# Case Study: Utilizing Ethernet Radios and Communications Processors to Integrate Remote IEDs


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Presented at the
DistribuTECH Conference
Tampa, Florida
January 22–24, 2008

Originally presented at the
9th Annual Western Power Delivery Automation Conference, April 2007

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***Abstract*—This paper describes the design and implementation of an economical supervisory control and data acquisition (SCADA) system and communications infrastructure for City of Minden Utilities.**

**City of Minden, located in northwestern Louisiana, is a small municipal served by Entergy ties. In addition, bulk power comes from American Electric Power (AEP). As City of Minden progressed into developing their power system, they started to upgrade and replace electromechanical relays and meters with intelligent electronic devices (IEDs). In the process, they discovered the vast amount of data that could be obtained from these IEDs. Thus an economical data acquisition system was needed to gather information from the newly developed substations and remote reclosers. In addition, a communications infrastructure was needed to provide the data link throughout the system.**

**Utilizing open protocols, existing equipment and software, and off-the-shelf communications equipment, City of Minden created a SCADA system and communications network with the following features:**

- **Remote engineering access to all IEDs**
- **Critical information retrieval from remote IEDs**
- **Remote IED control capabilities (future implementation)**
- **Reliable unlicensed Ethernet radio network**

**This paper discusses the technology and architecture of the Ethernet radio network and the lessons learned on installing Ethernet radios in conjunction with communications processors. Furthermore, this paper discusses utilizing a common communications channel to provide both SCADA and engineering access.**

## I. Introduction

City of Minden has operated as a municipal electric system since the 1920s. The city owns and operates two gas-fired steam generating units and five diesel units, which are only used for summer peaks. Normal power is supplied by AEP via Entergy transmission ties. A study commissioned in 2000 determined that the city required a major system upgrade/ expansion to ensure margins for system load capacity. The metering and protection equipment in service on the existing system was primarily electromechanical. The city made the decision to embrace newer technology in this system upgrade/ expansion project. The project required major substation upgrades because of a change in the transmission voltage from 69 kV to 115 kV. The city commissioned one new substation (East Street) and planned for major upgrades of two existing substations (Sheppard Street and Germantown). The city never had SCADA but did monitor the feeders from the steam plant in the plant control room through a mimic board. The desire to upgrade the metering, metering data acquisition, and data archiving at the power plant inspired the decision to undertake the SCADA project so that the remote substations could be monitored and possibly controlled.

In the late 1990s, the city began discussing its vision to have a SCADA system, originally planning to utilize fiber that would be provided by the cable company as part of the pole-use agreement. The city never contractually finalized the plan, and the cable company changed owners twice over the time span of the project. At the time, the city used leased lines and Bell 202 modem technology for water system monitoring. Experience with less than desirable reliability made this option for the new SCADA unacceptable. Radio technology seemed to be the only viable cost-effective communications to deploy, and the city made the decision to study this option. The radio manufacturer provided a study and some on-site tests that showed the radio technology would work in the system.

The SCADA project evolved as city operations and management personnel discussed the capabilities of the involved IEDs. As would be expected, the scope of the SCADA portion of the upgrade evolved as the total project evolved. Originally, the vision was to have traditional SCADA capabilities that included breaker status, station alarms, feeder and transformer metering, and switch and breaker remote control. This would have been easily accomplished using a serial connection from each of the three substations back to the power plant control room. After the city decided to use radio as the communications media, they realized that monitoring and control of the city's nine distribution reclosers located at various points around the city would be possible through the same radio system. Upon further brainstorming, they came up with the idea of using the manufacturer's interleaved protocol to communicate to the end devices. This would give the operations personnel the ability to gain engineering access to the relay IEDs via the power plant communications processor. The city, having had a history of vandalism on pole-mounted devices, decided to mount the recloser controls high on the distribution poles out of public reach. This hindered the ability of operations personnel to retrieve fault record data—an ability they wanted to regain with the new SCADA.

The topography of the city and the location of the equipment and substations presented some challenges for the radio system design. In addition, the merging of some power plant monitoring with substation SCADA and distribution reclosers (IEDs) outside the substation made this project unique and a quantum leap for a utility that had previously operated with no SCADA or monitoring.

## II. Communications and Protocols

Integrating various IEDs in remote locations is always challenging. A variety of communications technologies can be used to collect information from remote devices. In determining the type of infrastructure to use, one must consider the following: feasibility, importance of data, and cost. City of Minden determined that they wanted a SCADA system that could be implemented with readily available SCADA equipment.

### *A. Spread-Spectrum Radios*

Spread-spectrum radios are very popular and easy to implement. They do not require FCC (Federal Communications Commission) paperwork or licensing, which makes them easy to procure and install. They operate on the following radio frequency (RF) ranges (USA): 902–928 MHz and 2.4–2.483 GHz, providing bandwidths of 26 MHz and 83 MHz. These frequency ranges are designated as unlicensed and referred to as ISM (industrial, scientific, and medical) bands. The radios can be installed for point-to-point or point-to-multipoint communications. The communications distance can vary based on the line of sight between points [1].

There are two popular methods in which spread-spectrum radios can operate: direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS).

DSSS basically spreads its signal across the whole range of frequencies. This modulation technique provides devices with the ability to send high-speed data. Due to the spreading technique, DSSS becomes limited in range [1] [2].

TABLE I
SPREAD-SPECTRUM COMPARISON

| Feature | Frequency Hopping | Direct Sequence |
|---|---|---|
| RF Output Power | 1000 mW | 1000 mW |
| Receive Sensitivity | –110 dBm | –85 dBm |
| Bandwidth | Up to 230 kHz | Up to 20 MHz |
| Maximum Data Rate | Up to 115.2 kbps | Up to 20 Mbps |
| Operating Range | 25 miles | 5 miles |
| Interference Susceptibility | Low | High |
| Multipath Susceptibility | Low | High |

FHSS sends its signal over a range of different frequencies at pseudo-random intervals known to the transmitter and designated receiver, hence the name frequency hopping. This provides a built-in security feature because data are being sent seemingly randomly at different frequencies. However, this makes the FHSS modulation technique more complicated because both transmitter and receiver need to be synchronized, resulting in lower data rates but greater range as compared to DSSS [1] [2]. Table I summarizes the differences between DSSS and FHSS [3].

Implementation of a radio network requires one to conduct a transmission path study. Radio manufacturers can usually provide such studies. This study provides the means of how many and where the radios will be installed and provides height requirements for antennas so that they can achieve the best line-of-sight communications. A basic spread-spectrum communications link requires two radios, one radio acting as a master and the other as a slave. This is called a point-to-point system. If a master radio cannot communicate to a slave radio due to distance or interference, another radio (repeater) is installed between the two radios. The repeater, as the name implies, receives and resends the signal to the appropriate device(s). The repeater will be located at a point in which it can communicate to all devices. Fig. 1 shows the different methods of communicating over a radio. Because of the diversity of spread-spectrum radios, vendors have made them available in multiple forms. The two most popular forms are serial radios and Ethernet radios. They are both similar in that data are being communicated in a wireless form. The difference between the two is the connection between the radio and IEDs. One provides a serial communications connection while the other provides an Ethernet connection. The Ethernet connection is proving to be popular because it provides a simple means of connecting multiple devices or multiple communications ports on one device with one radio.

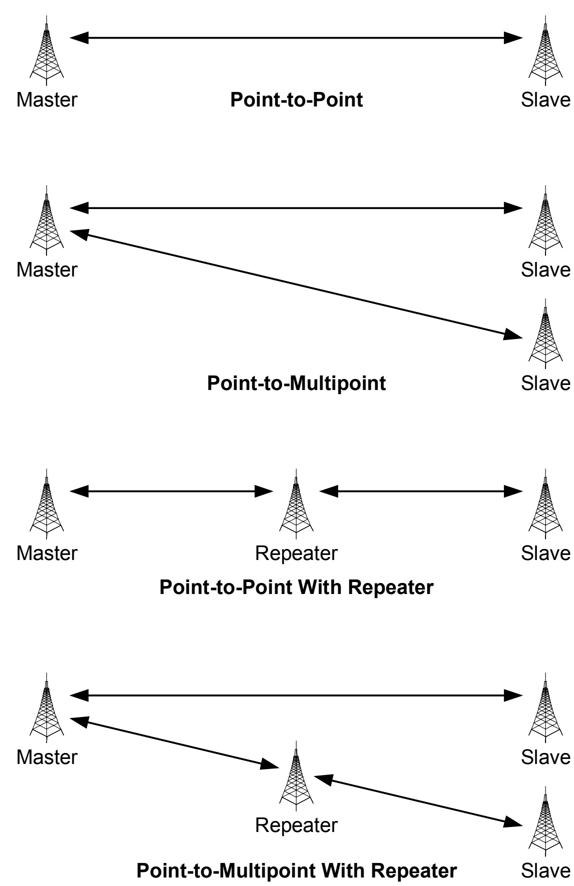


Fig. 1. Spread-Spectrum Radio Connections

## B. Ethernet

Because Ethernet infrastructure is becoming increasingly popular, IED manufacturers provide a model option to support Ethernet communications. Typical Ethernet networks, which are normally found in office environments, have migrated widely into home networks. Utility and industrial realms have adapted this standard for communicating with IEDs. The technology is so flexible that it can be used in different physical communications links. For example, Ethernet can be implemented using wire (copper connection), fiber, and radio (wireless). This flexibility allows protocols such as DNP (Distributed Network Protocol) and Modbus® to be communicated over Ethernet. The IEEE 802.3 Ethernet standard describes the process of how devices (IEDs) can communicate by utilizing CSMA/CD (carrier sense and multiple access with collision detection). This method provides the means for time-sensitive protocols such as DNP to be able to use the Ethernet standard to communicate with remote devices. Table II lists the popular Ethernet types that are widely used [4].

TABLE II
POPULAR ETHERNET TYPES

| Standard | Type | Speed |
|---|---|---|
| 802.3i | 10BASE-T | 10 Mbps over twisted pair (TP) |
| 802.3j | 10BASE-F | 10 Mbps over fiber |
| 802.3u | 100BASE-TX | 100 Mbps over TP |
| 802.3u | 100BASE-FX | 100 Mbps over fiber |

Various devices allow one to establish an Ethernet network. Hubs and switches allow multiple computers or devices to connect in a radial Ethernet network. Both hubs and switches broadcast data to all connected devices. However, the switch provides intelligence in that it allows data to be forwarded to the appropriate device, thus making communications more efficient and effective. The switch or hub allows one to group a collection of IEDs or nodes into a workgroup in which data can be shared with one another. Routers are intelligent devices that allow information to be directed from one workgroup to another. For example, routers often serve as gateways to other networks. There are also devices that allow legacy devices (serial communications devices) to communicate on an Ethernet network [5]. These devices are known as serial-to-Ethernet transceivers or media converters, see Fig. 2. Fig. 3 illustrates a typical Ethernet network using various Ethernet devices.

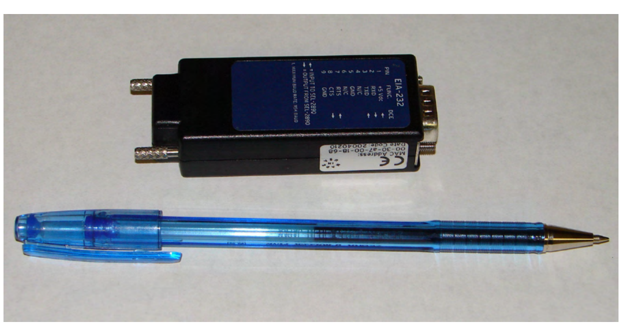

Fig. 2. Serial-to-Ethernet Transceiver

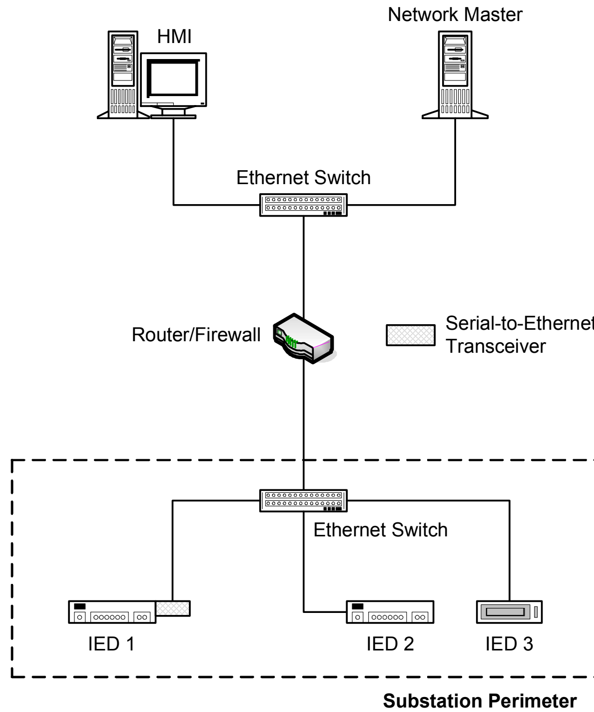


Fig. 3. Typical Ethernet Network Connection Diagram

## C. Protocols

The discussion of spread spectrum and Ethernet all involve how data are physically transmitted from one location to another. However, in order for devices to communicate with one another, it is necessary to have an understanding of communications protocols. Protocols are necessary for proper communications and data exchange between IEDs. A protocol is defined as "a set of conventions governing the treatment and especially the formatting of data in an electronic communications system" [6]. In other words, protocols provide the translation or common language for IEDs to communicate and exchange data with one another. There are numerous protocols available for integration applications, ranging from vendor-specific (proprietary) to standard protocols. The following protocols were considered for this project:

- DNP3—administered by a vendor-independent standards group (DNP3 User Group)
- Modbus—administered by a specific vendor (Modbus-IDA), but considered a market standard because of its simplicity and popularity
- TCP/IP (Transmission Control Protocol/Internet Protocol)—a suite of protocols for communications on the Internet and Ethernet networks
- Open proprietary protocols—vendor-specific but nonprivate protocols administered by the collective engineering staff of a single vendor

DNP is also known as DNP3. DNP3 is a nonproprietary protocol maintained by a users group of vendors and end users, rather than a proprietary protocol maintained by just one vendor. DNP3 was designed specifically to support typical SCADA communications over low-bandwidth communications channels. Its support of several data-acquisition methods, including the report-by-exception method that transfers only the data that have changed since the last poll, makes DNP3 very efficient. In addition, all data are referred to by labels that represent objects, such as analog value, status value, and alarm value objects, rather than by labels that represent memory locations, as in Modbus. Users can request each class of objects (analog, status, alarm, etc.) separately without needing to know how or where the data are stored in the source IED. Unlike Modbus, DNP3 provides event timestamping of the data, so that time-tagged change-of-state and analog rate-of-change data from the IED can be transferred with the appropriate timestamp. DNP3 supports many communications media and architectures, including both serial and Ethernet connections. The DNP3 protocol continues to evolve with Ethernet applications via DNP over Ethernet [6].

Modbus is also a nonproprietary protocol that was developed to allow master devices such as distributive control systems (DCS) to collect data from Modicon® programmable logic controllers (PLCs). It is less complex than DNP and other protocols. It provides a means of collecting data that are stored in registers by utilizing a simple syntax that requires the following: slave ID or address, a function code, data, and a checksum [6].

TCP/IP provides the means for computers and IEDs to communicate with one another over an Ethernet network (wide area or local area). This suite of protocols provides a way to provide each connected device with a unique ID or address. This concept of providing a unique address to each device allows non-addressable protocols to become addressable. This became important when integrating the vendor-specific protocol. TCP/IP provided the communications link between Ethernet spread-spectrum radios. It eventually allowed for creation of an addressable SCADA network workgroup by allocating addresses to each serial communications device.

Vendor-specific protocols can make integration simple because they are carefully designed to ensure communications among the vendor's devices. The vendor-specific protocol used in this project is open, nonprivate, and flexible, allowing the user to add features over time to enhance the capabilities of the communications systems. This open proprietary protocol became a requirement because it is the only protocol of any type that supports the City of Minden requirement to provide data acquisition, control, and engineering access at the same time and on the same channel.

This unique interleaved protocol allows data to be collected in a binary format and utilizes ASCII commands to provide remote engineering access at the same time.

## III. Integration

Determining the appropriate protocol was the next decision in developing City of Minden's SCADA system. The minimum protocol requirements were the following:

- Provide real-time analog values
- Provide real-time status updates
- Provide real-time substation alarms
- Allow engineering access to remote IEDs for fault collection and maintenance

DNP provided all the above listed features except for remote engineering access on the same communications port/channel. In order to accomplish engineering access, the installation would require two serial-to-Ethernet transceivers at every remote device—one for DNP and the other for engineering access. Furthermore, the cost of purchasing a new DNP master was prohibitively expensive.

The central communications processor served as the SCADA master that collected data from sixteen serial communications ports. Each serial port collected data from a remote IED or other communications processors and was simultaneously used for remote engineering access. The city chose the vendor-specific protocol for use between the central communications processor and other IEDs or communications processors. This protocol is connection oriented and faster than the other protocols, without the need for addressing each message. It is also communicated via serial channels or serial tunnels within Ethernet channels. Normally, a serial copper or serial fiber connection would be used between a communications processor and remote device. This dedicated serial link ensures that data are collected into their respective serial port. In order to emulate this star configuration, a pair of serial radios would be required for each communications processor serial port. Installing several serial radios at the central communications processor was very difficult and expensive; therefore, the city used Ethernet radios because they allowed one radio to serve as the master. However, in order to implement this Ethernet radio solution, the city needed to convert the communications processor serial connections to Ethernet. The serial-to-Ethernet transceiver was the solution for this conversion. The transceiver provided serial tunneling that allowed for emulation of the serial star configuration over Ethernet. Fig. 4 provides an illustration of this concept.

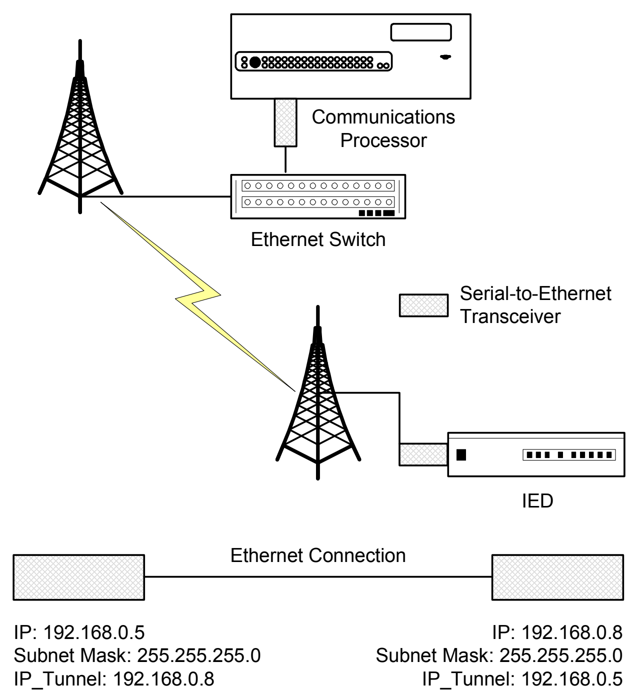


Fig. 4. Serial Tunneling Application

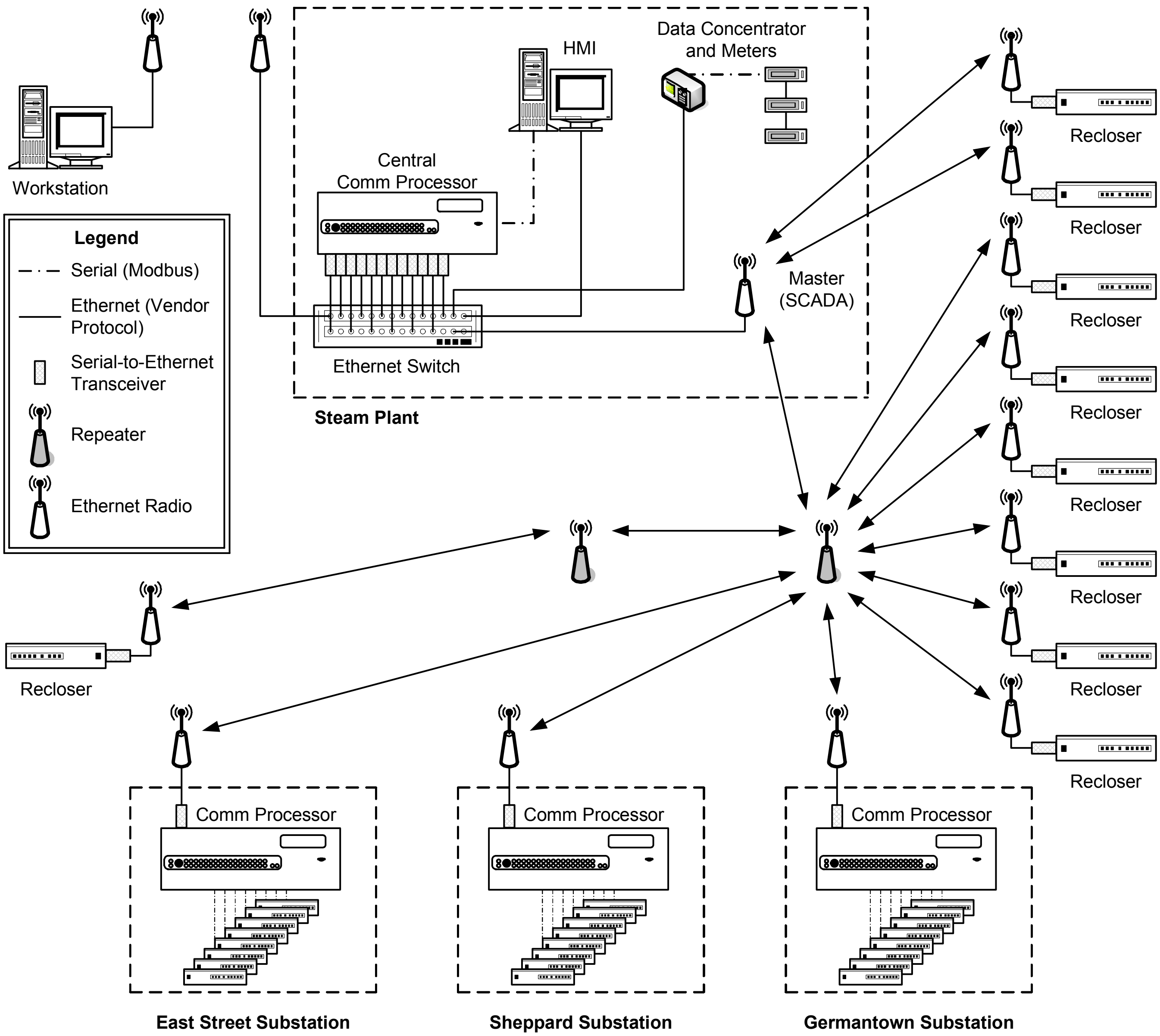


Fig. 5. System Communications Diagram

The city selected Modbus as the protocol to communicate between the central communications processor and the HMI because the HMI was already equipped with Modbus. This was the most logical choice because the central communications processor also supported Modbus. Therefore, in this scheme, the central communications processor collects all of the data from the remote devices and simultaneously serves as a port switch for remote engineering access to all IEDs connected to that central communications processor. The vendor's interleaved protocol provides this functionality. The central communications processor then serves the data to the Modbus HMI master by using Modbus RTU over a serial connection. Fig. 5 illustrates the communications infrastructure of the entire SCADA system.

## IV. Conclusions

Implementing a SCADA system is not always an easy task, regardless of the size of the system. By integrating various devices and utilizing wireless communications, City of Minden discovered and overcame various obstacles. One obstacle was the development and improvement of technology. The hardware and software technologies available for SCADA have been evolving rapidly in recent years. As with all technology-driven projects, one must draw a line and implement existing equipment. Options available today enable an even simpler infrastructure to accomplish the same results. Numerous updates in firmware and settings optimization have evolved more into an "art" rather than a "science." However, City of Minden is discovering the great advantages of retrieving analog and status information from remote devices. Furthermore, the remote engineering access feature has proven to be a great asset.

## V. References


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## VI. Biographies

**Fred D. Stewart** started with City of Minden in February 1980 as an operator at the diesel generating plant. Fred left City of Minden in May 1981 and returned in September 1983 as an apprentice lineman. He has worked for City of Minden for nearly 25 years. City of Minden, being a small municipal utility, provides a wide range of experiences in areas including generation, line construction, substations, communications, PCB disposal, and GIS systems.

**Randy Pylant** received his BS in electrical engineering from Louisiana Tech University in 1978. From 1980 until 1993, he worked for Entergy Corporation in Louisiana and gained work experience in many areas including protective relaying, SCADA, communications, distribution, and substation construction. In addition to his utility experience, he has over 13 years experience in sales of electrical protection, control, and communications products to the utility and industrial markets. He has been a member of the IEEE for over 28 years and is a member of ETA KAPPA NU, the Electrical and Computer Engineering Honor Society.

**Roger Baldevia, Jr.** earned his BS in electrical engineering from Seattle University in 1993. That same year he started working for Guam Power Authority's engineering department as a systems planning engineer and later transferred into operations as a SCADA engineer. His experience encompasses communications technologies, systems planning studies, and energy management systems. Roger joined SEL in 2003 as an integration application engineer. His responsibilities include providing technical support as well as assisting and training SEL customers with integration and automation applications. Roger obtained his Professional Engineering license from the U.S. Territory of Guam in 1997 and from the state of Illinois in 2005.