

Wireless Ethernet in Factory and Industrial Applications

Tim Cutler
Vice President Sales and Marketing
Cirronet Incorporated
Norcross, Georgia 30093

KEYWORDS

Wireless Ethernet, Spread Spectrum, Frequency Hopping, Direct Sequence, 802.11

ABSTRACT

The march to wired Ethernet in factory floor and industrial applications is well under way. Issues of speed and latency for critical timing and control have been addressed through higher speed Ethernet and network planning. The next wave of Ethernet will be wireless Ethernet and it is already making inroads. This presentation will discuss the various wireless Ethernet solutions and discuss strengths and tradeoffs for each. A comparison between wireless and wired Ethernet will be presented. The presentation will also discuss which factory floor and industrial applications are appropriate for the various wireless Ethernet products. The presentation will conclude with a discussion of implementation considerations for deploying wireless Ethernet on the factory floor and in industrial environments.

INTRODUCTION

Until recently, factory floor communications has been the domain of several “standard” buses: Modbus, Profibus, DeviceNet, etc. Early attempts to use Ethernet were unsuccessful due to the non-deterministic nature of Ethernet. With the advent of higher speed Ethernet and the decreasing cost of Ethernet switches and hubs, the obstacles to using Ethernet have largely been removed.

The advantages of Ethernet are many: Ethernet components are commodity items and thus are low cost; Ethernet can be used as a transport medium regardless of the PLC communications protocol by encapsulating the Modbus or Profibus protocol within the TCP/IP packet; the multi-drop nature of Ethernet provides a straightforward expansion path; and the destination devices that the information is sent to are already on Ethernet networks.

Even with the advantages above, Ethernet still shares one disadvantage with the other buses: Cable still needs to be run. In a typical installation, the cost of running the cable will exceed the costs of the rest of

the equipment. And when equipment must be moved, additional cabling expenses are incurred. There is a solution to this problem: Wireless Ethernet. Wireless Ethernet provides the benefits of Ethernet without the need to run cables. Wireless Ethernet allows for fast, easy deployment and redeployment and can cover miles of range.

Wireless technologies in office and factory environments have a bit of a speckled past. Some wireless vendors have been guilty of over-promising and under-delivering on their wireless products. However, when properly understood and deployed, wireless devices can provide reliable, robust communications.

WIRELESS TECHNOLOGIES

Wireless technologies employed in factory and industrial applications are both licensed and unlicensed. Licensed bands offer a reserved set of frequencies without concerns about other users occupying the same band. In 1987, the FCC passed the spread spectrum rules allowing unlicensed operation in specific bands. While no license is required, there is the possibility of interference from another user occupying the same band. The spread spectrum rules were written to allow multiple users to simultaneously occupy the same band with limited interference. In indoor factory settings, there is not much concern about interference from other users as the facility structure will provide reasonable isolation from outdoor users; however, the use of multiple networks at a facility can pose problems unless this situation is planned for in advance.

Outdoor industrial facilities, particularly in SCADA applications, have a long history of licensed wireless usage. However, since the spread spectrum rules were passed, unlicensed radios have been making steady inroads into these applications. An advantage that licensed radios have, since they do not need to allow other users to use the band, is longer range due to higher transmit power. The disadvantage, of course, is the need to get permission to use the spectrum from a frequency coordinator.

As the overwhelming majority of wireless Ethernet devices operate in unlicensed frequency bands, this discussion will be limited to unlicensed wireless technologies. There are three main frequency bands of unlicensed spectrum that are suitable for reasonably sophisticated data transmission. The IMS bands in the US include the 900MHz, 2.4GHz and 5.8GHz bands. The U-NII band is in the 5GHz band as is the HiperLAN2 band. Unfortunately, the 5.8GHz IMS band, the U-NII band and the HiperLAN2 bands use slightly different portions of the 5GHz band. Table 1 shows the various un-licensed bands and the requirements of operating in each band.

TABLE 1 - VARIOUS UN-LICENSED BANDS AND REQUIREMENTS

Band	Frequency Range	Radio Requirement	Other Requirements
ISM	900MHz – 928MHz	Spread Spectrum FCC 15.247 US	36dBm; limited availability, US, Canada, Australia and parts of South America
ISM	2400MHz – 2483.5MHz	Spread Spectrum FCC 15.247 in US; ETS 300 328 in EU	36dBm for pt-to-multipoint in US; 3 for 1 rule for pt-to-pt in US; 20dBm EIRP limit for EU
ISM	5725 – 5850MHz	Spread Spectrum FCC 15.247 US	36dBm EIRP
U-NII/ HiperLAN2	5150MHz – 5250MHz	FCC 15.401 US; TS 101 475 EU	23dBm EIRP Indoor Use only
U-NII	5250MHz – 5350MHz	FCC 15.401	30dBm EIRP, US only
HiperLAN2	5470MHz – 5725MHz	TS 101 475	30dBm EIRP, EU only
U-NII	5750MHz – 5825MHz	FCC 15.401	36dBm EIRP, US only

While the 2.4GHz band is still the predominant band, products are now appearing in the various 5GHz bands. The 900MHz band still enjoys wide acceptance in North America, but its limited bandwidth and limited geographical availability have curtailed wireless Ethernet development in this band. While the 5GHz bands offer more bandwidth, the 2.4GHz band remains popular due to the low component costs and the worldwide consistency of the band.

SPREADING TECHNIQUES

Spread spectrum radio technology, as the name suggests, spreads the information signal over several frequencies. By so doing, interference on a single frequency does not block the signal. There are two types of spread spectrum technology: direct sequence and frequency hopping. Recently, the FCC allowed the use of Orthogonal Frequency Division Multiplexing (OFDM) in the ISM bands.

Direct sequence spreads the signal by multiplying the data stream by a pseudo-random noise signal of high frequency than the data stream. This causes the resulting signal to be spread over a bandwidth equal to the frequency of the pseudo-random noise signal. The ratio of the spread signal to the unspread signal is called the processing gain. It is expressed in dB and reflects the amount of signal impairment that can occur without a loss of information. For the latest 802.11b systems, the information signal is spread over 22MHz of bandwidth. Using some more complex modulation techniques, they are able to maintain 10dB of processing gain. With the wider bandwidth used, DS systems offer higher potential data rates, although at the expense of lower receive sensitivity. Because of this tradeoff, 802.11 systems use a “best effort” approach where they transmit data at the highest rate allowed by the environment. For example, an 802.11b device will transmit at 11Mbps when it has sufficient signal strength to do so. If there is not sufficient signal strength, or if too many retransmissions are required, an 802.11 device will reduce the transmission rate to 5.5Mbps, 2Mbps or even 1Mbps.

Frequency hopping on the other hand, continuously varies the carrier frequency of the information signal. It transmits a small burst on data on one carrier frequency then changes to another carrier frequency and transmits another burst. By “hopping” to frequencies in a pseudo-random pattern, frequency hopping systems have a high degree of jamming immunity as well as immunity to multi-path fading. Until last summer, frequency hopping systems in the US were required to hop over at least 75

frequencies with a bandwidth of no more than 1MHz. Last summer, the FCC issued new rules that require hopping over just 25 frequencies and can occupy 5MHz of bandwidth. These new rules are consistent with ETSI rules that govern European radio operation. Because of the narrower bandwidth allowable, FH radios typically have lower data rates. However, with the narrower bandwidths

OFDM is a multi-channel technique similar to frequency-hopping except that it transmits over multiple channels or subcarriers simultaneously. All of the subcarriers are orthogonal which means that each subcarrier has a null at the center frequency of all other subcarriers. This avoids any intercarrier interference. The RF spectrum of an OFDM signal looks similar to a direct sequence spectrum but the similarity ends there. The theory is that while one or more subcarriers may be affected by multi-path fading or an interferer, others will get through. OFDM also makes use of training channels to characterize the RF paths. OFDM interleaves the data over multiple channels to improve the ability to reconstruct the data when subcarriers are impacted. 802.11a requires the use of forward error correction. OFDM will be similar in co-located networks as 802.11b due to the similar spectrum occupation.

MULTIPATH FADE AND INTERFERENCE

To decide which technology is best suited for an application, it is helpful to understand the factors that affect radio transmission. In indoor applications, including factories, two primary factors are multi-path fading and interference. Multi-path fading occurs when multiple copies of the signal arrive at a radio at the same time but with varying phase. This causes the multiple signals to cancel each other to some degree that results in a “faded” or reduced strength signal. Interference occurs when another RF source generates a signal at a frequency of interest that is of higher field strength than the intended signal. The interfering device does not need to be another radio. In the 2.4GHz frequency band, microwave ovens and welding equipment can be sources of interference. While interference acts to reduce throughput by requiring retransmissions of data, multi-path acts to reduce range.

In the past there was much debate over whether Direct Sequence or Frequency Hopping offered better immunity to jamming and interference. Currently, 802.11b is the predominant Direct Sequence product used. 802.11b uses minimal spreading to limit the occupied bandwidth of its signal. The spreading employed is the minimum amount of spreading necessary to meet FCC rules. As a result, it is generally recognized that Frequency Hopping technology provides superior jamming and interference immunity. This is especially true in rising noise floor environments such as factory and industrial environments.

802.3 VERSUS 802.11abg

802.11abg are wireless Ethernet standards designed to promote interoperability between vendors’ office LAN products with the goal to foster competition resulting in lower costs. The standards define not only the MAC layer but also the PHY layer for 802.11 radios. The PHY layer in this case refers to the over-the-air protocol used by the radios. While the goals of this standard are certainly worthy, the progress in achieving interoperability has unfortunately been limited.

802.3 is the standard that defines 10BaseT Ethernet (802.3u defines the 100BaseT standard). These refer to wired Ethernet. Wireless devices that are 802.11 compliant are actually 802.3 compliant on the connection to the network and 802.11 compliant in the over-the-air protocol. The important point here is

that while a wireless Ethernet device must be 802.3 compliant to connect to a wired Ethernet network, it does not need to be 802.11.

DATA RATE VERSUS RANGE

Usually, more is better than less. In the case of wireless communications and over-the-air data rates, more is not necessarily better. That is because in wireless communications, higher data rates are accompanied by a reduction in receive sensitivity. Receive sensitivity refers to the signal strength necessary to receive data at a given bit error rate. For every doubling of the data rate, the receive sensitivity is reduced by 3dB, other things being equal.

802.11-based products were designed for office LAN applications. As a result, they are trying to get as close as possible to wired Ethernet speeds, between 10 Mbps and 100 Mbps. This is important as typical office LANs are used to transfer Windows- based application files between computers or between a computer and a printer. This approach makes sense in an office environment where it is easy and inexpensive to place access points wherever they are needed. 802.11 systems vary the over-the-air data rate as conditions dictate. In factory and industrial environments, due the ranges and RF noise floors involved, it is common for 802.11 systems to drop down to the 1 Mbps data rate.

In factory and industrial environments, the data to be transferred tends to be tens of kilobytes rather than the hundreds of kilobytes transferred on office LANs. However, the ability, ease and expense of adding access points is very different. These difficulties are what have given rise to the need for wireless Ethernet. Thus the data requirements must be well understood to avoid paying for bandwidth that is not needed.

LINK BUDGET

Range is probably one of the most important criteria yet is the most difficult to assure. If the range is insufficient, the application may simply not work or may require repeaters or additional access points. In general, it is easier to predict range in an outdoor environment than and indoor environment. This is due to the relatively larger amount of multi-path observed in indoor environments compared to outdoor environments.

In its simplest, range is determined by the transmit power, the receive sensitivity, the antenna gain and the transmission medium. The Free Space Loss equation is typically used as an estimate for path loss for line of sight range. For the 2.4GHz band the FSL equation can be expressed as:

$$\text{Path Loss} = 40\text{dB} + 20\log(\text{distance in meters})$$

For example, a range of 1 kilometer would have a path loss of 100dB. Good radio practice will allow 10dB of “fade margin.” This margin allows for differences in the Free Space Loss, multi-path and other non-ideal realities.

For the 915MHz band the path loss can be estimated as:

$$\text{Path Loss} = 32\text{dB} + 20\log(\text{distance in meters}).$$

For the 5.7GHz band the path loss can be estimated as:

$$\text{Path Loss} = 48\text{dB} + 20\log(\text{distance in meters}).$$

To illustrate estimating range, consider the following RF system operating at 2.4GHz. The transceivers transmit at 18dBm and have receive sensitivities of -88dBm . The transceivers are fitted with 9dBi antennas. The link budget would be:

$$\text{Link Budget} = 18 + 88 + 9 + 9 = 124\text{dB}$$

Using the FSL equation and solving for range, results in an estimated line of sight range of more than 10 kilometers. In practice, the expected range would be a little less.

While in general a larger link budget will yield a longer range in indoor environments, there are other factors that impact indoor range. Probably the most important is the geometry of the indoor location. In indoor applications, many times multi-path signals will be the only signals that reach the receiver. So the ability of the signal to “bounce” off obstructions to reach the entire area will be needed to avoid any shaded regions where there is simply no signal present.

To insure reliable system operation in a variety of indoor locations, there is really no substitute for a site survey to identify and shaded areas and to determine the obtained range. This data should be used to plan the RF equipment deployment.

CONSIDERATIONS FOR DEPLOYING WIRELESS ETHERNET

The first step in deploying wireless Ethernet is to determine how much data is to be transmitted and how quickly it must be transmitted. Also, the amount of latency that can be tolerated must be understood. The first information will determine the amount of throughput needed. The latency will determine how much data can be sent at one time. Throughput and latency are inversely proportional. Regardless of how robust a radio link is, there will be times where a transmission is unsuccessful the first time and must be retransmitted. This retransmission is automatic and is not seen by the network, but it does introduce additional latency. Thus while a longer data transmission increases throughput, when a retransmission is required, a longer data transmission increases the latency.

Due to the fact that some data will have to be transmitted a second time, latency will vary in wireless systems. This is not to say that latency is unbounded. It is reasonable to expect latencies on the order of 25 milliseconds to 50 milliseconds. Thus, wireless Ethernet cannot be used in applications where latencies of this magnitude cannot be tolerated.

The architecture of the wireless Ethernet network should be determined next. How many remote devices will be connected wirelessly will figure in the decision of whether to operate one point-to-multipoint network, multiple point-to-point links or some combination of the two. This will impact the required throughput per device. If multiple links are employed, each link will need less throughput. If multiple links are to be employed in a single location, the ability of the wireless devices to operate in the presence of other devices must be considered. For example, typical 802.11b devices have just 3 non-overlapping channels. This means that only 3 separate links can be operational in the same location. By contrast,

frequency hopping systems which support multiple hopping patterns can support a larger number of co-located networks.

The location of the wireless Ethernet devices deserves some attention as well. The location of the factory device will determine the general location of the remote wireless Ethernet device and the nearest point of the wired network will control the base wireless device, there are still some considerations that can have an impact. As a rule of thumb, the antennas for all the devices should be placed as high as possible without placing them behind an obstruction. While 2.4GHz is considered a line-of-sight frequency band, indoors, particularly in factories, there are sufficient surfaces to reflect the signals to provide communications between two devices without line of sight.

Of particular importance in industrial settings where a range of several miles is needed is the ability to easily locate the antenna where line-of-sight can be obtained. It is expensive and difficult to install long RF cable runs. In addition, RF cable attenuates the signal reducing range or necessitating amplifiers. Products are available on the market where the radio can be located near the antenna and away from the Ethernet connection. This provides line-of-sight without substantial cost or a reduction in performance.

Another consideration in deploying wireless Ethernet is that the device is suitable for the environment. For example, it is not practical to place a device designed for an office environment in a factory or industrial setting. Along the same lines, what is the operating temperature range of the device? An industrial environment needs an industrial temperature range.

CONCLUSION

Ethernet is making its way onto the factory floor. Wireless Ethernet devices offer the benefits of Ethernet without the wiring. Given an understanding of how wireless devices operate and with some careful planning, wireless Ethernet can provide reliable, robust communications in even the noisiest factory environment.