connectBlue™

Wireless Technologies for Industrial Applications

Version 2.1 – 19/03/2012
Mats Andersson, CTO
connectBlue AB, Sweden
Phone: +46 733 207 105
E-mail: mats.andersson@connectblue.com
Web: http://www.connectblue.com/

Abstract

Wireless communication has been used in industrial applications for more than 30 years. Among the first applications where wireless was used was in wireless control of Automated Guided Vehicles (AGV) and cranes in warehouses where proprietary radios where used to achieve flexible control of the moving devices. During the last 10 years, standardized radio technologies like Wireless LAN (IEEE802.11), IEEE 802.15.4 and Bluetooth technology (IEEE802.15.1) have become the dominating technologies for industrial applications.

The main advantages for using a wireless solution in industrial applications are the following:

- Increase mobility.
- Eliminate expensive and maintenance heavy transmission media such as flexible cables, swivels, etc.
- Overcome large and problematic zones e.g. streets.
- Achieve fast and efficient installation and commissioning.
- Ensure personnel safety in hazardous areas (for instance, when needing to climb in a crane) by offering a control possibility from further distance than can be the case with a cable.
- Obtain flexible Human Interface Devices (HID).

Industrial plants consist of multiple devices interconnected in different ways. These varied types of devices include simple data collection units (I/Os) without built-in intelligence, more intelligent devices (sensors with built-in intelligence, single-loop controllers or programmable controllers) and supervisory systems (used as HMI, for data logging and supervisory control). All these types of devices are interconnected using different communication protocols and media types that in some cases can be replaced by wireless technologies to achieve the above listed advantages.

Not just one wireless technology offer all the features and strengths that fit the various industrial application requirements; and therefore, standardized wireless technologies Wireless LAN, Bluetooth technology and IEEE 802.15.4 as well as number of proprietary technologies are all used. The main requirement could either be high data throughput, robustness or low power (the latter especially for battery operated devices). Wireless

LAN is often used for production planning, data acquisition as well as applications where rapid roaming is required. Bluetooth technology is used for Human Machine Interfaces (HMI), programming, service/maintenance as well as real-time control tasks. During the last few years, other technologies like IEEE 802.15.4 (ZigBee, Wireless Hart etc.) and Bluetooth low energy technology have become increasingly used for sensors, actuators and other small devices that need to be interconnected.

The adoption of wireless communication in an industrial environment is typically a gradual process. The initial requirements include the creation of islands of wirelessly enabled devices connected to an existing infrastructure/wired network. The wired network may be a standard IP-based network or an industrial fieldbus network. Examples of fieldbus networks include Profinet, Modbus TCP, Profibus, Devicenet, Controlnet or Interbus-S.

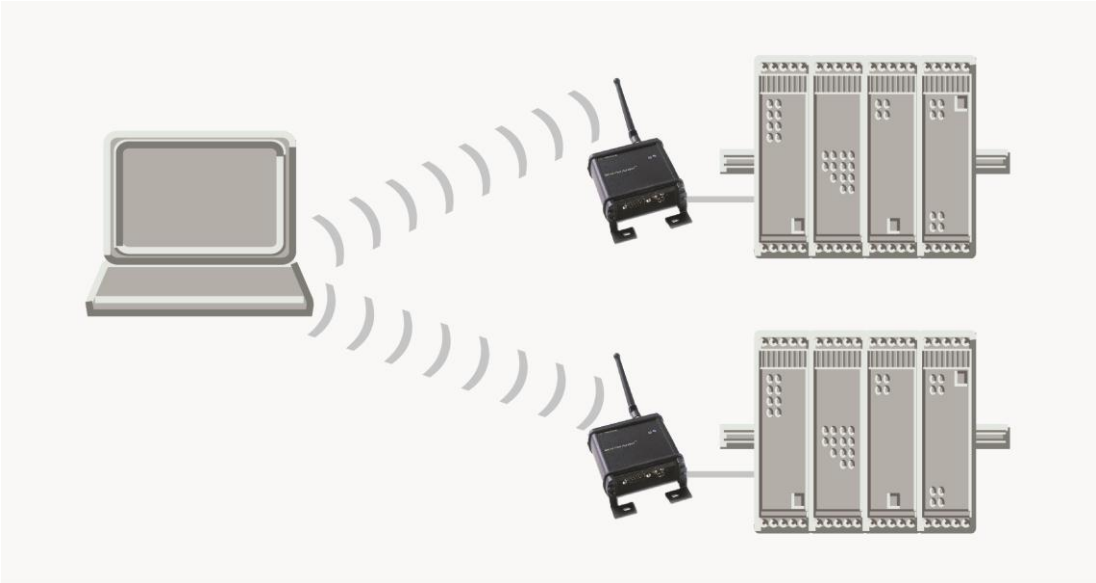
This white paper covers how various wireless technologies can be used to connect devices wirelessly to each other in an industrial setting. The paper also describes some specific requirements on wireless communication technology in industrial applications. The use of wireless communication is in this white paper divided into eight sections:

1. Serial cable replacement
2. Ethernet cable replacement and Ethernet infrastructure
3. Seamless Roaming
4. Fieldbus cable replacement
5. “App” in a smart phone or other mobile device
6. Wireless sensors and actuators network
7. Industrial Requirements on Wireless Technologies
8. Co-existence

Serial Cable Replacement

Many of today's industrial devices still use traditional serial interfaces (UART, RS232, RS422 or RS485) as the means to connect to configuration or programming tools. These tools are typically connected "ad-hoc" when a reconfiguration or reprogramming is needed and the tools normally operate on a standard PC. The tools typically use an application dependent or device specific communication protocol to communicate with the device. All these abilities make them good candidates for wireless connections.

***Caption*:** PC-based programming tool connected to a Programmable Logic Controller (PLC) with a serial cable replacement



***Caption*:** RS422/485 multi-drop serial port communication replacement

***Caption*:** Serial to Wireless LAN infrastructure

There are two ways in which one can create a serial cable replacement:

1. An external wireless adapter connected to an external serial port of the industrial device. The wireless adapter emulates a serial port and transfers the data over the air.
2. A built-in wireless adapter connected internally to the device electronics.

The serial cable replacement solution would either use Bluetooth technology or Wireless LAN. Both these technologies are standard in most laptops. For an ad-hoc connection, Bluetooth technology is the most suitable technology while Wireless LAN often is best suited for connections through an Ethernet infrastructure.

Ethernet Cable Replacement and Infrastructure

The use of Ethernet based communication in industrial communication is increasing dramatically. The most used protocols (MODBUS TCP, Profinet, and Industrial IP) transfer messages on an Intranet using Ethernet.

Ethernet cable replacements are most commonly used in industrial applications where there are mobile, rotating and temporary installations with either a need for replacing the Ethernet cable with a robust and maintenance-free wireless connection or a need to connect to a Wireless LAN infrastructure. For easy set up and wireless configuration, a transparent Ethernet to a wireless adapter or a gateway is typically used.

Commonly Used Scenarios

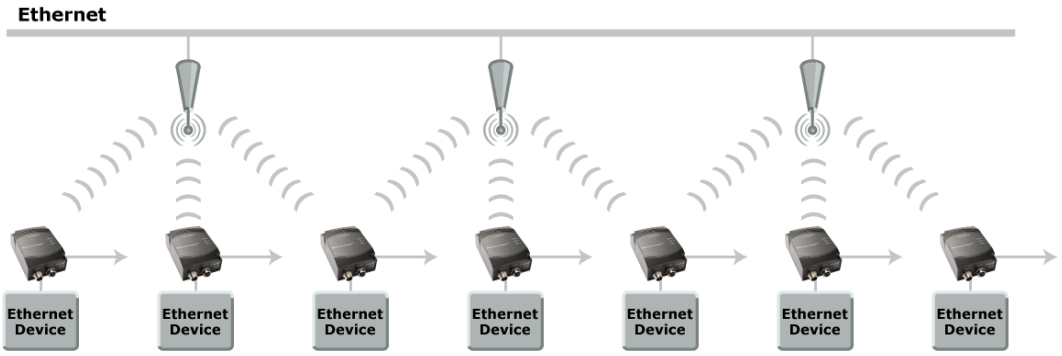
Caption: A simple point-to-point Ethernet cable replacement based on two Wireless Ethernet Port Adapters. For the wireless connection, Wireless LAN would be used for applications requiring high band width and Bluetooth technology would be used when robust data transfer and/or high system density is needed.

Caption: The configuration above is used when connecting devices such as PLC's and HMI panels to an existing wireless infrastructure which is typically a Wireless LAN network. Whether or not the devices have Ethernet ports or serial port interfaces there are industrial adapters available that can via a standard Wireless LAN access point transfer transparent data over the Wireless LAN network to the wired network backbone.

Seamless Roaming

Roaming is used in data communication for industrial applications where there are moving devices, such as Automatic Guided Vehicles (AGVs), or where the device's data communication path changes from one access point to another. In these cases, the existing connection performance is affected by the roaming procedure since a scan for new wireless networks is required and then the established wireless connection must be terminated before a new connection can be up and running.

In standard solutions, the device (client) scans for an available access point and then connects to it. In order to maintain the communication connection with the control system, the client stays connected to an access point as long as possible. When the radio signal gets too weak, the client starts to scan for new access points that can offer a better radio signal. When such an access point is found and selected, the client starts a connection procedure to the new access point. This handover phase can take anything from 50 milliseconds to several seconds until the communication connection is fully up and running again.



Caption: Seamless roaming as provided by connectBlue

There are solutions available that provide seamless roaming with handover time delays within a few ms. Some of these solutions require access points with supplier specific solutions but there are also others, such as the connectBlue seamless solution, that use standard access points with two or more wireless clients that cooperate on each moving device. An advantage of the latter solution, where several independent devices are used, is the opportunity to combine roaming with redundancy.

Fieldbus Cable Replacement

Well-known fieldbuses (Profibus, CANBus, DeviceNet, InterBus-S, etc.) have a large installed base and a wide range of available products/devices. The large existing installed base is the main reason why fieldbuses are installed in increasing numbers. However, there are tougher timing requirements when replacing a fieldbus with a wireless link than there are when replacing a serial port based device with a wireless link.

Caption: There is a large variety of fieldbuses in the industry that are either standard or vendor specific fieldbuses. An example of such a device is a CAN / Bluetooth Adapter.

“App” in a Smart Phone and Other Mobile Device

Mobile devices such as iPhone/iPad, Android, Win CE, and LINUX devices are widely used in everyday life. By installing a tailored “app,” the everyday mobile device becomes a powerful and cost efficient tool for industrial applications. An “app” is a third-party software program developed specifically for a smart phone or a mobile device. In industrial applications, an “app” can be designed to gather certain data, to perform specific tasks such as to act as an HMI panel or a remote control, etc.

The wireless communication between the mobile device and the industrial device typically uses a Wireless LAN TCP/IP based network connection or Bluetooth technology through the Bluetooth Serial Port Profile (SPP). Bluetooth low energy technology is a new technology that will be suitable for these types of applications because of its unique features (see more under the heading “Industrial Requirements on Wireless Technologies”).

Wireless Sensors and Actuators

Wireless communication to sensors and actuators are forecasted to have a rapid growth rate in the next coming years. The reason for this growth is the increasing requirement to keep better track of energy usage, controlling devices, and utilities. Also, many sensors and actuators are not yet part of a network and a large portion of these will be battery powered in order to lower installation cost.

Sensors and actuators may be of different types. Some sensors and actuators have a high level of built-in intelligence; others are simple I/O devices serving as low-end interfaces to the process equipment. Depending on the requirements, the choice of wireless technology and its accompanying implementation strategy may differ. The software for a simpler sensor or actuator may be implemented directly in the CPU of the wireless chipset.

An example of a more demanding device is a vibration sensor situated on a moving axis. In order to support a complete wireless solution, this application needs an alternative power solution in the form of a battery or other source. Some wireless technologies are better suited for low power modes than others. The wireless interface for these types of devices can be achieved by integrating a simple wireless module into the sensor/actuator or by using a more advanced wireless module with a built-in CPU capacity to handle the sensor/actuator functionality.

Industrial Requirements on Wireless Technologies

Industrial applications have the following high demands on the wireless communication:

- Reliable and robust communication.
- Advanced security features.
- Similar configuration and operation as commonly used automation tools.
- Real-time and deterministic behavior.
- Increased temperature range.

All these requirements are supported slightly differently by the various wireless technologies. In the segments below, the differences are explained in more detail and which technology is best suited for which industrial application.

Bluetooth Technology
Bluetooth technology (IEEE 802.15.1) is well suited for wireless integration of automation devices in serial, fieldbus and industrial Ethernet networks. Bluetooth technology is specified for devices with high demands on small footprint, low power consumption and cost-efficiency.

Bluetooth Technology Facts

- Range of 10 meters but can with a long-range module cover 200 - 400 meters (up to over 1 km in free line-of-sight).
- Cyclic and fast transmission of smaller data packages.
- Data through-put of maximum 780 kbit/s gross (up to ~700 kbit/s net). With Bluetooth v2.1+EDR (Enhanced Data Rate), the data through-put is 2.1 Mbit/s gross (~1.5 Mbit/s net).
- Latency of 5 –10 ms.
- Security features with 128-bit encryption that offers protection against data eaves dropping.
- High system density where several wireless devices can be connected in the same radio environment and operate flawlessly
- Robust features Adaptive Frequency Hopping (AFH), Forward Error Correction (FEC), narrow frequency channels, and low sensitivity to reflections /multi-pathing.
- High availability in consumer products

Bluetooth Low Energy Technology
During 2011, Bluetooth v4.0 with the hallmark feature low energy technology entered the market. Bluetooth low energy technology is especially well suited for sensors, actuators and other small devices that requires extremely low power consumption. Bluetooth low energy technology offers the following features in industrial applications:

- High numbers of communication nodes with limited latency requirements.
- Very low power consumption.
- Robustness equal to Classic Bluetooth technology.
- Good real-time features (if a small number of nodes are connected).
- Very short wake-up / connection time

Wireless LAN
Wireless LAN (IEEE 802.11) is well suited for monitoring, configuring and data acquiring, but can also be used for time critical control. Further, the built-in roaming functionality is useful in factory automation applications with moving devices. Implementing Wireless LAN in these types of applications often requires customized solutions such as tailored or proprietary roaming software as well as frequency planning and specific installation

means (for example, the use of expensive leakage-cables). With these tailoring of the wireless solution, one achieves stabile latency and low roaming hand-over delays.

Wireless LAN Facts

- Range of 200 meters (up to 400-500 meters in free line-of-sight) in the 2.4 GHz band and some 50 meters in the 5 GHz band (802.11a) (free line of sight up to 150 meters); however, obstacles and interference could lower the range substantially.
- Data throughput of 11 to 54 Mbit/s gross (~5 to 25 Mbit/s net) for IEEE 802.11b/g and 300 Mbit/s gross (~70 Mbit/s net for IEEE 802.11n).
- Security models like WEP, WPA, WPA2, TPIK and PSK EAP.
- IEEE 802.11a operates on the 5 GHz band and provides the possibility for 19 additional non-overlapping channels in addition to the three non-overlapping channels in the 2.4 GHz band.
- High availability in consumer products

ZigBee, WirelessHART, ISA SP-100

IEEE 802.15.4 is available in a number of standards as well as part of proprietary wireless protocols. ZigBee, WirelessHART and ISA SP-100 are all used in industrial applications and all are based on IEEE 802.15.4. The low power consumption makes it well-suited for battery operated devices. The technologies are mostly used in applications such as energy monitoring, process and building automation. The mesh network functionality t makes it capable to cover wide areas when there are no requirements on low latency.

IEEE 802.15.4 Facts

- Low power consumption.
- Short wake-up/connection time.
- High number of communication nodes.
- Possibility to automatically build mesh-networks.
- Gross data through-put of 20-250 kBit/s.
- Range, excluding mesh functionality, of 75 meters.
- Security features with 128-Bit encryption that offers protection against data snapping.
- Alternative radio possibilities operating on the 868 MHz and the 915 MHz bands.

	Bluetooth technology	Wireless LAN / WLAN	ZigBee / IEEE 802.15.4	Bluetooth low energy technology
Data throughput	+/-	++	-	-
Robustness	++	+/-	+/-	++
Range	10-1000m	50-300m	10-200m + mesh	10-250m
Local system density	++	-	+	++
Roaming	+	++	N/A	N/A
Large scale network	-	+/-	++	+
Low latency	+++	+/-	+	++
Connection set-up speed	-	+/-	++	++
Power consumption	+	-	++	+++
Cost	+	-	+	++

+ = Good
++ = Strong
+++ = Very strong
+/- = Average
- = Weak

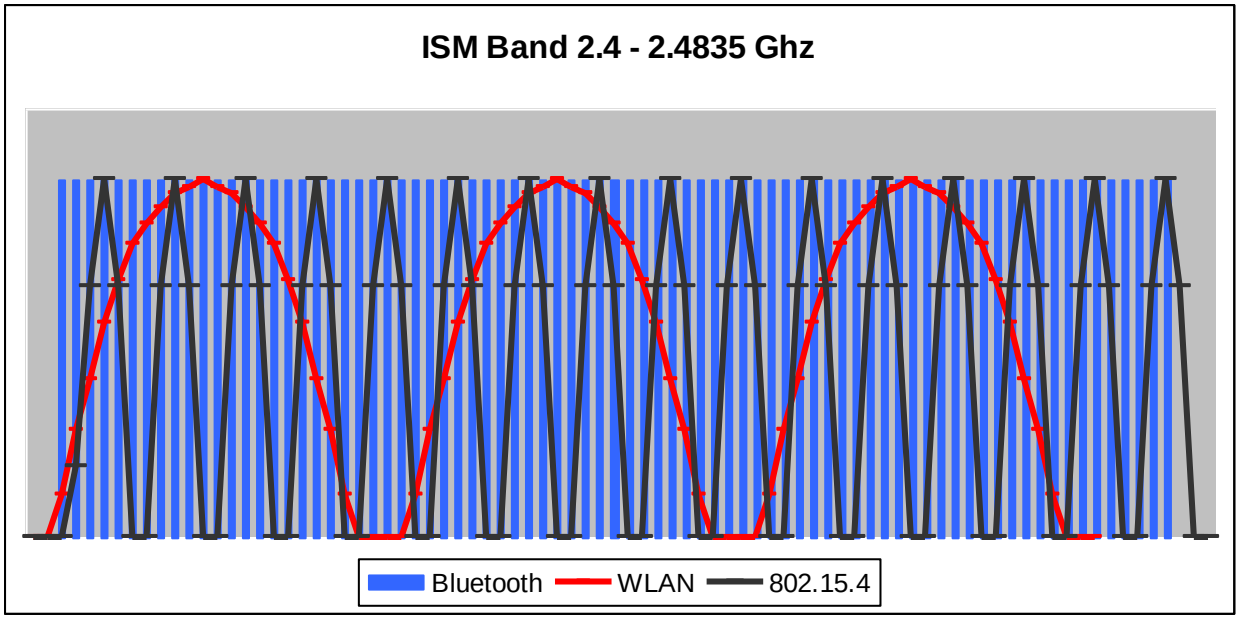
Caption: The table offers a quick overview of the differences between the wireless technologies offered in industrial applications.

Co-existence

As more than one wireless technology is often used in parallel, there could potentially be disturbances which are not allowed in an industrial application. Therefore, it is important to optimize co-existence of various wireless technologies in order to get a disturbance-free operation.

All of today's most used wireless technologies operate in the 2.4 GHz band and they address potential disturbances in the following manner:

- Wireless LAN has three non-overlapping channels with a bandwidth of 22 MHz and is using Direct-Sequence Spread Spectrum (DSSS). DSSS makes sure that the transmitted signal takes up more bandwidth than the information signal that is being modulated and thereby the wireless communication link becomes less vulnerable to disturbances.
- Bluetooth technology has 79 channels with a bandwidth of 1 MHz and combines this with Adaptive Frequency Hopping (AFH) in order to avoid interferences. AFH monitors the bit-rate and when disturbances (such as when another wireless technology occupies the link) are found, Bluetooth technology stops to use the channels that are occupied. The channel is monitored in the background and as soon as the occupied channel is free, it can be used again. Bluetooth low energy technology also uses AFH; but Bluetooth low energy technology only uses 40 2 MHz wide channels.
- IEEE 802.15.4 has 11 channels with a bandwidth of 5 MHz and is using Direct-Sequence Spread Spectrum (DSSS).



Caption: Wireless LAN, Bluetooth technology and IEEE 802.15.4 work in the same 2.4 GHz frequency band.

Enhanced Wireless LAN Co-existence Possibilities

As you see above the 2.4 GHz frequency band is very crowded. This is especially true for Wireless LAN which is well-established throughout offices on to the production planning. In order to get disturbance-free communication, one first has to secure that Wireless LAN is not disturbed.

Another solution is to use the 5 GHz band (IEEE 802.11 a) instead of the 2.4 GHz band for the Wireless LAN communication links. However, even though the 5 GHz band is increasing in popularity in industrial applications, there is a large installed base of IEEE 802.11 b/g networks that requires a good co-existence solution.

In cases where Wireless LAN and IEEE 802.15.4 are used in parallel, co-existence can be implemented by making room for some IEEE 802.15.4 channels in-between the three Wireless LAN channels. By doing so, it is possible for Wireless LAN and IEEE 802.15.4 to work reliably in parallel.

Bluetooth technology in itself is built to be robust mainly thanks to AFH. But when performing service discovery or establishing a device connection, the Bluetooth activities can disturb a Wireless LAN network. In order to make sure that Bluetooth technology operates smoothly in parallel with other wireless technologies, connectBlue has developed an extended Bluetooth co-existence feature. With the connectBlue Low Emission Mode™, co-existence is solved during service discovery and connection set-up. The Low Emission Mode combines limited output-power with optimization of service discovery and connection set-up parameters without jeopardizing the Bluetooth Specification or interoperability between various Bluetooth enabled products.

To summarize, this white paper has covered the most popular wireless technologies in use in industrial applications. It has addressed the specific requirements from industrial applications, typical use cases and how the wireless technologies vary and are best applied.

About the Author

Mats Andersson is the CTO (Chief Technology Officer) at connectBlue. Mats has devoted his 30-year-long career to wireless communication and product development within industrial automation. This includes managing development of industrial automation products at Alfa Laval Automation and ABB Automation Products. Read more at http://www.connectblue.com/press/press-kit/backgrounders/mats-andersson/.

About connectBlue

connectBlue™ is a leading provider of robust Industrial and Medical wireless solutions, designed and tested for the most demanding applications and environments. Based on Bluetooth technology, Wireless LAN (WLAN) and IEEE 802.15.4 / ZigBee, connectBlue provides ready-to-use products and modules as well as custom design solutions. connectBlue has its head office in Sweden and local offices in Germany and USA. For more information, please visit www.connectblue.com.