5.4 In-House CERT as Know-how Partner

Siemens has its own in-house Computer Emergency Response Team (CERT). An organization such as this that discusses subjects critical to IT security and issues current warnings is normally only maintained by universities or governments in order to provide users with cross-industry information.

The Siemens in-house CERT was established in 1997 and since then has issued warnings about security loopholes, while offering approaches for solutions which are processed especially for the company’s areas of competence. As know-how partner, the work of the Siemens CERT also involves drawing up rules for the secure development and programming of in-house products and the continuous further training of in-house programmers.

CERT checks the products for weak points by means of selective hacker attacks. The team also collects and distributes reports on weak points and upgrade reports for third-party components and links them to recommendations, concrete proposals and implementation specifications.
8.5.5 Sensible Use of Standards

The object of standards is to guarantee quality, to increase IT security in the long term, and to protect investment. There are now hundreds of IT security standards in existence, but only some of them are really necessary and worthwhile for a system.

On the basis of its many years experience in the market, Siemens chooses those standards and guidelines that protect a network reliably and effectively. This also includes advising customers on which IT security standards need to be observed at international and also at regional level.

From the outset, they meet the most stringent security requirements – including those of the BDEW Whitepaper (German Association of Energy and Water Industries) and NERC CIP (North American Electric Reliability Corporation, Critical Infrastructure Protection), and certification in accordance with the process industry security standard WIB 2.0 ("Working-party on Instrument Behaviour"). The main parts of the WIB requirements will be merged under the roof of IEC 62443.

The object of Integrated Energy Automation (IT Security) is permanent IT security for the system in the long term. Therefore reliable and secure products and infrastructures are not enough. With Integrated Energy Automation, Siemens also implements appropriate security processes that ensure that IT security is actively implemented throughout, both internally and at the plant operator’s, and is guaranteed over the entire life cycle of the plant.

8.5.7 Integrating IT Security in Everyday Operations

A system is only as secure as the user operating it. A high standard of security can therefore only be achieved by close cooperation between manufacturers and operators. The patch management process is also important after acceptance testing of a system. For this purpose, the Siemens CERT issues automated reports on newly discovered weak points that could affect third-party components in the products. This enables the Siemens customers to be informed promptly, and allows time to define any service activities arising from this.

A very wide choice of helpful tools is available to enable users to make IT security a regular part of everyday operation of a system. Standardized security processes, for example, for updates and system backups, are implemented directly. At the same time, efficient tools are provided for administering access in a system network. This includes effective management of rights as well as reliable logging tools. Automatically created protocols or log files are not only stipulated by law, but also help determine at a later time how damage to a system occurred.

With Integrated Energy Automation, Siemens offers an intelligent interaction of integral solutions for simple and reliable energy automation.

8.5.6 IT Security Grows in the Development Process

The integral approach with Integrated Energy Automation not only involves keeping an eye on the entire system, but also means that security of products is already integrated in the entire development process, and not just in the test phase.

IT security guidelines for development, processing, service and other functions ensure that IT security is actively implemented throughout all processes. Examples of this are security briefings for product management before a product is developed or programmed in the first place. Programmers operate according to defined guidelines for secure coding, which are specified by the Siemens CERT.

For an effective patch management, Siemens tests updates of third-party components, for example, operating systems, router with firewalls and third-party SW components. Continuous penetration tests of all relevant products are stipulated in a test plan. This also includes the definition and establishment of a security test environment and matching test cases.

In this way, Siemens subjects its products to an objective and critical certification process with which IT security is guaranteed and made transparent on the basis of suitably selected standards.
8.6 Services

Siemens focuses not only on providing custom-made communication network solutions, customers can furthermore benefit from Siemens’ unparalleled energy and communication know-how and project experience.

Siemens experts are the single point of contact for build, care and professional services for the complete end-to-end communication solution. Customers can focus on their core business, leaving the communication network in Siemens’ expert hands.

Fig. 8.6-1 gives an overview about our service portfolio for smart communication solutions.

Communication Build Services

**Site Survey**
Our experts collect data on the field according to given Siemens work instructions in order to ensure a smooth implementation of the products or solutions offered. After the survey, the recorded data are analyzed, and the results are documented in the site survey report.

Benefits
The Site Survey provides a transparent and complete database, as an input for effective network planning, as well as for fast and efficient project execution.

**Project Engineering & Integration**
The overall know-how of our experts guarantees the perfect interaction of different net elements, and is the precondition for a fast installation process and optimal network operation.

**Build Services**
- Site Survey
- Project Engineering & Integration
- Factory Acceptance Test (FAT)
- Installation, Commissioning & Site Acceptance Test (SAT)

**Care Services**
- Hotline Service
- Technical Support
- Maintenance Services

**Professional Services**
- Network Consulting Services
- Training
The Siemens offering includes:

- **Project management**
  Siemens offers qualified project management services based on individual customer demands.

- **Installation of cabinets**
  Siemens provides robust standard cabinets, especially designed for the utility market. The services include the cabinet model layout, wiring engineering documentation, construction and cabinet wiring according to given technical specifications.

- **Network planning**
  For a given scope, all relevant network parameters, such as bandwidth, frequency plans, allowable latency, data routing, protection concepts, etc. will be defined, documented and configured. Additionally, IP addresses, data communication network concepts and frequency plans, including quality of service aspects, will be elaborated.

- **Supervision**
  Siemens offers technically qualified supervision to support installation or commissioning of customer projects.

**Benefits**

Siemens offers overall system know-how, which ensures the perfect interworking of different network components, being a precondition for a fast and effective installation.

**Factory Acceptance Test**

The FATs will usually be performed at Siemens premises. The basic testing is done according to Siemens standards and customer-agreed procedures. Certainly, Siemens offers additional testing of customer-specific functions. The FAT can be expanded by a factory inspection.

**Benefits**

The FAT ensures that the product functionalities comply with the customer requirements, and provides a chance for the customer to see his communication solution in operation upfront to the actual shipment.

**Installation, Commissioning & Site Acceptance Test**

Siemens installs and integrates the complete communication solution into the customer’s network. The successful Site Acceptance Test (SAT) finalizes the installation & commissioning process, and is documented according to Siemens quality standards.

**Benefits**

Siemens offers a one-stop installation of the complete communication solution, which includes in particular the optimized interworking of different communication elements. The customer receives a field-tested solution.

**Communication Care Services**

**Communication Hotline Service**

In order to assure a fast and qualified support for our customers in case of network problems, and to keep the outage times to an absolute minimum, we offer a 24x7 hotline service. The hotline acts as the first contact to insure ticketing process and query identification for clarifications.

**Benefits**

The Siemens hotline service assures fastest and competent support in case of network problems. Defined contact partners provide continuous assistance throughout the complete problem solving process. Network downtimes are minimized.

**Communication Technical Support**

The technical support is usually located in the region and supported by HQ specialists. Our experts care for rapid fault clearance providing optimal network availability.

**Benefits**

The Siemens technical support is experienced, well-trained and worldwide available. These specialists, who are supported by HQ, provide fast and effective clearance of technical problems, which minimizes the downtime of the customer’s communication network.

**Communication Maintenance Services**

In order to optimize the lifetime of the installed communication solutions and to reduce/avoid downtimes, Siemens offers a complete range of maintenance services consisting of:

- **Preventive maintenance**
  The idea is to execute a regular check of network elements and perform various routine maintenance works, depending on the manufacturer’s recommendations and the customer’s requirements. On-site maintenance will produce a regular report of activities with further instructions.

- **Extended warranty**
  Siemens offers a prolonged warranty compared to the normal Siemens standard.

- **Repair and replacement**
  This service covers the repair of a defective module within a defined turnaround time of Siemens and third-party telecommunication partner products.

**Benefits**

Siemens maintenance services extend the lifecycle of the customer’s investments and reduce/avoid network downtimes. The customer is able to plan his staff resources efficiently and avoids a large spare part stock.
Communication Professional Services

**Communication Network Consulting Services**
Siemens is offering network consulting services regarding communication technologies and their optimized mix and operation in customer's individual technical and regulatory environment.

Our services consist of:
- **Technology consultancy**
  Siemens offers technology consultancy for the complete lifecycle of a communication network, from setting up a complete new communication infrastructure until the migration of the existing network towards new technologies.
- **Proof of concept**
  Siemens offers to prove the feasibility of customer’s telecommunication network concepts, for example, for the preparation of a planned mass rollout of communication equipment.
- **Interoperability lab**
  Siemens offers testing of complete end-to-end communication solutions including third-party products at Siemens or customers premises. We are using mature test management framework, labs and services based on established telecommunication testing models.

**Benefits**
Siemens as technological leader is a member of all important standardization committees, and guarantees future-proof investment decisions. Our network consulting services provide overall comprehensive communication solutions, based on geographical, technological and regulatory customer requirements.

The proof-of-concept service confirms the customer’s overall concept and reduces planning and budget risks.

Our interoperability lab ensures tested end-to-end solutions across different components and technologies. This is a precondition for cost-optimized mass rollouts of new applications.

**Smart Communications Training**
Professional training of staff for the optimal configuration of a communication network is crucial to obtaining the full benefits from the customer's investments. Siemens focuses not only on providing custom-made communication network solutions, but also on sharing its knowledge and experience with the customers. Siemens offers a comprehensive training support program in communications solutions for power supply companies. Customers receive training which is tailored to their area of responsibility, and which also includes relevant technology and practical exercises.

The course program is aimed at everyone who is active in the field of communication technology, for example:
- Consultancy
- Engineering
- Installation
- Commissioning
- Operation
- Maintenance.