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Section 10, Power System Components, 10.7 Supervisory Control and Data Acquisition Systems pp 10-147 to 10-168, by Robert J. Landman, President, H&L Instruments; Senior Member IEEE

Supervisory Control and Data Acquisition (SCADA).[1,2] SCADA (also called telecontrol) consist of one or more computers with appropriate applications software (Master Stations) connected by a communications system (wire, radio, power line carrier or fiberoptics) to a number of remote terminal units (RTUs) placed at various locations to collect data and for remote control and to perform intelligent autonomous (local) control of electrical systems and report results back to the remote master(s). SCADA systems are used for fault identification, isolation and service restoration, breaker control, recloser blocking, generator control, feeder switching and reconfiguration, line switching, voltage control, load management, automated meter reading (AMR), archiving processes, automatic generation control (AGC), dispatch accuracy feedback, economic dispatch, energy purchased and sold, system load, system emulation, capacitor bank switching, monitoring voltage regulators, transformer temperature, as well as metering power functions.

Control Centers.[3] Control centers are generally for the operation of generation-transmission (energy management system or EMS) or distribution (distribution management system or DMS). Modern control centers make extensive use of redundant, "open systems" standards. The IEEE defines an "open system" as one that provides capabilities that enable properly implemented applications to run on a variety of platforms from multiple vendors; is interoperable with other systems applications; and presents a consistent style of interaction with the user. Such a system must be consensus driven and standards based and have specifications that are freely available at low cost to any interested party. One such open standard is the Inter-Control Center Communications Protocol (ICCP) developed by the Electric Power Research Institute (EPRI) and Northern States Power (NSP). ICCP was developed to give utility organizations throughout the world the ability to exchange data over wide-area networks between utility control centers, utilities, power pools, regional control centers and non-utility generators. ICCP allows the exchange of real-time and historical power system monitoring and control data, including measured values, scheduling data, energy-accounting data, and operator messages. Data exchange occurs between multiple control center energy management systems (EMS), EMS and power plant distribution control systems (DCS), EMS and distribution SCADA systems, EMS and other utility systems. For additional discussion, see also Chap. 25 in the *Standard Handbook*, "Computer Applications in the Electric Power Industry".

2. ***Remote Terminal Units.*** RTUs are special purpose computers which contain analog to digital converters (ADC), digital to analog converters (DAC), digital inputs (status) and outputs (control). RTUs are ruggedly constructed; inputs and outputs are fully protected against spurious electrical transients per the Surge Withstand Capability (SWC) test specified by IEEE Std. 472 and ANSI Std. C37.90a. RTUs are designed for an extended temperature environment (-40 to

+85°C) expected of the electric utility environment. RTUs may be either AC powered (120/230V) or battery powered (12, 24, 48, 125 or 250V). An RTU may have multiple communications ports so that more than one master station can share the RTU.

Transmission Substation RTUs. These large RTUs are deployed at substations and generation facilities where a large number (perhaps several thousand) control and data points are required. They are usually enclosed in a floor standing NEMA enclosure which has card cages allowing for multiple microprocessor cards as well as multiple analog to digiital (ADC), and digital to analog (DAC) converters and digital input and output cards. Some newer transmission RTUs have a distributed input/output (I/O) design whereby I/O modules are connected to a communications "data highway" which loops through the substation (§ 10-154) Alternatively, the main substation RTU can connect to many other RTUs in the substation, each with a specific function or functions, including closed loop control and computation. Many RTUs have the ability to interface with other substation devices generally referred to as IEDs (Intelligent Electronic Devices).

Intelligent Electronic Devices (IEDs). Such devices are used in transmission and distribution substations and include meters, relays, reclosers, voltage and var regulators, and tap position indicators which are interrogated by the substation RTU(s) which reports information from these devices back to the SCADA master. In many cases, data from IEDs reduces or eliminates the need for external RTU transducers. IEDs are also substation host computers, RTUs, Programmable Logic Controllers (PLCs), time and frequency standards, communications processors, digital protective relays, sequence-of-events and fault recorders. Most IEDs currently in use in substations today use proprietary communication protocols leading to "islands of automation". A secondary, but growing, class of applications is the digital monitoring and protection of power system devices, e.g. lines, switchgear, busses, transformers, and feeders, and the transfer of protection system data between IEDs in the substation and to external systems.

Distribution Automation RTUs. These smaller RTUs are usually enclosed in a rain tight NEMA 4 enclosure and are used to control switches and VAR compensation capacitor banks on utility poles, pad mounted switches, monitoring and automating feeders and underground networks and in smaller distribution substations. These "DA" RTUs are have all inputs, outputs and the RTU microprocessor on just one printed circuit board. If the RTU is expandable, additional input and output cards are connected by flat ribbon cables rather than plug-in cards, making the system more rugged and compact. These RTUs usually contain an integral lead acid gelcell battery backup system and integral communications module (radio, telephone modem or fiberoptic transceiver). Some distribution automation RTUs have a feature called *direct inputs* that eliminates the need for external electrical transducers to convert AC voltages and currents to DC voltages required by the RTU's ADC. Advanced distribution automation RTUs utilize digital signal processing (DSP) technology to perform fault detection and calculate electrical quantities.

Programmable Logic Controllers.[4,5] PLCs have been used extensively in manufacturing and process industries for many years. They have been used to implement relay and control systems in substations and, as this has happened, the distinction between PLCs and RTUs has been blurred. PLCs were initially attractive because of lower cost (which has risen to be equivalent to RTUs of similar complexity thus proving the old adage that "you don't get something for nothing"). PLCs can have extended distributed I/O systems similar to large transmission RTUs. The control outputs can be controlled by software residing in the PLC as well as via remote commands from the SCADA system master computer. The PLC user can make changes in the software stored in non-volatile electrically programmed read-only memory (EEPROM) without making any major hardware or software changes. PLCs are modular; most manufacturers offer so-called *distributed I/O* modules which add input or output points, usually in blocks of eight on a simple twisted pair EIA-485, coaxial cable or fiberoptic data highway LAN. The software is typically a high level language, such as *relay ladder logic* (RLL), which the PLC manufacturer supplies for a one-time fee. Some of the newer designed RTUs can be user-programmed in the field; RLL EEPROM software is an option in the latest models of RTUs. For tight (time-wise) closed-loop PID control applications, a PLC with RTU reporting capability may have advantages over conventional RTUs. There is no longer a clear distinction between RTUs and PLCs.

Electrical Transducers. In the electric industry, the term *transducer* means an electronic module that converts an electrical signal of one form into another. They are, in effect, analog computers. Functions available include Watt, Var, Watt/Var, Watt/Watthour, Var/Varhour, Volt-Amp, Volt-Amphour, Current, Voltage, Phase Angle (PF), Voltage Angle, Frequency, Temperature, DC Isolation and signal conditioning. Transducers scale, buffer and isolate (protects the RTU). Typically, AC signals are converted to DC signals for RTU analog inputs. Typically, transducer output is 0-1 mA. The package is designed to be mounted in a NEMA enclosure. Transducers can be self or external-powered. Their signal inputs are designed to be compatible with instrument transformer outputs (potential transformers (PTs) and current transformers (CTs)). PT's generally output 115 Vac nominal, and CT's range around 5 amps. Transducer functions (volts and amps) have been incorporated in distribution RTUs as *direct inputs* which means literally that the AC signals can be directly put into the RTUs. IEDs may be used to condition and pre-process transducer inputs for substation RTUs.

Interposer relay. Interposer relays provide additional isolation and increase the current handling capacity of the RTU output relays. For instance, a circuit breaker trip coil requires more current than can be handled through a small RTU relay. The RTU relay would be used to drive a larger relay that could handle the larger current requirement. Interposer relays can also be used to isolate the RTU inputs from field devices.

Wetting voltage. This is the DC voltage, supplied by the RTU (usually the same voltage source that powers the RTU is used) across the digital input terminal pairs to sense dry external contact closures, such as limit switches (microswitches), relay contacts, and thermostats. The wetting voltage ensures that environmental air pollution does not prevent worn or contaminated contacts from making a positive connection.

Pulse Accumulators. Where energy values are derived from counting rotations of a mechanical disk (gas meters or a conventional watt-hour meter), a set of contacts is opened or closed in direct proportion to the disk rotation rate. Transducers can convert this by integrating a voltage. RTUs can take this signal directly and accumulate the pulses in software counters. Accumulators can be frozen either by remote command, or periodically, to report, spontaneously or by exception, the accumulated count.

Maintenance point. Many utilities provide a maintenance point at each RTU. This point is controllable both locally and from the master. Opening the maintenance point removes the control voltage from the outputs of the RTU. This allows maintenance personnel to test the RTU's control relays without controlling external devices. Other utilities use individual disabling switches to block RTU control to critical points.

3. ***RTU Software.*** RTU software is written by the manufacturer, usually in a high level language such as C, and is designed to interpret commands (polling requests) from a master computer and to initiate reports of out of bound conditions. If the RTU has sufficient processing power, local control may be possible. Automatic switching of capacitor banks for Var compensation and feeder fault isolation are examples of local control. Some RTUs allow for user programming of the local control functions by the user using Relay Ladder Logic (RLL). RTUs are designed to be robust. A software driven *watchdog timer* is implemented to time out and reset the RTU should the program freeze due to a minor problem with the system.

Arm/Operate. Supervisory *control* of power system components, such as breakers, is accomplished by electromechanical or solid-state relays. Control is normally (for safety reasons) a multi-step sequence; device selection (arm a point, i.e. a relay drive circuit in the RTU), identification (check the armed point to see that it is the correct point), and commanded execution (energize the relay). RTUs may have circuitry (used during the identification step) to detect whether or not a relay coil has failed open. Master station software may, once execution is requested, verify control to ensure that the operation is allowed under the conditions currently existing in the system (control permissives). If the control is valid, it is transmitted to the RTU. As a further precaution, many RTU's require an enabled point to be operated within a predefined time, usually 10 seconds or less. Historically, this methodology has evolved because of safety concerns. Other terms for this SCADA function are: *select before operate* and *trip/close*.

Logging. If the RTU has sufficient memory, an electronic chart recorder function can be performed on analog values and digital input status (see *Sequence of Events*).

Polling report by exception. The master station collects only values which differ from those last reported.

Peer-to-peer communications[6]. There is no need for a master station in a peer-to-peer system. All members (peers) have equal status and can communicate with any other member. While it has been in common use in computer networks for many years (e.g. MS Windows for Workgroups, an Ethernet connected bus network), the concept is becoming more commonplace in SCADA systems. It has been common practice to allow decentralized distributed control using pole-top IEDs that make independent decisions to operate based on local line conditions. An extension of this concept allows teams of sectionalizing equipment to communicate with each other and, based on the information exchanged, to operate to isolate faulted line segments and restore service. Results of action are usually reported back to the energy management system and provision is usually made for remote control by system operators to override local automation when necessary for system stability.

Spontaneous report by exception. This process allows RTUs to interrupt the master to announce a status change or analog limit violation (alarm condition).

Sequence of Events. A transmission system fault can trigger several (sometimes hundred) related alarms. In order to determine the root cause of a system fault, RTU's are utilized that can accurately record and report (to one millisecond resolution) the date and time of each change of state. Several methods are employed to synchronize the time of all RTU's so that accurate time is reported. Many protocols incorporate time synchronization commands, but for the highest accuracy, GPS clocks are used. This is a requirement that older PLCs were not designed to accomplish. With faster microprocessors and the growing substation automation market, as well as the need in the manufacturing industry for improved control and monitoring systems, this logging can now be done with some PLCs.

4. ***SCADA Protocols.***[2,5,7,8,9,10] A protocol is necessary in order for a SCADA master to create a path for exchanging information with IEDs; it establishes the necessary conventions, a standard communications path, and a standard data element, the language, so to speak, that all devices use. A protocol is a logical concept, not a physical connection (a physical connection is called an *interface)*. Historically, it was RTU manufacturers (long before there were "IEDs") and utilities that developed protocols without regard to standardization, i.e. one company's RTU cannot communicate with another company's master station unless they use the same protocol. Most SCADA manufacturers developed emulators of each others protocols while some companies maintain copyright protection of their protocols. In recent years, the electric industry in such standards organizations as the IEEE and the IEC have moved towards open published protocols that anyone may use without royalties; DNP, IEC 60870-5 and UCA are examples of open protocols.

Bit Protocols. Prior to 1980, most protocols were bit (not byte) oriented. Hardware for the most part was custom made, slow and expensive. Bit protocols usually transmit long data words, some over 72 bits long, and tend to use synchronous data transmission methods. Data in bit protocols are generally grouped into "frames" with data "words" encoded within the frame. RTU points (status, analog and accumulator) are usually hard coded to specific data bits within each data word. To retrieve data from an RTU, the master requests the RTU to reply with a certain number of frames, starting at a specific frame. Bit protocols usually have a slower data through-put because the master must continually request (poll) the RTU points to determine if a point has changed. Examples of so-called *proprietary* bit protocols are ACS, L&N Conitel, Moore Systems, Westinghouse REDAC, BBI/CSI, TELEGYR 7500, TRW, and Rockwell.

Byte Protocols. An (asynchronous) byte protocol generally takes 10 bits (1 start, 8 data, and 1 stop bit) which represents one ASCII (American National Standard Code for Information Interchange) character; all commands and data can be represented by 256 unique ASCII characters. Even though there is more overhead associated with asynchronous data transmission, due to the start and stop framing bits, actual throughput is generally faster with these protocols when the protocol allows for report-by-exception. Byte protocols use various methods of data encoding; generally data encoding is similar to bit protocols. The data is transmitted in "packets"; electronic envelopes ,so to speak. The size of the packet is usually variable – usually in the range of 1 to 1000 bytes containing several data “blocks”. The shorter the packet, the more robust it is to electromagnetic interference (EMI).

Byte protocols are compatible with standard 8/16/32-bit microprocessors and support hardware used in modern RTUs and PLCs. They can also take advantage of newer data transmission methods, such as fiberoptic networks; the older bit protocols cannot except by using dedicated custom designed communications equipment or older slower analog wireline, microwave or trunked radio modems (at 300 or 1200 baud). The price/performance ratio of computers has improved by many orders of magnitude since bit protocols were the norm in the electric utility industry. The higher level computer languages and standard off-the-shelf serial interface cards are ASCII compatible. Commercial network communications analyzers will work with most asynchronous communications protocols; those RTU manufacturers not supporting asynchronous open standards must supply custom communications analyzers. Examples of byte oriented *open* (published non-proprietary) protocols that will work with communications analyzers are DNP, IEC 60870-5, UCA, Landis & Gyr 8979 and PG&E.

Error-Correction Coding. Embedded within either the bit or byte protocol is error checking. It may be a simple parity bit or a cyclic redundancy check (CRC). The number of check bytes required depends on the length of the packet and the confidence level one requires (the Hamming Distance). This allows the error-correction decoder to detect and/or correct erroneous data and restore the received data stream to the original data stream. In extreme cases, forward-error-correction coding can be employed, so that detected errors are corrected in real time by redundant data bits encoded into each packet. All forward-error-correction codes have a theoretical limit called the Shannon Limit and as this limit approaches, the complexity and code-block size increases exponentially. There are several methods, Reed-Solomon and Viterbi are examples of such codes and in VSATs, Intelsat satellites and digital video broadcasts, Reed-Solomon is used. Audio CDs use this technique to play essentially flawlessly despite being physically scratched.

Utility Communications Architecture™. In 1986, the Electric Power Research Institute (EPRI) began an investigation of network communications requirements, existing standards, and possible new approaches to providing enterprise-wide utility data communications for both business and system control applications through EPRI Project RP2949, "Integration of Utility Communications Systems". The first two phases of the project: "Utility Communications Architecture"(UCA), and "Database Access Integration Services" (DAIS) were completed by the end of 1991. Both projects were completed with the issuance of the UCA1.0 Specification and the DAIS 1.0 Specification, respectively. To the extent possible, the UCA is built on current and emerging computer industry standards, with particular attention to electric utility requirements. Both UCA and DAIS recommend the use of standards which conform to the 7-layer International Standards Organization (ISO) reference model. Several standards are recommended for physical and data-link layers which allow utilities to use a wide variety of physical media in an interoperable manner. A narrow set of standards are recommended for the middle layers of the model, so that enterprise-wide connectivity can be achieved at the network level, while a rich set of application layer standards are recommended to support both process and business functions. UCA and DAIS specify the use of application layer standards for process control (Manufacturing Message Specification - MMS), file access (File Transfer, Access and Management - FTAM), Virtual Terminal (VT), Directory Services(DS), Electronic messaging (Message Handling

Services - MHS), Network Management (Common Management Information Protocol - CMIP), and Remote Database Access (RDA). (For a tutorial on the OSI concept and references to IEEE and ISO publications on the subject, which are beyond the scope of this text, see references 10 and 11.)

With the release to the industry of the UCA and DAIS specifications, the industry needed a place to learn about, to challenge, and to discuss implementation issues related to the use of the recommendations. Therefore, in May of 1992, EPRI and Northern States Power Company (NSP) convened a conference, meeting several times a year, called "The Forum for Electric Utility ISO 9506 (MMS) Implementation" (aka the "MMS Forum"). Working groups from the Forum focused on the use of the Manufacturing Message Specification (ISO 9506), which the UCA specification recommended for process control. Working groups were formed to address issues related to customer interface, distribution automation, substation automation, power plants, and control centers. A "profiles" group was established to address issues related to the use of MMS across multiple communication media and communication profiles.

Work originating in the MMS Forum, and from a series of demonstration projects, has resulted in more detailed specifications for three areas which address interoperable communications in the utility industry: communications profiles, application services and object models for IEDs.

The UCA communications profiles specify a set of protocols that are used in specific application areas. All profiles for process control make use of MMS as the application protocol to provide real-time data access and supervisory control functions. UCA specifies the use of MMS running over a variety of different underlying network protocols depending on the needs of the particular system. For instance, in a distribution automation environment, where point-to-point and multi-drop serial links used over fiber, multiple address (MAS) and spread spectrum radio systems must be supported, there are profiles of UCA that run over RS-232. For LAN environments, such as a substation or control room network, there are profiles using Ethernet with TCP/IP or ISO/OSI protocols. UCA supports the following basic profiles:

- A 3-layer reduced stack with MMS over an Asynchronous Data Link Control (ADLC) layer for operation over RS-232.

- A "Trim-7" 7-layer stack running over ISO/OSI transport over ADLC and RS-232 with a trim version of ISO Session and Presentation.

- A 7-layer stack running over TCP/IP over Ethernet.

- A 7-layer stack running over ISO/OSI over Ethernet.

The UCA application service model is referred to as the Common Application Service Model (CASM). CASM specifies a generic set of services, such as reporting, select before operate, logging, etc. that are available for UCA applications. While the CASM model is designed to be generic enough to support a number of different application protocols, UCA provides a mapping of CASM to MMS only.

Device and object models are specified by the Generic Object Models for Substation and Feeder Equipment (GOMSFE) specification. The GOMSFE provides detailed device models for common electric utility equipment, such as relays, breakers, switches, meters, RTUs, load tap changers, voltage regulators, etc. Each GOMSFE object model contains a comprehensive list of predefined, pre-named objects that the device may contain. The GOMSFE allows a device to support only a subset of these objects. The GOMSFE also provides the ability for a device vendor to add their own unique features in a manner that still supports interoperability between devices and UCA applications. UCA and GOMSFE allow the object models to be carried in the device. This allows the UCA client to download the object model and variable names directly from the device over the network.

In 1998, work began to progress the UCA 2.0 work for the use of MMS into the International Electrotechnical Commission (IEC) for international standardization of the UCA practices for utility system automation and control.

EPRI Research Project RP3599. Entitled "Substation Integrated Protection, Control and Data Acquisition" it's purpose is to develop an open system communication architecture and specification of protocol requirements to permit interoperability of IEDs in substations, regardless of manufacturer. In the case of RP3599, "IED" is taken to mean practically every device in the substation, including RTUs, substation computers and data concentrators. Use of layers protocols in accordance with the OSI Reference Model, using commonly available or standard protocols for each layer, is a cornerstone of RP3599. The project also bases much of its framework on the work of the MMS Forum. and is the subject of reviews by the IEEE Power Engineering Society covering Protection, Substations, and Communications. Appropriate groups in the IEC will be asked to review the project results.

Distributed Network Protocol (DNP)[12]. In 1993, GE-Harris Canada (formerly Westronic, Inc.) developed DNP using as its basis several IEC 60870-5 documents that were then in development; but extended and/or modified these to accommodate North American preferences and practices. Work has been done to harmonize the European IEC 60870-5 protocol documents, which were later made International Standards, with the DNP variations, but this has not been completed. DNP (3.0 as of this writing) is essentially a three-layer protocol using the layers 1, 2 and 7 of the ISO/OSI communications profile set. The protocol supports data objects and functions as needed by IEDs and RTUs. Some examples of supported functions are: unsolicited reporting, configuration upload/download, file transfer by multiple fragment messages, multiple masters, sequence of events, time synchronization, confirmed/unconfirmed messages, secure communication transfers, peer-to-peer communications, addressing to 65,000 devices and integrity to Hamming distance of 6 (the minimum number of incorrect bits that shall be received in order for a packet to be considered invalid).

Master Station. The SCADA Master Station, client or host station/computer, which monitors and controls RTUs and their attached electric apparatus, is no longer a turn-key custom product. The graphics capabilities of the modern workstations (and to a limited extent PCs) generally results in a human/machine interface (HMI) that makes it possible for the operator to easily deal with a variety of systems without sensory overload. The Master Station has a core program which is called the operating system. Running on the operating system are the applications programs written by the utility or the SCADA vendor.

Dynamic data exchange (DDE) mechanisms, in the operating systems, allow the computer to link automated mapping/facilities management (AM/FM) databases to the SCADA system. The Master Station can not only monitor and control RTUs but can call up customer records from a networked billing computer, a map of the affected area from an AM/FM database on the mapping system. Artificial intelligence programs will be able to filter alarms and perform corrective actions without operator intervention. The ability to call up multiple databases in conjunction with SCADA alarms allows for more efficient maintenance crew callouts when trouble occurs.

PC Based Systems. The most common Master Station today is the ubiquitous Personal Computer (PC) microcomputer with either Microsoft Windows 3.1, 95 or 98, IBM DOS, IBM OS-2 or Microsoft Windows NT disk operating system (OS). PCs can be networked so the processing and displays can be distributed either for multiple users or to share tasks. True multi-tasking (running several independent programs in parallel) on a single PC is possible with OS-2, NT and QNX. NT is growing in popularity, displacing UNIX systems running on more costly workstations. Linux (from Red Hat and others) is an open, low cost robust UNIX-type OS and there are now X-Windows-like HMI's that will run on top of Linux . There are also several variants of Unix that are PC compatible, but their use in SCADA is minimal. The PC superVGA display screen (the highest standard available for the PC) is considered a high resolution device (1600x1200). While there are special drivers and video boards to enable non-standard higher resolution modes, such components require special software drivers. Mouse, touchpad or trackball cursor pointer support is available as is a LAN system, such as Ethernet.

Workstation Systems. Workstations (COMPAC/DEC, HP, IBM, SUN etc.) running the UNIX multi-tasking operating system, represent the next level of sophistication. These very powerful, reduced instruction set (RISC) based, computers have large high resolution display screens utilizing standard open systems software screen drivers such as Motif and X-Windows. Workstations can also be networked; typically one has the hard disk and is the server while the rest are diskless nodes. Mouse support is standard as is an Ethernet port and LAN software.

Minicomputer Systems. For very high powered computational situations, which is typical of large AGC and EMS systems, the traditional mainframe super-minicomputer, such as the DEC VAX family, has been used with diskless (no hard disk) workstations serving as smart display terminals. How much longer these "big iron" machines will continue to be used in place of distributed networked workstations is open to debate.

SCADA Communications.[13,14] To connect RTUs or IEDs and master stations, a communications network is required. Six basic types of networks are defined by IEEE Std 1379-1997 (which defines an IED as a small peripheral device to a larger RTU):

Point-to-point: This is the simplest topology - one RTU is connected to one master station. A simple IED connected to an RTU would be such a network.

Multiple point-to-point: The master station is connected to RTUs by multiple point-to-point links and each RTU has a direct link to the master station. This is not a common arrangement but it may be used where high speed polling is required and the master station has sufficient ports to accommodate all RTUs or IED.

Multipoint-party line star arrangement: The master station is connected to one or more RTUs by one common port at the master station. Multiple Address Radio systems use such an arrangement. Only one remote may be polled at a time and each must have a unique address (ID) that only it responds to. Ethernets which use hub architecture are also in this category (10BaseT, 100BaseT).

Multipoint-party line bus arrangement: The master station is connected to more than one RTU by a common path. Only one remote may be polled at a time. A leased telecom line, on which many RTUs are multi-dropped, is an example of such as system as can a Thinnet coaxial Ethernet system.

Multipoint-ring: The ring is the preferred network, as it has a redundant path for communications with all remotes. Fiberoptic rings are an example of this type of network. Optical switches can provide additional bypass capability in the event of a failure at one node.

Composite: A meshed network configuration comprising a combination of more than one type of network as previously defined.

Peer-to-peer communications:[6,15] This network type is not mentioned by IEEE Std 1379-1997 but is being used to implement distribution automation (see UCA section). There is no need for a master station in a peer-to-peer system. All members (peers) have equal status and can communicate with any other member. While it has been in common use in computer networks for many years (e.g. MS Windows for Workgroups, an Ethernet connected bus or star(hub) network), it is becoming more common in SCADA systems. Decentralized distributed control uses pole-top RTUs that make independent decisions to operate based on local line conditions (intelligent sectionalizing switches). An extension of this concept allows a group of sectionalizing switches to communicate with each other and, based on the information exchanged, to operate to isolate faulted line segments and restore service. Results of peer-to-peer action are usually reported back to the energy management system by fiber, telecom line or radio, and provision is usually made for remote control by system operators to override local automation, when necessary, for system stability (§ 10.6.3).

Utilities use composite networks; wide area networks (WANs), composed of not only several network types but also several media types (e.g. radio, fiberoptics and telephony), because a single technology is often not economically practical for utilities whether they span a town (municipals) or several states or are simply IPPs (independent power producers such as hydro, wind or solar energy plants). For long distances, power line carrier has been used for voice and protective relaying, while telephone lines, and microwave relays were the only choices until long distance fiberoptic systems became available in the early 1980's. Open standards in computer local area network technology (LANs) link the distributed processing of information. This is made practical by the modern client-server model and the availability of high speed communications technology, the predominant standard now being proposed for substation LANS being TCP/IP over Ethernet by the IEEE Task Force C2TF4 "Task Force on Communications

Between Intelligent Substation Devices", both at the original 10 Mbits/s over coaxial cable or twisted pairs and the new 100 Mbits/s over Category 5 twisted pairs. Both are also being used via fiber and spread spectrum radio. The emphasis at the substation is for peer-to-peer communications using the EPRI UCA 2.0 protocol.

All radio communications frequencies discussed herein pertain to geographical areas regulated by the Federal Communications Commission (FCC) in Washington D.C. In June 1992, the FCC began reviewing frequency allocations in a variety of services. The expectation is that utility and other private frequencies will be re-allocated towards more public use, as the FCC expects new technology to provide more efficient spectrum utilization. The reader is advised to seek up-to-date information from the FCC at http://www.fcc.gov.

In 1998, the Telecommunications Association (formerly Utilities Telecommunications Council (UTC) released a report that found the following:

The total "new spectrum" required by the year 2000 will be an additional 1.0 MHz with 1.9 MHz more by 2005 and 6.3 MHz more by 2010.

There will be an increase in the use of wireless applications, and that they will need additional spectrum to accommodate these applications.

There is substantial interest within the utility community to implement wireless video and wideband data. As technology improves and the cost of terminals decreased, it will become common for the utility industry to deploy these technologies.

How this may be done in the face of unfavorable FCC Rule Makings and Congressional legislation, such as the Telecommunications Act of 1996, remains to be seen.

Nationwide high bandwidth services are used to network information between co-operating utilities, government entities and IPPs. Private communications systems are preferred over leased systems for conventional SCADA, DA, DSM, and AMR functions because utilities have not experienced dependable, reliable service from telecom providers. Government regulations could force the sharing of resources, especially if eventually *Fiber-To-The-Home* (FTTH) becomes a reality. It is predicted that FTTH costs, for voice and video services alone, exceed the resulting revenues expected.

Metallic Cable.[16,17,18] Wire systems have been the first choice of electric utilities. Leased telephone company (telco) lines are preferred to public switched network lines when conditioned lines are required (for higher speed communications). The provision of high voltage protection for wire lines entering electric power substations has been a requirement of telcos and utilities to prevent *ground potential rise* (GPR) from injuring communications workers and damaging equipment. It is not sufficient to provide a ground mat in the substation; lines must be isolated by either installing special transformers or fiberoptic line isolators. Private electric utility wirelines may be an economic alternative to telco lines when maintenance and reliability requirements are considered. A high speed service called distribution loop carrier (DLC) was the first telco digital service offered. Using a DLC system, analog signals from up to 24 customers are converted to digital signals (multiplexed) and transmitted on two cable pairs: one from the DLC system to the central office (CO) and the other from the CO to the DLC. Each of these cable pairs operates at a transmission rate of 1.544 Mb/s; this is known as the T1 rate. Most towns and cities are covered by DLC systems linked by fiber backbones at up to 622 Mb/s.

Now that the 1996 Telecommunications Act has been signed into law in the US, several electric utilities have a head start with telecommunications projects. Hybrid Fiber Coax and other technologies are being applied to solve SCADA and AMR communications problems and provide conventional telco services to electric customers. In the context of the 1996 Act, the use of the term "telco" in this section refers not only to Regional Bell Operating Companies (RBOCs) and independent telephone co-ops, but also electric companies.

A newer digital telco service has been available in some areas since the early 1980's called Integrated Services Digital Network (ISDN). ISDN offers one voice and two 64 kbs data channels per circuit. Newer high speed services include ATM (Asynchronous Transfer Mode), SMDS (Switched Multi-megabit Data Service), Frame Relay and SONET (Synchronous Optical Network). The RBOCs have, so far, been quicker to support and implement Frame Relay than higher bandwidth service specifications, such as SMDS and ISDN, because it operates at speeds inherent in most leased lines and many public lines - from 64 kbps up to T1. Since it supports a wide range of speeds and efficiently supports bursty traffic, it is cost-effective for connecting a large number of geographically distributed LANs but ISDN use is still quite low. It appears it was rolled out too slowly to be widely adopted; other better technologies have hold more promise.

xDSL is another class of telco service in trials. There are four different types of service. (hence the "x" designation). HDSL is high-bit rate DSL (digital subscriber line); it's the only technology available today (1998). It has been standardized as ETSI RTR/TM-03036. This symmetric transmission system replaces T1/E1 repeater services and is excellent for high-volume upstream and downstream traffic. It claims over 200,000 installations since 1992, and operates at 1.54 Mbps to 2.048 Mbps on two twisted-pair lines, at a 12,000-ft distance, reaching about 80% of the telco customers. There is also single-pair HDSL that provides 10Base-T Ethernet speeds. MDSL (moderate or multi-rate DSL) is a new variant of HDSL and is used to increase the capacity of a copper loop. It transmits from 272 kbps to 784 kbps and, it is hoped, it can reach to 22,000-ft. ADSL has an asymmetrical transmission method as it's roots are in video on demand to the home. ADSL provides 1.5 Mbps to 9 Mbps downstream; upstream ranges from 16 kbps to 640 kbps up to 18,000-ft. VDSL (very high-bit rate) is a developing technology for fiber in the loop (FITL) applications. The developing standard includes both asymmetric and symmetric schemes with 13Mbps to 52 Mbps rates. When these systems will become fully deployed is uncertain.

Hybrid Fiber Coax[19]. Upgrading telephone systems, to handle megabit rates, is already underway in many areas as local switches are upgraded and fiber migrates outward to the entire backbone. The bottleneck remains between the telephone pole and the home. Running optical fiber straight to every house is still very impractical. It is far too expensive to convert the fiber signals to telephone, cable TV, AMR, load shedding and Internet services. The challenge, as was discussed regarding xDSL, is to use the existing twisted-pair. Cable TV systems, on the other hand, have tremendous bandwidth but, until recently, have lacked the intelligent infrastructure;

that is changing rapidly due primarily to the phenomenal growth of the Internet. The Organization for Economic and Cooperative Development, or OECD, indicates that e-commerce represented .5% of retail sales in 1997. By 2003 however, they expect it to hit $1 trillion, or 15%, yet they consider that it won't have a significant impact on the global economy anytime soon. OECD does admit, however, that e-commerce has the potential to change sales in some product sectors dramatically, and in the way nonphysical products, such as stock trading and airline tickets, are sold. It will also change the rules of international trade, pricing and competition in these areas. So, will high bandwidth come to the home? Yes, and hybrid-fiber coax is already doing it in many cites across the USA.

This broadband-based architecture is good for building inexpensive one-to-many distribution systems by adding intelligence at both ends, plus providing extra bandwidth to support new services, such as Telephony. There is an optical backbone, or trunk line, to the neighborhood with laser repeaters, which is then coupled to a coaxial local feeder loop to the homes of 0.5 to 2 miles in length. Typically, up to 500 homes are served by coax from one fiber drop point. Useful bandwidth is up to 750 MHz. MPEG II (Motion Picture Experts Group) is used as the standard compression algorithm for transmitting digital video and most feeds to Cable-TV Control Centers from premium movie services, such as HBO and Showtime, and TV networks that used to come in via large aperture satellite dishes, now arrive via redundant 622 Mb/s fiberoptic SONET rings. The coaxial cable to the home now supports full two-way 10 Mbps Ethernet via cable modems so that customers are hooked up and on-line on the Internet 24 hours/day.

In 1996, a consortium formed to work on what is called the Residential Gateway (RG). Hewlett-Packard, Bellcore, B&C Consulting, David Sarnoff Research Center, GTE, IBM and Reltec were working to muster support for this concept. They suggested that a given residence would have a broadband service provided by a telephone carrier, a CATV service provider, a utility company, and/or a wireless communications provider through copper wire, hybrid fiber/coax, RF transmission or fiber-to-the-curb (FTTC). The consortium believed that it was important to create a set of interface standards between the broadband residential access network(s) and the communications services required by the residence. That work did not reach a consensus. There is no standard for the home today (1998). It remains for the marketplace to sort out the winners and losers.

In late 1998, AT&T announced that it would acquire Tele-Communications Inc. (TCI). That move will merge cable modem technology with one of the world’s largest long distance phone companies. It comes at a time when local exchange carriers (LECs) are beginning to market xDSL technology. This could settle the question whether cable TV can provide competitive service. As it stands now, Internet cable modem customers are expected to reach 400,000 by the end of 1998 and over 1 million by the end of 1999. Cable modems will be the dominate consumer access technology due to their price/performance, the content relationships of the multiple service providers (MSOs) and their aggressive rollout schedules. xDSL is predicted to not succeed as well but will find significant acceptance among small and medium sized businesses. Some electric utilities wish to play a significant part in this market using the infrastructure for SCADA and metering.

Derived Telephone Channel Technology.[20] Telco central offices are using computers for switching and some electric utilities are using the telephone network for automatic meter reading (AMR), as well as load shedding demand-side management (DSM). This system uses the existing telco communications infrastructure which has almost 100 percent coverage of residential and commercial customers. Cable TV is another derived channel technology that has been experimentally evaluated for AMR and DSM functions. There has not been much interest because it is not nearly as universal a service as the switched telephone network. However, with Internet service and telephony, it may be the medium of choice for the foreseeable future, especially if the telcos continue to delay implementation of xDSL technology.

Power Line Carrier.[21,22] Power line carrier systems use electric transmission and distribution lines to carry digital data and voice. Voice transmission via power line carrier dates back to the 1920's. Protective relay (pilot wire) applications followed soon after. The primary advantages of the system are complete coverage of and control by the utility. However, should a transmission path be faulted, the communications circuit is disabled and, therefore, detailed telemetry of the faulted condition may not be possible until the fault is cleared and the line restored. The main drawback when using power line carrier for protective relaying is that a fault that causes a relay operation can also cause a loss of signal when it is needed most. Most utilities provide a backup relay set and communication path (usually microwave) for critical relay applications. (see also §16.3.1)**.**

Two-Way Automatic Communication System (TWACS) patented by Distribution Control Systems Inc., is designed for operation at the 35 kV or lower distribution voltage class circuits. Several fully operational two-way systems controlling and monitoring a few hundred thousand points exist today. The outbound signalling technology is based upon modulation of the power frequency voltage at a precisely controlled region near the voltage zero crossings. The modulation is obtained by drawing a short pulsative single phase load at the bus of a distribution substation autotransformer. The inbound transmitter is located at the remote sites at the service voltage level (typically 208/240V). A signal is generated by drawing an impedance limited load current starting at an angle of 25 electrical degrees before the voltage zero crossing. The single loop current pulse is superimposed on the bus load current at the distribution substation. The inbound receiver extracts the inbound signal from the bus current. Unsolicited inbound reporting is supported. Propagation distances up to 90 km have been reported.

Due to broadband noise and distortion, the power line has not been a popular means of voice or higher speed communications. With the advent of spread spectrum technology, that may be changing, especially in Europe where hundreds of homes are served by a single distribution transformer. High frequency carriers cannot easily pass through the transformer. In the US, companies are concentrating on applying spread spectrum technology to build local area networks within homes and commercial buildings.

Another power line carrier technology, being used primarily for automated meter reading (AMR), is Hunt Technologies Turtle Energy Management System. Utilizing ultra narrow bandwidth (UNB) communications in cooperation with the National Rural Electric Cooperative Association, one-way transmitters are mounted inside most single phase meters. The system transmits signals at lower frequencies and is highly resistant to noise. Signals travel through transformers, long lines and capacitors without additional equipment. The Turtle Energy Management System requires three system components: Turtle transmitters in the meters, Turtle receiver(s) located at the substation and Turtle System software and host computer. The system has inherent power outage reporting ability that automatically reports within 1/2 minute to 25 minutes. Individual programming, sending readings from once every 14 hours to once every 27 hours. Options include kWh, peak demand, minimum demand and power failure counts.

Two Way Land Mobile Radio.[23,24] Some utilities assign separate radio channels (VHF 154 to 173 MHz or UHF 450 to 470 MHz) which are dedicated for data communications. Where there is a shortage of available frequencies, voice channels are used for secondary signaling. Voice and data communications share the same channels. The advantage of this solution is that the same infrastructure (radio repeaters, base stations, antennas, etc.) are better utilized. To ease the frequency shortage in the U.S., the FCC has assigned special *splinter channels* in the VHF band, and *offset* channels in the UHF band. These options allow the use of narrow frequency bands assigned for data communications in between standard frequencies.

Trunked Radio.[23] Trunked radio networks (810 to 890 MHz) utilize five to twenty channels (repeaters) to service a given area. When a member of the trunked group sends a message, the system opens a link by assigning one of the channels to the member. Then, the system sends a message to all the members of the group, switching their radios to the assigned frequency. When the communications is completed, the channel assigned to the group can be reassigned for new traffic. Because of the shared nature of the service, call completion is not 100 percent on the first attempt.

Multiple Address Systems (MAS).[23,25,26] To meet the growing needs for data communications of the U.S. electric utilities, the FCC assigned part of the MAS band (between 928 to 960 MHz, specifically the 928/952 MHz pair) for data communication and DA SCADA under part 94 of the regulations. A typical MAS consists of a centrally located master radio station communicating bi-directionally (full duplex) with RTUs within a licensed area. The technology requires essentially line-of-site transmission with a maximum range of 70 to 115 km. Additional licensed frequencies are very difficult to obtain. Frequency reuse, utilizing an integrated packet switched network management system, solves the problem by maximizing the use of available spectrum. A network, of microprocessor-based master stations, communicate with the RTUs. Masters and RTUs are equipped with omnidirectional antennas providing overlapping coverage. RTUs include a two-way microprocessor-based transceiver.

Spread Spectrum.[27,28] This system utilizes a constellation of packet radios with low power transmitters (less than 1 watt) within the 902 to 928 MHz band under FCC Part 15.247 which do not require licensing. Radios are typically mounted on distribution poles or street lights. When radios are installed, they automatically *learn,* and continually generate and maintain, a dynamic routing table of all other radios within their reception range so that, in the event a nearby radio is busy when a message needs to be passed on, it can reach one of the alternate radios. This system requires a number of radios in order to transfer data and have, typically, at least four radios at the master station for redundancy (as this is the critical path), and to receive messages from multiple directions at the same time. Software processing is required at the radio base station to sort the messages and send them on to the master computer. Additional radio base stations (at a distance) are used to further reduce the latency (delay) of multiple hop messages.

The resulting mesh network architectures cause the latency to be non-deterministic and statistical in nature with a substantial variation between minimum and maximum delays. The system is designed primarily for automated meter reading and distribution automation monitoring and control, where delays are not a concern and where the density of radios is expected to be high thus ensuring coverage. Interference from jamming, due to the low power unlicensed nature of the radios, depends upon the strength of the utility's spread spectrum signal in relation to all interfering (and also unlicensed and unregulated) sources on the same frequency. The frequency agility (hopping) of the system makes it more immune to such sources. In a system, it is not practical to use a polling technique from the master, as this has been shown to slow the retrieval of information. Spontaneous reports from RTUs are the preferred mode of operation.

Utilities can subscribe to the service and use the radios with conventional SCADA. One RTU provider (EnergyLine Systems) has implemented small peer-to-peer distribution automation systems for up to seven RTUs at a time using Metricom UtiliNet radios at 9600 bps which are specifically designed for utilities. This system does not require a conventional SCADA master station. Peers in the system communicate with each other, typically to open or close sectionalizing switches in response to faults that are locally detected. Another Metricom spread spectrum product, the Ricochet 28.8 kbps modem, is being deployed by a few large metropolitan utilities like Potomac Electric Power Company in Washington DC, who partnered via an unregulated subsidiary (PepData) to offer customers Internet services and piggyback SCADA on the same system at a considerable discount to themselves.

Cellular Telephony.[29] The US mobile cellular system today is an analog radio time division multiple access (TDMA) system of adjacent small hexagonal cells. The use of small cells tends to fill in gaps in the cellular coverage and increases overall capacity by allowing the same frequencies to be used in nearby, but not adjacent cells. The customer base was 33.8 million subscribers in 1996 and data accounted for only 2% of that traffic.

There are two approaches being considered to accommodate the anticipated needs of carriers and users in the coming years. E-TDMA is an enhanced TDMA system, endorsed by the Cellular Telephone Industry Association (CTIA) that maintains compatibility with the existing system. Code Division Multiple Access (CDMA) is a digital spread spectrum technology that has promised a 10 to 20-fold increase over current analog system capacity without expanding bandwidth and better coverage for smaller lower power portables. As of 1998, a modest four-fold improvement has been realized.

The FCC has recognized the need to encourage more efficient use of the spectrum. FCC Docket 87-390 opened the mobile cellular band for new services beyond the traditional voice telephone call. A low-speed wireless packet network has been developed (and patented) by Cellular Data Inc., which uses a scheme of frequency coordination to insert data into the existing TDMA cellular system and will be compatible with the proposed E-TDMA system. CDMA is expected to also support Docket 87-390 requirements. The base stations share the antenna and low noise amplifiers(s) at the cell sites with the cellular operators equipment, as well as the communications link between the cell site and the mobile telephone switch office, where the data packet switch is located. Remote radio terminals are located at metering and SCADA sites.

Due to the nature of most dial-up modems, when the data stream is interrupted for a brief period, the modems assume a hangup has occurred. The Microcom Networking Protocol (MNP 10) and TX-CEL protocols were designed to facilitate data-over-cellular in such harsh conditions but they do not make data-over-cellular nearly as reliable as dial-up modems used over wireline telephone circuits. Usage is normally charged on connect time rather than the volume of data transmitted.

Cellemetry Data Service. . Cellemetry Data Service is a patented technology of Cellemetry L.L.C. It is a two-way communication platform that links remote equipment devices to central monitoring centers where there is cellular coverage. It utilizes the non-voice or "control" channel, which cellular systems use for "roaming" applications, so it doesn't contend with voice traffic. These control channels are used to transmit necessary information for all call initiations (both incoming and outgoing) between the cellular system and the cellular customer. The message handling capacity of these control channels is far greater than is required by the existing cellular system, even during the busiest times of the day. Cellular carriers such as Bell South offer this service.

CDPD Technology. The Cellular Digital Packet Data system overlays an existing analog cellular network and has been implemented in over 50 metropolitan areas. It can use the idle time between voice calls, or in a heavy traffic environment, can use one of several dedicated channels. CDPD can provide wireless data communications at speeds up to 19,200 bits per second, versus the typical 2400 or 9600 bps speeds possible with analog cellular modems (14,400 bps cellular modems are also available). CDPD call setup time is a few seconds, versus the 20 to 30 seconds typical with analog cellular modems. The data is transmitted over CDPD reliably and securely, it is claimed, using error correction and encryption technology, while on an analog cellular call, the data is carried "in the open," with line conditions that may interrupt or terminate the connections. CDPD supports several of the leading open networking architectures, including the Open Systems Interconnect (OSI) model and the Internet. Coverage may vary and, as with all radio transmission, coverage may be affected by topography and other environmental factors. In those areas along the border of coverage, clarity and reception may be diminished.

Microwave.[30,31] The region from 1 to 30 GHz is (rather loosely) considered the microwave region of the electromagnetic spectrum. Propagation is line-of-sight; due to the high power allowed in the band, passive repeaters (reflectors) can be used to extend the transmission path. Utilities use microwave for protective relaying, SCADA long and medium haul data and voice communications. Weather (heavy rain and snow) can cause fading, so propagation studies must be conducted that consider local conditions. In 1992, the FCC announced that it allocated 220 MHz of the spectrum between 1.85 and 2.20 GHz for emerging public telecommunications technologies, such as personal communications services, because Europe and Japan have moved to reserve spectrum between 1 and 3 GHz. Based on a review of the FCC licensing records by the Telecommunications Association (formerly UTC), there are about 3700 utility-owned microwave stations in the 1.85-2.20 GHz band. The FCC says utilities can move to the 4 or 6 GHz band or switch to other technologies, such as fiberoptics. The 4 GHz band is already being used by backyard satellite dishes, which means that, potentially, all 2 GHz users could be displaced to 6 GHz. The 6 GHz band is already crowded; new users would have to change transmission paths in high-use areas or find frequencies for new paths.

On April 25, 1996, the FCC adopted a Report and Order and Further Notice of Proposed Rule Making in the microwave cost-sharing proceeding, WT Docket 95-157. The Commission decision largely kept intact the microwave reallocation procedures and adopted a new mechanism for allocating the costs of microwave relocation among those PCS cellular licensees who benefit from such relocations. The microwave relocation program will sunset in the year 2005. Thereafter, incumbents must relocate their own facilities upon six months' notice from a PCS licensee, provided, however that there is a reasonable option for a continuing means of communication. Furthermore, the Congress is considering the "Grand Spectrum Bill" which would give the FCC permanent auction authority as well as expanded authority to impose user fees. The bill would require the FCC to "exhaustively" license all available spectrum by selecting bands of unallocated and unassigned frequencies and auctioning those bands.

Satellites.[32,33,34,35,36,37,38] Commercial communications satellites have been in use since the launch of Early Bird I in 1965. They are used for high speed point-to-point applications, broadcast video, broadcast radio and telephone transmission. Carriers, such as Communications Satellite Corporation (COMSAT), lease satellite channels to customers on a full or part-time basis. Because of the delay, due to the geostationary orbit altitude (35,680 km) of the satellites (GEOs), echo suppression must be used for two-way voice communications. Transponders (repeaters), in the satellite, receive, down or up convert, and retransmit received signals from the earth stations. Spare transponders are standard and multiple satellites are available should switchover be required due to a failure (re-alignment of the earth stations might be necessary). Data security and geographic coverage is the primary advantage of satellite communications over leased landlines and microwave.

Very Small Aperture Terminals (VSATs) were introduced in 1984. Because of it's small size and relatively low cost, compared to standard satellite earth stations, the VSAT is now used as an element in many data communications networks and are being used to replace older radio and microwave networks. The diameter of the antenna determines how well the signal is received. VSATs cannot communicate in pairs; they must relay through a larger earth station or hub. The *double hop* architecture uses a VSAT from the master to the satellite transponder to the hub, back to the satellite via a second transponder to the remote VSAT. The *single hop* architecture uses a land wireline to the hub. From the hub, the signal is sent to the satellite where it is relayed to the remote VSAT. VSATs are claimed to offer 99.9 percent availability. VSAT networks offer superior performance over terrestrial radio media; typical bit error rate is 1 in 10^9. As of January 1992, there were over 50 SCADA systems operating on VSAT based communications networks. One example is Mountain View Electric Association in Limon, Colorado. The utility serves about 23,000 customers via Nova-Net, a division of ICG Satellite Services. The system uses a combination of spread-spectrum radio and VSATs to transmit meter reading information and to send signals to control electrical equipment such as water heaters in 4-8 seconds. There are 12 KU-Band VSATs deployed at 11 of the substations, and one installed at the operations center. KU-band (12/14 GHz) is an unlicensed service used for SCADA, load management, remote metering, distribution automation and business transactions. Data rate is up to 56 kbps. Sun position is not a problem. The earth terminal is a 1.8 M offset parabolic oval. Fading, due to rain or snow, may be a problem. AT T1 leased telephone line connects the center and headquarters.

C-band (4/6 GHz) is an licensed service and is used for SCADA, load management, remote metering and distribution automation. Data rates are from 1200 bps to 19.2 kbps. Sun position can cause fading due to sensitivity to thermal noise in the earth receiver. The earth terminal is a 1.4 M offset truncated parabola. Fading, due to rain, is not a problem.

Low earth orbiting satellites (LEOs) circumnavigate the earth at much lower altitudes – 400 to 600 nautical miles – so their coverage areas (footprints) move over the earth as they pass overhead. Operators of LEO systems (also called Little LEOs or LEOSATs) must deploy a constellation of satellites, often launching eight in one launch vehicle to provide the same coverage as that of the GEO by use of a very innovative launch technique. Orbcomm/Scientific Atlanta used a winged Pegasus rocket deployed from a L-1011 aircraft to launch it's satellites. Sun synchronous orbits, typically deployed at LEO altitudes, enable the satellite to pass over a specific point on the earth at the same time of day each month. Initially 95% of the messages (using a store and forward technique) will reach destinations within 3 minutes[37].

Deployment of a 66-satellite Motorola Iridium constellation has been completed with the launch of five spacecraft from Vandenberg AFB, California in 1998. By spreading out across the equator, Iridium forms an electronic mesh which covers the world. Most of the technology equipment in the Iridium system is modeled after GSM digital cellular technology. The satellites will communicate with terrestrial subscribers using QPSK modulation and time-division multiple access (TDMA) protocol to support up to 4 digital connections per channel. The bit rates will be 1200 or 2400 bits/s to conserve bandwidth. Satellites will talk via microwave L band (1.6 GHz), employing the first phased array antennas ever used in space. Each spacecraft moves so fast that it only spends 9 minutes in it's 2000 mile coverage zone and then the call is handed off to the next satellite to be in the zone – in effect, the cells move instead of the phones. The system is operational and the company donated portable satellite phones (slightly larger than a cell phone) to countries in Central America such as Honduras that were hard hit by massive hurricanes that wiped out almost all land based communications in the country.

ICO Global Communications begun the launch of batches of 12 medium-Earth orbit satellites (MEOs or MEOSATs) in mid 1998, and expects to begin service in mid-2000. Their satellites will orbit at 6477 miles so they can cover the globe with 10 operational spacecraft and two spares and just 12 ground stations. ICO is a spin-off of the Inmarsat maritime satellite consortium. Another is Globalstar, a union of Qualcomm and Space Systems/LORAL. Their next 36 satellites will be placed in circular orbits, 879 nautical miles above the Earth and will cover most populated land masses and coastal waters. When completed there will be 48 satellites in the constellation.

Not to be outdone, Teledesic, conceived by Microsoft founder Bill Gates and cellular telephone mogul Craig McCaw plan to launch 840 interlinked LEOs. Thus far, only the LEO satellite companies are actively pursuing electric utility communications applications, but with so many satellites in or planned to orbit, the sky's the limit.

Satellites do have their own unique problems. In 1998, a potentially damaging Leonids meteor storm threatened. It was to be the most intense storm in 33 years. There were, at the time, 600-plus satellites in low, medium and geostationary orbit as well as the Russian Mir space station. Some operators reoriented satellites (10 deg. or less) to protect solar panels and components from impacts. These tiny particles (micron sized) have the impact of a .22-caliber bullet, scattering molten material inside the spacecraft, creating ionized plasmas that could cause electrostatic discharge (ESD). In August 1993, a European Space Agency satellite failed when it lost pointing control and a solar array following impact by a Perseid meteoroid. In 1991, a Japanese solar observation satellite lost a Sun shade to a Perseid meteor. Fortunately, the 1998 Leonids caused no damage and have been deemed too unpredictable. Also, in 1998, the Earth passed through the tail of comet 55P/Tempel-Tuttle. Particles in the comet's tail ranged in size from house dust to grains of sand traveling at 71-72 km/sec (160,000 mph); there was no damage caused by impacts.

Another significant problem with satellites is the risk involved in getting them into orbit. Satellite launch vehicles have exploded with increasing frequency in recent years. Of course, when that happens, the satellites aboard are lost as well as the launch opportunity. For example, PanAmSat lost its Galaxy 10 satellite in 1998 when a Delta 3 rocket exploded. The launch was insured for $225 million and the company plans a replacement in early 2000. One recent development is the use of the US Space Shuttle to retrieve satellites that have failed in orbit to be brought back to Earth to be repaired and re-launched. The Shuttle Challenger disaster delayed satellite launches for several years because the US had put all its launch "eggs" in the Shuttle's "basket". Now several other countries (including China and Russia) and numerous launch vehicles including a sea-launch joint venture between Boeing and Russia are competing for launches

Solar Effects on Communications.[39,40,41,42] Solar effects on communications have been recognized for over 100 years. Solar activity peaks every 11 years; during the peak, 50 to 100 flares occur daily and flares large enough to seriously disrupt communications occur weekly. The effects are unpredictable and very little warning is available. Some in the electric utility industry would like to position a monitoring satellite far enough away from earth, about 1.6 million kilometers, to give a one hour warning (the solar particles travel much slower than radio waves, so an alert could be beamed back before the satellite was swamped by radiation). Radio is particularly susceptible, from low frequencies (<3 MHz) through the microwave region (1-30 GHz), absorption, reflection, and refraction (fading, noise and interference) can occur. A deep space satellite called the Solar and Heliospheric Observatory (SOHO) has revealed a previously unknown kind of solar eruption that directly affects our planet called a magnetic inner tube that circles the sun's equator and collects electrically charged particles. Then, unlike the well-known flares that eject narrow jets, this outbursts becomes a global event because it shoots out highly energetic particles in all directions (http://sohowww.nascom.nasa.gov).

On March 10, 1989, during a solar maximum, a solar flare sent X-rays and charged particle towards the earth. Two days later, protons and electrons, captured by the earth's magnetic field created auroras that illuminated the sky as far south as Florida and Texas, disrupting communications systems, satellites and electric systems throughout the world. The worst effect was at 2:45 a.m. EST, when virtually all of the province of Quebec was blacked out. There were reports of fading at utility microwave and power line carrier communications and loss of SCADA telemetry. The US Coast Guard reported problems with LORAN navigation, the US Navy marine HF radio circuits were out world-wide while 144-148 MHz systems were receiving powerful signals from far beyond their normal range. California Highway Patrol messages were overpowering local transmissions in Minnesota. A Japanese satellite was permanently damaged. Seven geosynchronous communications satellites had considerable problems maintaining orientation. A NASA satellite fell half a kilometer as the start of the storm and dropped a total of 5 kilometers during the entire period. (Satellites are very vulnerable to fluxes of charged particles, which can damage solar arrays, which power satellites and perturb their orbits). Metallic terrestrial circuits were also affected.

Satellites continue to be plagued by space storms because they lack the protection of hardened defense and intelligence spacecraft against heavy doses of radiation. Even the U.S. Global Positioning System (GPS) is vulnerable. One such violent outburst was blamed for the failure of Telestar 401 on Jan. 11, 1997. The growing role of satellites in every day life was highlighted May 19, 1997, when PanAm Sat's Galaxy 4, a Hughes HS 601 spacecraft, lost its primary and backup control processes; the 5 year-old satellite is expected to be declared a $165 million loss. The failure blacked out millions of radio pagers across the U.S. and affected television, cable and radio transmissions such as Walmart, Chevron and National Public Radio. Though solar storms were not the cause of these failures they did trigger electrical failures in three Lockheed Martin-built spacecraft in 1994: Intelsat K and two Canadian Anik television satellites. The odds are increased annually by the sheer number of satellites slated for orbit. Another 800 satellites are slated for orbit in the next five years. Low earth orbiting satellites will be vulnerable to increased drag as Earth's atmosphere thickens from the heat of the solar activity, according to NOAA scientists. To improve its outreach, NOAA began posting electronic Space Weather Advisories on the Internet at http://www.sec.noaa.gov. Fiberoptics are expected to be the medium that will be most dependable during a solar disturbance, provided their power supplies are protected against induced ground currents.

Fiberoptics.[13,43,44,45,46] Communications by light is an ancient technology dating from the signal fires that burned on prehistoric hills. Signal lamps in the steeple of Old North Church warned Paul Revere that the British were coming during the American Revolution. Today, lighthouses still warn ships and warships communicate by signal lamps. Optical telegraphs (systems of moveable arms on towers) were made practical by a Frenchman, Claude Chappe in the 1790s. He using multiple towers and teams of signalmen with telescopes where distances between stations were great. The first optical telegraph line ran between Paris and Lille. England which was fighting the French at the time devised their own system and a similar system was used between Boston and Martha's Vineyard and Island off the Massachusetts coast, 104 km from the city. When the electrical telegraph was invented, optical telegraphs were quickly replaced but the desire to communicate by light persisted. Alexander Graham Bell demonstrated what he called the Photophone on February 19, 1880 for transmitting voice by light. Today light is still used for signaling at street intersections and on railroads throughout the world. How to conduct light great distances through fog and rain around or over mountains without repeaters (human or otherwise) has been a challenge. In 1870, Tyndall demonstrated that light, by the phenomenon of total internal reflection, could be guided within a water jet. In 1934 a patent for an optical telephone system that used glass or quartz was filed by Norman R. French of the American Telephone and Telegraph Company. The first dielectric light waveguide to be studied at optical frequencies was the glass-coated, glass fiber developed for fiberoptics imaging applications in the

1960s. The basic design is the same, regardless of the use, namely there is a central core glass which conducts the light and an outer clad glass which minimizes light leakage out of the core material. The effect is due to index of refraction differences in the two materials. In 1966, Dr. Charles Kao postulated that optical fibers could be used for communications provided the (then) gross attenuation of the fibers (200 dB/km) could be reduced to a satisfactory level. By 1977, the technology had begun to be deployed in telephony applications.

Fiber Technology. There are two materials used to make modern fibers, plastic and glass. Plastic fibers are not suitable for distribution applications, as their high loss (1000 dB/km), limited operational temperature range, low strength and low bandwidth, limits their use to distances of 50-200 meters. Glass fibers transmit most efficiently in the near and far infra-red portion of the spectrum (800-1550 nanometers (nm), so light emitting diodes (LEDs) and semiconductor lasers are used as electro-optic transmitters and silicon, germanium and indium-gallium-arsenide photodiodes are used as electro-optic receivers. The working range of fiberoptic devices is from +5 dBm (singlemode semiconductor laser) to -50 dBm (indium-gallium-arsenide avalanche photodetector detection limit for a bit error rate of 1 part in 10^{-9}). Information is encoded into light pulses by amplitude (AM), frequency (FM), frequency shift keyed (FSK), pulse shift keyed (PSK) or pulse code modulation (PCM) techniques. Each has its advantages and disadvantages.

There are three types of glass fiber which are described according to their central core glass construction as step index, graded index and singlemode. The step and graded index fibers are multimode fibers. All glass fibers have an outer glass covering called the clad. Step index fiber is useful for short distances (less than 2 km), as it suffers from the highest loss and has the poorest bandwidth. Hard clad silica (HCS), with a 200 micron core and 230 micron clad (200/230), has a 20 MHz/km bandwidth and is used in office LANS, industrial control applications and in some aircraft LANS.

An older (and now rarely used) step index fiber, is 100/140, requires connectors which are non-standard, as the clad diameter is larger than the more commonly used 50/125 and 62.5/125 fibers. While 100/140 has a useful 100 MHz/km bandwidth, it is still somewhat lossy and has, for the most part, been replaced by less costly, higher bandwidth and lower loss graded index 50/125 and 62.5/125 fibers.

Unlike 100/140, which can only be used at 850 nm, modern dual window graded index fibers can be used at either 850 or 1300 nm; the attenuation at 1300 nm is typically one third of what it is at 850 nm; by using more expensive transmitters and receivers, the range of the system is tripled. 50 micron fiber has a slightly lower loss and higher bandwidth and is presently somewhat less costly, but, when spliced or joined by connectors, the smaller core size causes joint losses to be somewhat higher. Less light can be coupled (launched) into 50 micron fiber than 62.5 although the lower overall loss on long distances makes up for the launch deficiency. 62.5 micron fiber has gained in popularity, over other multimode fibers, due to its extensive use by AT&T and other major users; it has become a defacto United States industry standard. 50 micron fiber has become a defacto standard outside the U.S.

Singlemode fiber has an extremely small core, 8-9 microns in diameter, while the clad is the same as multimode fibers, 125 microns, so similar connectors can be used. A higher precision is required when mating or fusion splicing fibers as misalignment of cores introduces significant attenuation. Transmitters cannot launch much light into such a small core, however, as the internal losses are minimal, due to only the (TEM_{oo}) waveguide mode being supported (.35 dB/km). Thus, for the maximum unrepeatered distance, singlemode fiber is preferred. The bandwidth is much higher for singlemode fiber because higher order modes, which would cause the light pulses to propagate slower and which would distort the light pulses, are not supported. The transmitter characteristics are the only limit to achieving virtually infinite bandwidth. In general terms, singlemode systems cost significantly more than multimode systems.

Three new developments hold great promise: solitons, semiconductor optical amplifiers and dense wavelength division multiplexers. The soliton is a light "packet" that, once launched into a singlemode fiber, does not degrade with distance. Semiconductor optical amplifiers consist of an optical gain medium pumped by a semiconductor laser. The device offers bi-directional direct amplification of the optical signal. There is no need to convert to the electrical domain. Dense wavelength division multiplexers (DWDM) are a method whereby a single fiber may carry many virtual light channels at slightly differing optical wavelengths. Traditional electronic multiplexing techniques, such as SONET or ATM, are then used to encode the data/video/voice channels into each wavelength “channel”.

The Growing Uses of Fiber. In April of 1977, General Telephone installed the first link carrying regular telephone service in Long Beach, California at 1.544 Mb/s over a graded index fiber with a 6.2 dB/km loss. In December 1998, just 21 years later, scientists in Gothenburg, Sweden achieved 40-Gb soliton pulse transmission over a 400-km distance on commercial dispersion shifted fiberoptic cable. The line tested used erbium-doped amplifiers at intervals of 57 km. The solitons were 10 ps wide. Un-repeatered distances of 100 km are now possible. Use of multiple optical wavelengths may provide the stimulus for increases in fiber capacity according to the FCC 1991 *Fiber Deployment Update*. Ultra low-loss halide fiber, currently in the research stage, "can potentially provide transmission without repeaters over distances exceeding 2000 miles (3200 km)."

The use of fiberoptics for telephone communications has so expanded that only fiberoptics is being used for new transatlantic and transpacific submarine cables. According to a recent report by Kessler Marketing Intelligence (Newport, RI), North America leads the world with 47 percent or 15.7 million fiber-km installed, between the years 1978 and 1991 (the world-wide total is 33.1 million fiber-km).

Fiberoptic SONET (Synchronous Optical Network) systems such as that deployed by The Southern Company and Baltimore Gas & Electric now operate at OC48 (2.488 Gbps) and carry 32,256 voice circuits, whereas a few year’s ago, OC-12 (622 Mbps) was commonplace. (A microwave radio channel may carry 2016 circuits.) OC192 systems are just beginning (1998) to be shipped; they have a four-fold increase over OC48 capacity over the same fiber span utilizing time division multiplexing techniques (TDM) which rely on ever faster semiconductor technology. Thus, the same span can replace an OC48 signal with an OC192 signal or, utilizing DWDM, it can launch four OC48 signals down the same fiber at different wavelengths. Eventually, perhaps 16 wavelengths can be carried by one fiber, each having an OC192 rate for a combined 160 Gbps rate. That will happen within the next 5-10 years.

Electric Utility Utilization of Fiber. It is far more commonplace for fiberoptics to be used by electric utlities now than it was when the previous edition of *the Standard Handbook* was published. Fiberoptics is being used in traditional data and voice communications applications where its increased bandwidth (capacity) is badly needed to increase capacity or for future capacity for long term growth. Some utilities are able, through public utility commission deregulation rulings with the impetus of the 1996 Telecommunications Act, to sell or lease excess fiber capacity to third parties and by doing so, pay for the system costs. The non-conductive nature of fiber results in a communications media with very low noise, excellent natural immunity to electromagnetic interference (EMI); it, like radio, is a solution to the GPR/telco problems in substations. Fiber has similar advantages to metallic conductors, as the utility facilities can be used for right-of-way where underground ducts are available or transmission and distribution lines already exist. Of course, there is no licensing requirement. Where radio problems exist, such as microwave multipath problems downtown, the avoidance of obstructions from new downtown construction (which would mean re-siting a microwave facility) or where a lack of available radio frequencies exists, fiberoptics may be advantageous. One must still consider round-trip transmission delays with fiber. There are meteorological effects, the dominant ones being atmospheric temperature, on the delay variation. At 5 AM, the effects are atmospheric while at 1 PM the effects include atmospheric temperature, sunshine duration, wind speed and precipitation. Variations have been measured from 60 to 100 ps/km.[47]

The Telecommunications Association[13] (formerly UTC), in a September 1998 report, announced that the number of cable miles more than doubled since it's 1994 survey, and the number of planned cable miles almost tripled. Among the 157 respondents, 103 reported 40,549 installed cable miles and over the next three years, 91 respondents plan to install 36,628 more cable miles. The number of fibers per cable is also increasing. SONET-capable equipment and ring configurations are becoming more common (38.2 percent versus 16.6 percent in 1994).

An example of how fiber is displacing other SCADA communications is City Public Service of San Antonio, Texas. CPS is in the process of constructing a system-wide, state-of-the-art, fiberoptic network to meet the long term communications needs of the electric and gas distribution systems. The company will use this new communications network to link its major distributed computing systems, which include SCADA, GIS, corporate mainframe system, mobile data terminal systems and power plant control systems. CPS will also use the fiberoptic network to connect all of the electric substations, which will facilitate the implementation of distribution automation and energy management programs. The network will ultimately replace existing analog microwave radio and telephone-line communications systems which are deemed not adequate to meet future needs. This effort was given impetus by the FCC reallocation of frequencies. The system will have approximately 300 miles of fiberoptic cable.[48]

7. ***Network Distribution SCADA.***[49,50,51,52] A non-traditional use of SCADA is for monitoring and controlling underground grid and spot electric distribution network systems. Underground networks offer much greater reliability than other commonly used distribution systems. Unfortunately, because a network system is designed for maximum service reliability, maintaining power to customers, even if one of its primary feeders or transformers fails, there is no obvious indication that there is a malfunction. Low current arcing faults on 480Y/277V spot

network secondaries can sustain themselves for extended periods of time and cause extensive damage, more so than at 208 volts. The greater potential allows the arc to re-strike and sustain a fault instead of just "burning in the clear". There is a need to prevent total network shutdown from secondary faults, prevent a catastrophic failure in a building vault, and minimize damage to customer and utility facilities. Until SCADA systems became practical, periodic visual inspections were required, as well as preventative maintenance, to detect incipient failures. Practically speaking, inspections cannot be frequent enough to detect defective equipment. Scheduling preventative maintenance on network protectors wastes a considerable amount of money and human resources.

Examples of Network SCADA. In the Consolidated Edison NY system, the protector status, fuse status, transformer oil temperature (above or below 90°C), and load current, in percent of nameplate, are monitored. In the Pacific Gas & Electric system, RTUs monitor: protector status, protector heat sensor, transformer temperature, vault temperature, vault water level, 3-phase secondary current, and a transformer sudden pressure relay. In the PG&E system, master station screens found to be most useful for the operators and engineers were: alarm log, quick scan of each loop (showing all RTUs), individual vault screen, feeder loads, 2-unit spot clearances, diagnostic communications screen, protector operation count, and protector blown fuses. The ConEd system is the largest in the world, covering 22,000 transformers and protectors. At the time it was developed (1971), only radio, telephone, metallic cables and power line carrier were the technologies available. The system had to run submerged; radio was too expensive and it was doubtful that coverage would be uniform: the need for multiple repeaters, the difficulty in siting RTU radio antennas, mechanical installation and reliability issues. Telephone and electric vaults were virtually separate systems and would have also been too costly to be considered. Power line carrier became the most feasible, practical and cost-effective method. The system operates on a random burst transmission principle, which means that each unit turns on and transmits randomly so that there is a 98 percent probability that all units can be heard from in a 30 minute period.

Fiberoptics versus Radio or Power Line Carrier. The PG&E system was developed in 1985. In addition to the technologies considered in the ConEd system, fiberoptics was considered as this technology had now become a practical alternative. Fiberoptics was selected as it was found to have several advantages over power line carrier. Radio was rejected when it was realized that vault RTU antennas would be occasionally blocked by passing or parked motor vehicles (this effect has been observed at other utilities). The workaround is to place the radios on buildings or light poles and then connect by fiber or wire or power line carrier to the vault RTUs. Being non-conductive, the fiber cables were placed in existing PG&E ducts that contained 12/34 kV feeder cables. Fiber’s immunity to electromagnetic and radio interference was also a positive factor. Power line carrier was not selected because a fiberoptic system would be easier to install as there would be no connections to feeders, communications would not be interrupted in the event of a feeder fault or an open switch operation (expected difficulties in locating and repairing feeder cable failures), slow and uneven data rates and, perhaps, most significantly, power line carrier was one-way (from the network to the Master station). It was important that data be received in a predictable time (rather than the statistical probability model power line carrier systems have due to collisions between randomly reporting remotes) as it was expected that in the future, control might be required (for high side switches or to operate protectors remotely based on fire alarms from the heat sensors).

Operational Benefits of Network SCADA. Alarms are triggered by any abnormal conditions so that corrective action can be promptly taken to avoid or minimize damage. The protector operation count has been found to be most useful. It is recommended, based on operating experience at PG&E, that the SCADA Master software be set to flag any protector which fails to close after a three-day period. Protectors can fail (or not operate) for many reasons: burned out motors, being left on manual-open instead of auto-close, contacts are defective, and master and phasing relays fail or go out of adjustment. To clear a feeder, instead of having to send a crew to check every protector, which would take many hours, operators can send crews directly to vaults with hung-up protectors. Transformers can go over-temperature when automatic vault ventilation fans break down or when crews turn fans off and neglect to turn them back on again. This can require replacement of the silicone oil or derating of the transformer until it can be retested and recertified for full load service. While network components are designed to work submerged, according to the manufacturers, continued submerged operation is not recommended. Water alarms tell crews which vaults to pump out. When a fusible link opens on one of the protectors, a customer still receives three-phase power because all customers are on two or three spot transformers or a grid. One of the transformers is now only feeding two phases because of the failure; this is immediately apparent with a SCADA system. This situation could cause overheating of the transformer and reduces the manual and emergency loading capability of the vault. Corrective action can be scheduled to replace the link. It is significant that network distribution problems can be identified and corrected in minutes instead of hours or days. Network SCADA systems have proven to be significant cost savers. For example, the time it takes to close network feeders and transformers have been significantly reduced. Utilities are more aware of the condition of the network when a planned outage is started. This may allow the use of two-unit spots as opposed to three-unit spots (if a scheduled clearance would cause an outage on the two-unit spots, the clearance is modified). Shifting of load can defer the need to upgrade feeders. The need to physically check protector status, which required three visits to each protector affected by a clearance, is eliminated. The cost of crews (persons and equipment) to monthly inspect all vaults is also eliminated so that crews can be re-deployed.

Utilities can load equipment and cables much more efficiently because the customer's true load factor is known, as is the load factor of individual pieces of equipment. Future benefits may include load management and meter reading. Since these are large customers, the dollar advantage in a faster turnaround of billing are significant.

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