WHITE PAPER

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Wireless technologies for hydroelectric facilities

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Introduction

From simple monitoring and control to Supervisory Control and Data Acquisition (SCADA), hydroelectric facilities are adopting wireless technology in many ways. Wireless provides highly reliable data communications in harsh and interference-heavy environments. Compared with traditional cable and fiber-optic based circuits, wireless technology offers several advantages, including increased flexibility, easy installation, and cost savings.

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In hydroelectric plants, potential wireless applications include:

Process management – equipment temperature, vessel/piping flow and pressure, valve monitoring, leak detection, oil-in-water monitoring of dam sumps, transformer monitoring, intake flow monitoring.

Asset management – vibration and air-gap monitoring on the turbo-generator sets, acoustic sensors to detect cavitation, lubrication fluid viscosity/density/temperature, leak detection, corrosion detection, trash rack systems.

Wildlife management – fish counting and detection systems, automated fish screen monitoring, animal tracking and counting, food station monitoring.

Environmental – water temperature at various depths, dissolved oxygen monitoring of the headrace and tailrace, pH and conductivity measurements, reservoir level, air pollutant analysis for pumped storage systems, greenhouse gas monitoring of new lakes.

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Facility management – HVAC, intrusion, and security systems; video surveillance and camera control; leak detection; gate control; back-up power systems; motor monitoring.

Wireless has quickly grown from something used in our everyday consumer lives for convenience to a means of collecting information and controlling systems in the most demanding industrial applications. With rapid developments in wireless, the technology can go farther, communicate faster, and provide increased reliability and security. Thanks to these improvements, many industrial users are adopting wireless technology.

Understanding wireless technology and what is available is the key to making an informed decision about which technology or product a facility should deploy. This paper will define general radio frequency (RF) characteristics such as distance and speed, transmission methods, and the various wireless technologies available.

General RF characteristics

It is important to have a fundamental understanding of RF prior to evaluating different transmission methods and wireless technologies. All wireless systems operate on some frequency, communicate some distance, and offer some over-the-air (OTA) data rate. These properties impact each other, so it is important to find the balance between them to satisfy the needs of a particular application.

Frequency

First, frequency is the key identifier for a radio. The frequency on which a radio operates defines whether the system is license-free or whether it requires a license from the local regulatory body such as the FCC (Federal Communications Commission). In the United States, there are three generally used license-free frequency bands: 900 MHz, 2.4 GHz, and 5 GHz. These are commonly called the ISM (Industrial, Scientific, and Medical) bands, allotted by the FCC for license-free radio operation. To utilize one of these license-free bands, the FCC requires that a radio operate within specific guidelines including the use of some spread spectrum technology, which will be discussed later in the "Transmission methods" section of this paper.

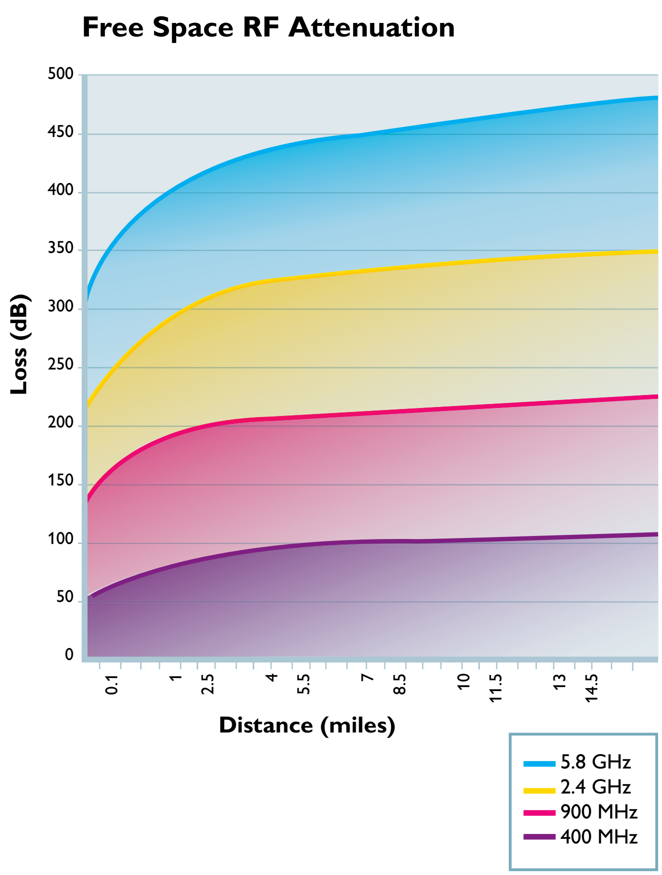
If a radio does not operate in one of the specified license-free bands, then an application must be submitted to the FCC to utilize a radio. This type of radio is considered a licensed radio and typically uses fixed frequency technology (further explained in the "Transmission methods" section of this paper).

Transmission distance

Frequency not only defines if a radio is licensed or license-free, but it can also play a large part in transmission distance. In radio networks, once a signal has left an antenna and is communicated over the air, it instantly loses energy. Energy will continue to be lost over the communications path. This general energy loss is considered free space loss, which is a function defining lost energy at a frequency over a distance.

Fundamental principle: Using a technology with a lower frequency will result in greater communication distances

For specific values, Chart 1 shows free space loss at popular radio frequencies over distance. This chart shows that as frequency and distance increase, so does free space loss.



Over-the-air (OTA) data rate

A radio does not operate at a single frequency; instead, it operates in a frequency band. This band can be used in its entirety or in smaller sections, typically called channels. Radios that operate in the license-free bands are not allowed to use the whole band and must use channels. The spectrum that the radio operates in (whether it is an entire band or specific channels) is considered the radio's channel bandwidth.

A high-speed radio uses a wider channel bandwidth regardless of the transmission method. Channel bandwidth refers to the amount of data that can be transmitted by radio signal. It is measured in bytes transferred over a specific prescribed period of time (kbps or Mbps). Higher-speed communications require a wider bandwidth, making high-speed radios more susceptible to interference. This is because there is higher probability of existing interference over the utilized band and because there is less energy per data bit.

Energy per bit is the amount of energy available to send each bit of data over the air. The slower the transmission rate, the higher the energy level per bit. Higher energy per bit results in greater achievable transmission distance. Therefore, longer range and higher interference immunity result from reducing the transmission speed.

Fundamental principle: A general tradeoff must be made between distance and over-the-air (OTA) data speed. The slower the OTA speed, the farther the radio system can communicate.

Transmission methods

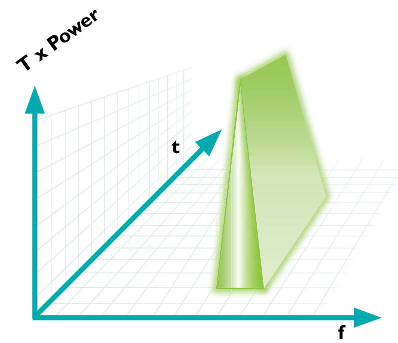
There are several different wireless transmission methods available, each with unique characteristics. The types of methods include:

- Fixed frequency
- Frequency-hopping spread spectrum
- Direct-sequence spread spectrum
- Orthogonal frequency-division multiplexing

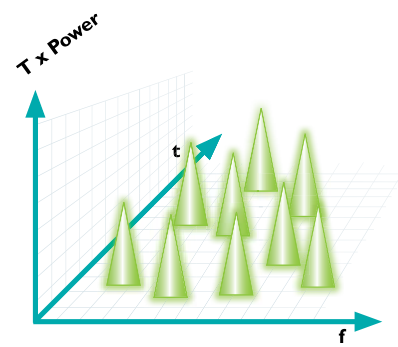
These variations result in the ability to communicate different amounts of data at varying distances. One or more of the following transmission modes are used in each of the wireless technologies defined later in this paper. The illustrations to the right of each description show the transmitter power (Tx Power) in relation to both frequency and time.

Fixed frequency transmits a signal on a single frequency with a specific channel width (usually very narrow). Fixed-frequency radios typically have high-power transmitters and require a license to operate.

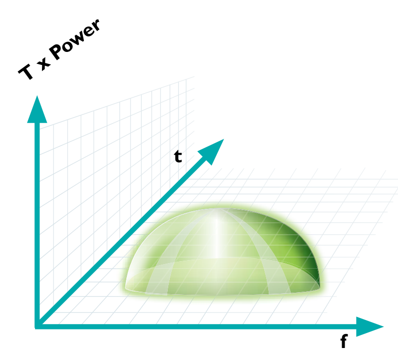
A strong interference can affect a fixed frequency transmitter if it is in or near the channel. The licensing requirement prevents a nearby system from operating in the same channel, reducing the likelihood for interference.



Frequency-hopping spread spectrum (FHSS) transmits radio signals by rapidly switching a carrier among many frequency channels by using a pseudorandom sequence known by both transmitter and receiver. FHSS tolerates interference because a transmission will immediately resend on the next hop if it is blocked on a channel.



Direct-sequence spread spectrum (DSSS) broadcasts transmission signals that spread over the channel bandwidth of a device's transmitting frequency. User data is combined with a "spreading code" before it is sent over the air, creating a wide band transmission. Interference is primarily rejected in the demodulation process in the receiver. When the spreading code is removed to extract the user data, the noise signal is simultaneously suppressed.



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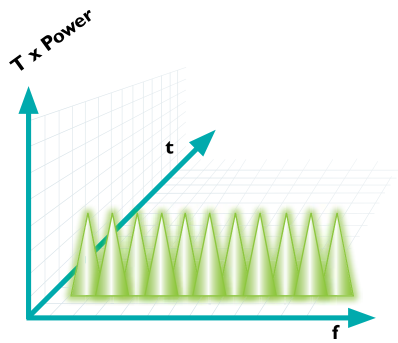
Orthogonal frequency-division multiplexing (OFDM) broadcasts on multiple sub-carrier frequencies simultaneously. Each sub-carrier is essentially a narrow band transmission, summarily allowing high data rates to be achieved. OFDM is flexible in coping with severe channel conditions. Because of the higher complexity of OFDM transmission, a variety of methods handle interference. Narrowband interference is tolerated because of the high number of interleaved sub-carriers and channel coding mechanisms similar to DSSS.

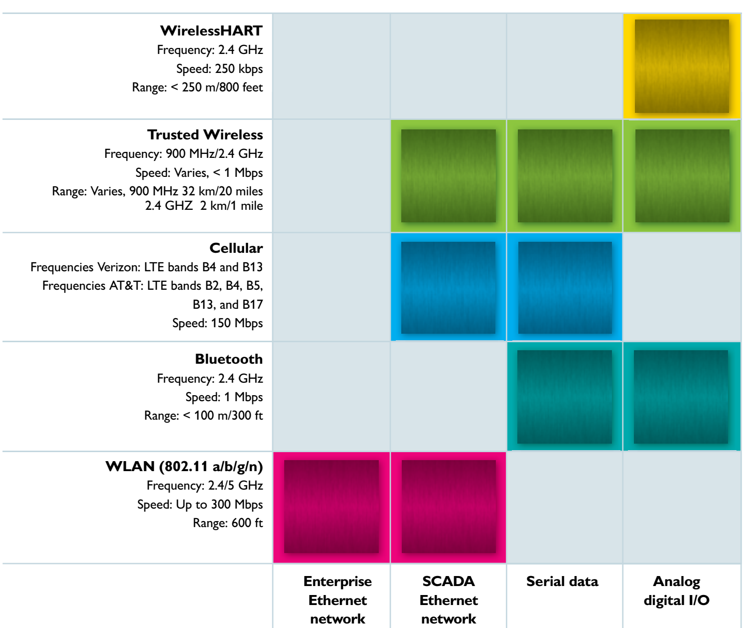


Wireless technology

There are a variety of wireless technologies designed for a number of different types of applications. Each of the technologies defined uses a frequency and one or more of the transmission methods previously discussed. Each technology is defined below.

Chart 2 shows the ideal industrial applications for each technology. Understanding the different wireless technologies will make it easier to select the proper technology for a specific application.

Chart 2: Wireless application selection guide



802.15.4 (WirelessHART/ISA 100.11a/ZigBee)

Frequency: Generally 2.4 GHz
Distance: Generally <300 feet
Description:

- Intended for inexpensive, self-organizing mesh networks that require low data rates
- Resulting network uses small amounts of power, allowing individual devices to run for up to five years on the original battery
- A key application in the hydroelectric facility is to utilize information already available in HART-equipped transmitters

Proprietary spread spectrum

Frequency: Depends on manufacturer
Distance: Depends on manufacturer
Description:

- Radio technology is unique to the device manufacturer and will not operate with another manufacturer's devices
- Customizable to fit a specific application
- Available in a wide price range based on features and performance
- In hydroelectric applications, can often be used to bring in I/O points from the field that in the past were not economically feasible to hardwire

Licensed radio

Frequency: 400 MHz
Distance: Typically 2-50 miles
Description:

- Requires a frequency license from the local regulatory body (such as the FCC) to operate on a single, fixed frequency
- Used for long-distance links because it uses high-power transmitters (up to 5 W)
- Hydroelectric applications include the transmission of information from pumping stations and other remote monitoring sites back to the plant

Cellular (4G LTE)

Frequency: 700/800/850/900/1800/1900/2100/2600 MHz
Distance: Around the world
Description:

- Cellular technology that is globally available, providing access to anywhere in the world that cellular servers exist
- Requires a service plan
- Applications could be to transmit information to corporate headquarters anywhere in the world

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Bluetooth®
Frequency: 2.4 GHz
Distance: Generally <500 feet
Description:
- Used in commercial phones, printers, headsets, and other products
- Industrial products use Bluetooth technology to send I/O, serial, or Ethernet data
- Typical applications in hydroelectric facilities include the short-range transmission of sensor data to a collection point, for example with vibration sensors monitoring the turbine-generator set

WLAN (IEEE 802.11 a/b/g/n/ac)
Frequency: 2.4 GHz/5 GHz
Distance: Generally 1,000-3,000 feet
Description:
- Provides high-speed wireless data networking up to 54 Mbps to 2.3 Gbps
- Enables networking for static and mobile applications
- For devices that already have Ethernet connectivity such as security cameras, intrusion control systems, and other equipment.

Conclusion

There are many different types of wireless technology available today. Each is designed for a specific type of application, and it is important to understand the differences. Knowing these differences allows the user to make an informed decision about the correct technology for a particular application. In addition, it is useful to understand the general principles of wireless communication. That is, generally, the lower the frequency and OTA data rate used, the greater the distance that can be achieved.

Wireless communication is no longer just for the consumer industry. The technology has its place in industrial applications. Wireless can replace cables, reduce installation times, and increase productivity by providing the ability to access data that might previously have been unobtainable.

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Phoenix Contact develops and manufactures industrial electrical and electronic technology products that power, protect, connect, and automate systems and equipment for a wide range of industries. Phoenix Contact GmbH & Co. KG, Blomberg, Germany, operates 50 international subsidiaries, including Phoenix Contact USA in Middletown, Pa.

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