Extend your plant network with industrial wireless Ethernet

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Ethernet has taken industrial data communications by storm. Virtually every brand of programmable controller (PLC), remote terminal unit (RTU), and SCADA hardware now has models with Ethernet ports. Once the subject of great controversy regarding its suitability in the industrial environment, Ethernet is now occupying an ever-growing niche in data acquisition and process control. Its application is no longer limited to just information exchange, but is used routinely for real-time data retrieval and command and control. It is also now used as much for its ease of connectivity and inherent multiplexing characteristics as for its high data throughput.

Ethernet has already proven itself in the business office, and more recently on the plant floor. Now, wireless Ethernet is showing itself to be a good tool that provides multiplexing and connectivity in remote network applications.

This article looks at applying Ethernet to wireless systems. It explains the advantages and disadvantages of different radio transmission standards, and their efficacy with Ethernet.

Wireless Ethernet

The increasing use of wireless Ethernet in industrial applications is being driven by more than convenience and the elimination of wiring. For example, plants often need to connect remote or isolated devices to a main Ethernet network but can't because: (1) the devices are farther away than permitted by Ethernet cable length; (2) the connection would not be economically feasible; or (3) the devices are mobile. Each of these situations presents special installation and operating considerations involving trade-offs of data throughput, range, data integrity, and physical restrictions.

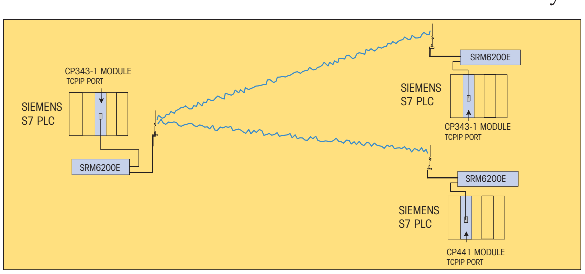

FIG. 1: License-free Ethernet radio modems support half/full duplex modes at up to 20 miles without repeaters.

Several parameters (e.g., interference, signal levels, licensing) related to radio transmissions affect the data integrity and throughput, cost, and ease of installation and maintenance of wireless Ethernet communications. Therefore, anyone designing a wireless Ethernet system should give careful thought to the expected EMI/RFI noise environment, the nature of the data being communicated, antenna requirements, system interconnectivity, and licensing legalities.

An operating license can be a very important issue since obtaining one (if even available in any given area) is time consuming and expensive. The operation of any radio transmitter is subject to the acquisition of either a license or an exemption. Some years ago, the Federal Communications Commission in the U.S., followed by Canada's regulators, set aside bands for license-free operation (subject to meeting certain conditions and limitations) for industrial, scientific, and medical (ISM) use. In North America, the most used bands are 902 to 928 MHz and 2.4 to 2.483 GHz. Both bands permit the operation of spread spectrum radio modems, which can successfully and routinely communicate at ranges from a few feet to tens of miles at data rates from 1200 bits/s to several megabits/s. A new 5.8 GHz band with similar characteristics to the 2.4 GHz band is just becoming available.

Spread spectrum radio modems: Frequency hopping and direct sequence

Spread spectrum radios were designed to be immune from jamming, including by their

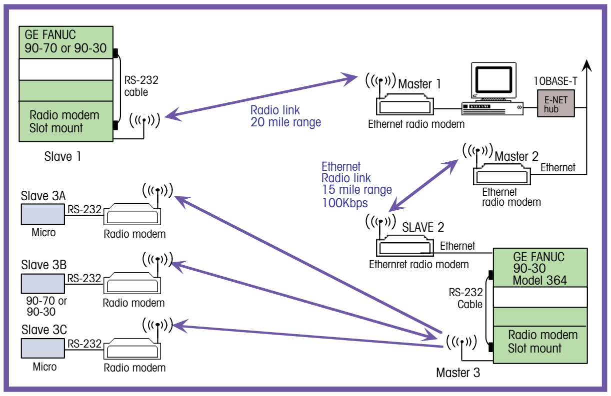

FIG. 2: Ethernet provides connectivity and open architecture in remote access to a network. This license-free multitier, multidrop installation connects GE Fanuc Series 90 PLCs to wireless Ethernet along with several other RS-232-based devices.

own signals. The result is remarkable technology that, when fully refined, yields secure and reliable radio communications at very modest output power and at ranges of up to many miles.

With spread spectrum technology, the transmitted information is spread over a significant portion of the available spectrum, some 26 to 83 MHz. The two most popular spread spectrum techniques are direct sequence and frequency hopping.

Direct sequence involves spreading the transmitted information over a large portion of the available band. This technique provides for a relatively high data throughput because of relatively low operating overhead. However, moderate to high levels of in-band noise will greatly reduce throughput or stop data altogether.

Frequency hopping radios, on the other hand, send packets of data out in narrow sub-bands, which are changed every few milliseconds by pre-established algorithms. Any packets corrupted by noise can be detected and retransmitted; in essence, the data hops around noise. Frequency hoppers have inherently somewhat lower data throughput, but have much greater noise immunity. The ability to get the data through under adverse conditions has generally made frequency hopping the technique of choice in industrial data communications.

Frequency considerations

The 2.4 GHz spread spectrum band offers a greater bandwidth than the 902-928 MHz band, providing somewhat higher data throughput. The trade-off is reduced range at legal transmitted power. Both frequency bands provide only line-of-sight paths between antennas. Field experience has shown that typical 2.4 GHz radio modems require directional antennas to achieve operating ranges of more than a few thousand feet. Some 900 MHz radio modems will function with omnidirectional antennas at ranges of 35 to 42 miles, with 20 miles being the conservative published specification *(Fig. 1)*.

Government regulations somewhat limit the worldwide use of 900 MHz radio devices. Their use is permitted in North America, most of Central and South America, and most former Commonwealth countries (but not Great Britain). The 2.4 GHz devices can be used in most of the world, but Europe imposes transmitted power and data rate restrictions, limiting effective range.

Combining the radio modem with Ethernet

Industrial spread spectrum radio modems are available in both asynchronous (typical format for RS-232/422/485 data) and Ethernet versions. Asynchronous radio modems have maximum port speeds of from 9600 to 115.2 Kbps, depending on brand and model. Ethernet modems have port speed capability of up to 10 Mbps.

Just remember: port speed and data throughput are not the same thing. This difference is a consequence of operating overhead (packetizing, error detection, buffering) and the number of retries needed to get the data packets through. Depending on noise conditions, range, operating power, antenna type, and internal data processing, the throughput can be markedly different than port speed. This is particularly true with Ethernet radio modems. Even cabled Ethernet 10BASE-T (10 Mbps) very rarely operates with throughput above 7 Mbps because of its own collision avoidance and packetizing functions.

Likewise, due to internal methodologies, most 2.4 GHz frequency-hopping Ethernet modems are limited to 2 Mbps maximum throughput. In reality, depending on the noise environment and range, actual throughput for 2.4 GHz can rapidly drop to under 500 Kbps. In the case of 900 MHz modems, throughput is typically between 50 and 100 Kbps, but there is little degradation with range (80 Kbps at 20 miles with omnidirectional antennas is real). This difference in range between 2.4 GHz and 900 MHz radios has to do with the modem's receiver sensitivity, operating methodologies and internal data processing.

Impact of data throughput

On the surface, the difference between typical cable rates of 7 Mbps and the conservative radio capabilities of 50 to 500 Kbps would appear to be unacceptable. However, when we examine what the radios are being called upon to do, and how Ethernet works, it turns out that such performance is perfectly acceptable.

If two local wired networks are being connected via radio with large amounts of data traffic (for example, large file transfers) high throughput is certainly desirable. In such a case, if noise is low and range not great, 2.4 GHz direct sequence spread spectrum modems may be the best choice.

However, more and more often Ethernet is being used industrially not for its high speed, but rather for its ease of connectivity and open architecture in remote access to a network *(Fig. 2)*. Here, even 50 Kbps is almost always fast enough for the tasks at hand. For example, the remote device may be polled and exchange only a few bytes of data occasionally. Data throughput in this case is almost irrelevant.

What is important is the optimization of total system performance, and a special feature of some wireless Ethernet modems contributes significantly to this. The feature, which is called a *learning bridge* (a software function), monitors and records (and thereby learns) the physical addresses of the local devices on each side of itself. Then, by monitoring packets, it filters the addresses and only allows packets with destination addresses not recorded (therefore, on the other side of the bridge) to cross, greatly reducing traffic on the bridge. Thus, it only sends what it needs to send. An Ethernet radio without this address filtering capability will be required to pass much more data, substantially increasing throughput requirements.

Performance objectives

Product performance specifications must always be considered in the context of what the job is about. Specific applications will dictate the performance objectives for any given industrial Ethernet radio. Data reliability is usually the primary objective, particularly if any near-real-time data acquisition and control is being done. There are instances, however, when only noncritical, information-level data is being conveyed—where data reliability is less important. But in other cases, the data must get through—even at the sacrifice of data throughput and speed.

The data rate vs data integrity issue is at the heart of the selection process of direct sequence vs frequency hopping equipment. Most industrial Ethernet radio modems use frequency hopping technology to achieve the data reliability requirement. Beyond data reliability, objectives are usually dictated by physical circumstances—for example, the distance between the devices to be linked, the noise environment, the mobility or immobility of the remote devices, and the minimum data throughput needed.

From an economic standpoint, installation and maintenance costs also come into play. There are many factors to be considered, and each application has its own priorities. All must be considered in detail to optimize the system design and performance, and to select the appropriate Ethernet radio modem.

FIG. 3: Data-Linc slot-mount radio modems provide wireless Ethernet connectivity for PLCs. Shown above (from left to right) are the SRM6000/GEFanuc-90/30, SRM6000/Modicon 984, and SRM6000/Allen Bradley SLC5.

Some antenna fundamentals

Spread spectrum radios use two basic types of antennas—omnidirectional and directional. At the 900 MHz and 2.4 GHz frequencies, omnidirectional antennas consist of single straight elements, usually oriented perpendicular to the earth. They are the easiest to install, since no alignment or pointing is necessary, and radiate equally in all directions horizontally to the earth

Directional antennas, which include Yagi, planar, corner, parabolic, and dish, focus radiated energy and amplify received radio signals. All antennas can be designed to provide some degree of gain (increase in radiated power) beyond that delivered by the radio transmitter. Expressed in dB of gain (a 10-based logarithmic scale), theoretical gain can typically be up to 6 dB for omnidirectional and up to 40 dB for directional (in the direction of the focusing).

Because government regulations limit the total radiation allowed in each ISM band, both the power of the transmitter and the gain of the antenna must be considered. In some cases, a high-gain antenna with reduced trans-

FIG. 4: SRM6200E industrial Ethernet radio modem by Data-Linc Group uses spread spectrum technology and operates in the 902-928 MHz band. It supports IEEE 802.3 Ethernet V.2 and 10BaseT, and has a range of up to 10 to 15 miles line-of-sight, without repeaters.

mitted power is a good choice since there is antenna gain for the receiver function as well. However, in higher noise environments, signal-to-noise ratio is critical and maximum transmitted power and minimum receiver gain is the best choice. Also, keep in mind that the higher the antenna gain, the vertical radiating angle of the antenna becomes smaller, allowing you to reach distant receivers, but at the same time causing the transmitted signal to skip over close-in receivers. This is known as the *cone of silence*.

Cable loss between the radio unit and the antenna must also be factored in. The loss at 2.4 GHz is about six times higher than at 900 MHz, so most 2.4 GHz systems must be located close to the antenna. For 900 MHz units, low-loss antenna cable with lengths of up to 200 feet can be tolerated.

Noise, range, mobility, and maintenance

The selection of the best Ethernet radio modem for a specific industrial application is most often influenced by potential interference, distances, and whether the devices are fixed or mobile. At the relatively high frequencies used by Ethernet radio modems, interfering noise is usually caused either by other in-band devices, such as other spread spectrum radio networks, or high power-radiation of devices in nearby bands, such as cell phone towers.

Noise can be hard to predict. Because the bands are license free, new devices and, thus, new interference can be introduced at any time. Inherent robustness (immunity to interference) is highly desirable. Frequency hopping is usually the best choice (in close proximity, hoppers will almost always knock direct sequence modems off the air—in theory it isn't allowed, but it does happen). If data throughput requirements permit, 900 MHz Ethernet modems with 50 to 100 Kbps throughput will provide far greater noise tolerance and operating range than 2.4 GHz units. The ability to use omnidirectional antennas has an impact on installation and maintenance issues and obviously is a must if the remote devices are mobile.

Two system design and cost issues that tend to be overlooked or underestimated are installation and maintenance. Industrial data acquisition and control systems are usually expensive and often are subject to fixed price bidding. Nobody wants surprises! Issues of present or future interference are best dealt with *before* equipment purchase. Careful attention must be paid to line-of-sight operation. If repeaters are required to get around obstacles, the radio modem or brand selected should be able to support economical repeaters.

The placement and type of antennas can have significant impact because of their initial cost and the effort involved in setting them up. Omnidirectional antennas are much easier to set up, particularly at distances of a mile or more, since the visual sighting required to align directional antennas becomes difficult beyond that distance and requires special equipment. Likewise, keeping the directional antennas in alignment, if outdoors in heavy weather, can be an ongoing maintenance problem.

Practical experience

Many wireless Ethernet networks have been installed on factory floors, and many wireless modems are available for programmable controller slots *(Fig. 3)*. Some wireless networks involve communication to moving robotic devices, but more recently, a number of long-distance, outdoor systems have been implemented. A particularly interesting application involves communications between a fleet of ferry boats and a shore facility. Data is gathered on the boats through an Ethernet fiber optic network, which is directly connected to an Ethernet radio modem (fiber to antenna). The 900 MHz Ethernet modems maintain reliable and uninterrupted communications at a range of 35 miles.

Another mobile application provides network connectivity with Allen-Bradley PLCs for operations managers in pickup trucks in a large iron mine in Northeastern Canada. The Ethernet radio network includes a repeater six miles from the office site, and the trucks can be up to 15 miles from the repeater.

A petroleum company in Texas uses a wireless Ethernet link to monitor alarms, then control a remote camera to view the alarm site using Modicon PLCs. These and other field

Why use Ethernet for industrial control?

Ethernet initially evolved as a standard means of interconnecting PCs at high data rates in business offices and has become the most popular and widely used networking topology today. It comes in several configurations, with data rates of 10 Mbps and 100 Mbps, but its most common form now is known as 10BASE-T (10 Mbps over unshielded twisted pair). Ethernet's long and successful operational history has resulted in an exceptional degree of reliability, universal connectivity, and availability of standardized system components and devices at reasonable cost.

The adaptation of Ethernet to industrial data communications has involved little change to the equipment and its basic mode of operation. Some hardware has been environmentally hardened, but Ethernet is still Ethernet, and all the experience and most of the hardware is transportable from the office environment to the factory floor or field.

What has changed, in many cases, is the emphasis on certain of Ethernet's operating characteristics. In office networks, high data rate is extremely important and probably Ethernet's most important feature. In many industrial applications, however, high data rates (Mbps) are not required, but ease of connectivity, the ability to operate a multitude of devices on one common network, and the inherent multiplexing function of Ethernet makes it a particularly attractive choice.

When adapting Ethernet to industrial applications it is important to remember that there are a number of practical operating criteria imposed by the environment, which must be taken into account. First and foremost is data integrity. The operating environments in offices and most commercial locations are usually very predictable and benign. Industrial operating environments are typically just the opposite: mobile, outdoor, as well as indoor, often with high electromagnetic interference, involving both point-to-point and multipoint/multidrop connections, and a broad range of devices.

The relative unpredictability and potentially harsh conditions pose special challenges requiring attention to detail and the need to make more choices when designing an optimized network. Among the issues are trade-offs between system data throughput, operating range, and data integrity and reliability. It's important to realize that industrial Ethernet provides a greater degree of uniformity in connectivity than is the case with many conventional serial techniques, such as RS-232 based protocols.

applications have also demonstrated the remarkable ease of bringing an Ethernet radio system up and running. Most Ethernet radio modems are transparent to protocol and can be seamlessly connected between Ethernet devices such as programmable controllers, PCs, or hubs without any special configuration.

With wireless Ethernet the subtleties count

The industrial use of Ethernet is expanding dramatically, due in large part to the experience and success in business office communications. However, as we've discussed, industrial Ethernet applications vary considerably compared with the typical, predictable business office environment. Fortunately, industrial Ethernet radio modems *(Fig. 4)* now come in several varieties, each with their own particular characteristics and advantages.

Industrial applications pose a number of special problems having to do with many different and often unpredictable environments and situations. Some criteria, such as high data throughput, are often not very important, whereas issues such as guaranteed delivery of error-free data and antenna type and placement are. With industrial Ethernet wireless communications, success comes to those who pay attention to the subtleties. ▮

About the authors

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For more information...

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