Coexistence of wireless technologies in an open, standards-based architecture for in-plant applications

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Some process operations may have been hesitant to adopt in-plant wireless applications because of concerns that radio frequency interference between wireless solutions could affect the reliability of essential communications. An open, standards-based wireless architecture from Emerson Process Management and Cisco Systems addresses these concerns by using mesh network technology and other methods to provide high levels of communication reliability at both the field-network and plant-network levels. Coexistence tests of real-world applications using this architecture demonstrated no noticeable impact on network reliability.

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Introduction

New in-plant wireless technologies are gaining market acceptance in the process industries because they offer lower installed cost and faster deployment than traditional wired solutions. Example applications include monitoring process and equipment conditions, giving workers easy access to information from anywhere in the plant, and tracking mobile assets and personnel.

However, some operations may have hesitated to adopt these and other new applications because of concerns that radio frequency (RF) interference between various wireless technologies – such as radios using the IEEE 802.11b/g and IEEE 802.15.4 [1] protocols -- might affect the reliability of essential communications.

Because 802.11 and 802.15.4 radios use the same Industrial, Scientific and Medical (ISM) 2.4GHz non-licensed frequency band, questions have been raised about how these technologies would work together. However, much of the prior research on this issue has focused on static channel operation of both radio types. Information has not been available on real-world coexistence of devices using more recent advancements such as channel hopping and mesh network technology.

An open, standards-based wireless architecture from Emerson Process Management and Cisco Systems uses several of these advancements to provide high levels of communication reliability at both the field-network and plant-network levels. Extensive testing of multiple applications within this architecture has shown that these technologies can and do coexist very well even under the most difficult circumstances.

There are other aspects of network design that need to be considered when deploying a comprehensive wireless network implementation. These other aspects include security and network management. This paper is focused on addressing RF compatibility and how that is achievable today with Emerson / Cisco joint implementations. Cisco and Emerson have solutions to address these other areas (such as security and network management), and both companies are committed to continue testing and publishing best practices for wireless network implementations in the process industries.

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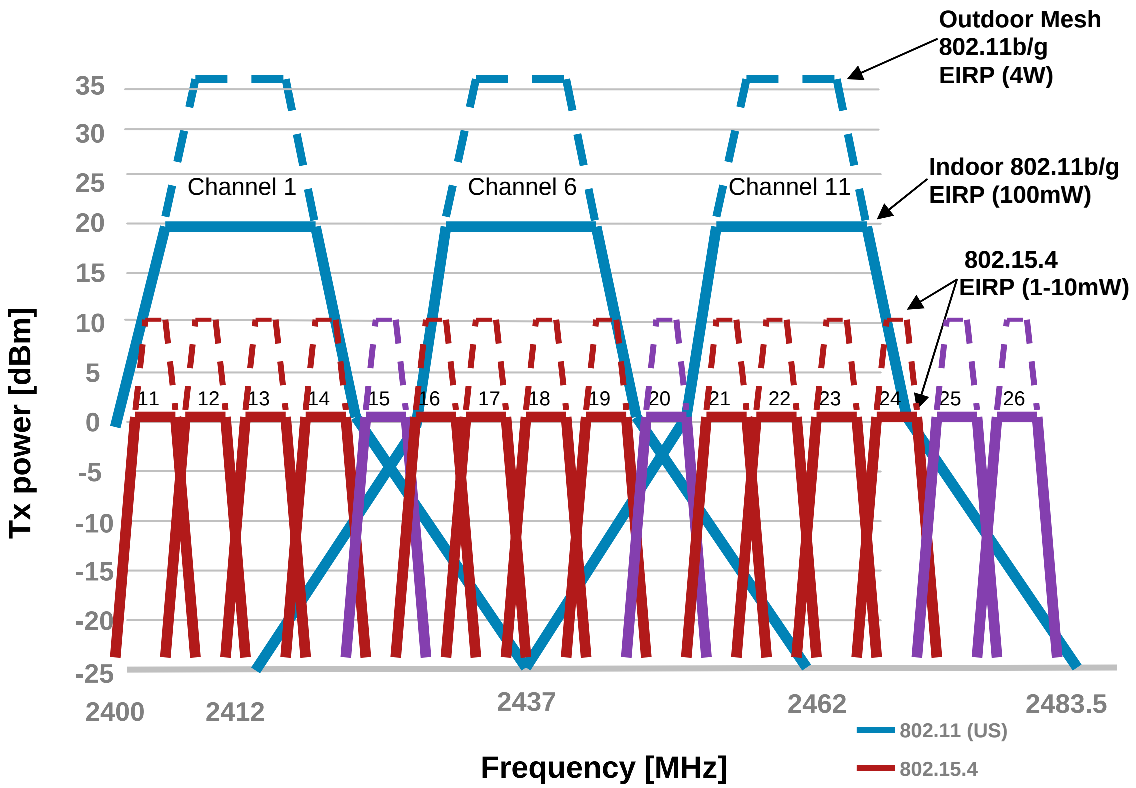
Coexistence basics

Coexistence is defined as “The ability of one system to perform a task in a given shared environment where other systems have an ability to perform their tasks and may or may not be using the same set of rules” [2]. It is measured by end-to-end message delivery success rate.

Coexistence problems can occur when two or more transmitted packets with sufficient interference energy "collide" or overlap in time and frequency – unless the network is designed to avoid or mitigate the effects of those collisions. Mechanisms used to combat coexistence issues may include

- Frequency diversity – Channel hopping
- Time diversity – Time Division Multiplexing and Clear Channel Assessment
- Power diversity – Low power output (<= 10dBm)
- Space diversity – Mesh technology that allows for space coverage through multiple hops instead of using just output power.
- Coding diversity – Use of advanced Direct Sequence Spread Spectrum

The diagram below shows areas of potential interference between transmissions using IEEE 802.11b/g (Wi-Fi) and IEEE 802.15.4 radios.



For overlapping channels, 802.11b/g radiated power is 10-100 times indoors than that of 802.15.4, and up to 4000 times for outdoor 802.11b/g mesh.

For non-overlapping channels, 802.11b/g side-slopes will impact 802.15.4 channels falling in the guard band between 802.11b/g channels (in purple in the preceding figure), though to a lesser degree. These channels are 15, 20, 25 and 26 in North America and 15, 16, 21 and 22 in Europe.

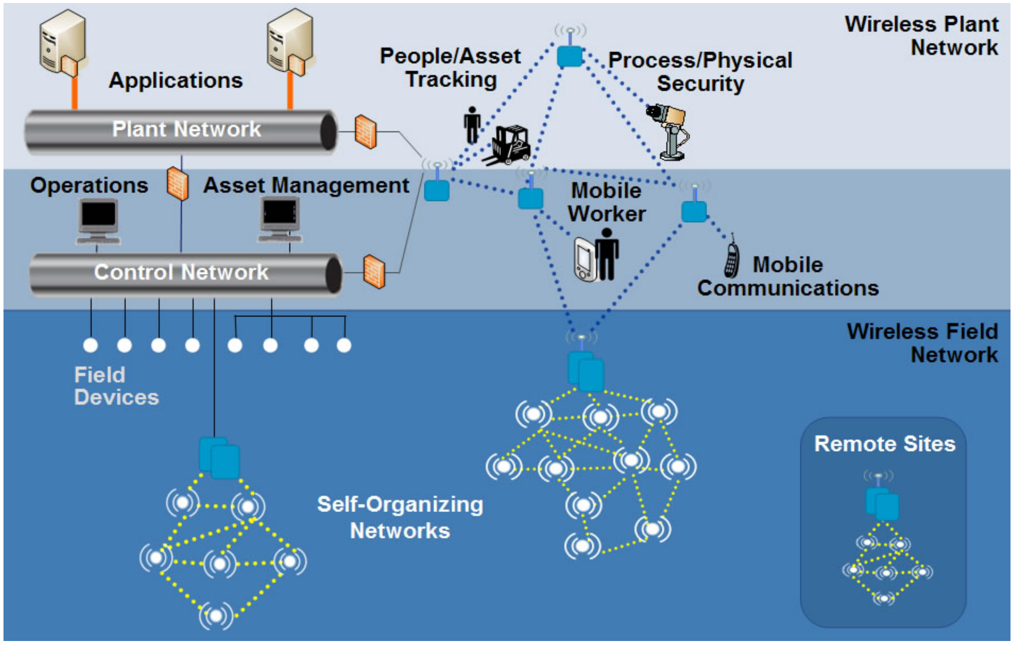
Although previous research and testing in this area has shown an impact by 802.11b/g on 802.15.4, it is important to note that none of this testing involved radios that used the techniques mentioned above, which are combined in a method called Time Synchronized Meshed Protocol [3] -- an approach which would be expected to reduce the effect of interference.

The effect of extremely low-power 802.15.4 radios on 802.11b/g should also be minimal.

Wireless architecture

Emerson and Cisco together offer an open, standards-based in-plant wireless architecture that benefits from Emerson's industry-leading technology in process automation and from Cisco's leading technology in Internet-protocol (IP) infrastructure.

Because both companies are familiar with users' concerns about coexistence, the wireless networks at both the field and plant levels of this architecture were designed specifically to provide robust, reliable communications under in-plant conditions.



Wireless field network

Emerson's Smart Wireless field network solutions take advantage of self-organizing mesh network technology using IEEE 802.15.4 radios. This is the same technology that is the basis for the WirelessHART standard [4].

The mesh capability provides redundant communication paths (path diversity) for better reliability than solutions that require direct, line-of-sight communication between each device and its gateway. Whenever there's a change in the network or environmental conditions that affect communications, the devices and gateways work together to find a path that optimizes data reliability while minimizing power consumption.

Other features also enhance communication reliability. Pseudo-random channel hopping provides frequency diversity. Time Division Multiple Access (TDMA) provides time diversity by ensuring only one device is talking on the channel at a time. Low-power devices provide power diversity. And Direct Sequence Spread Spectrum (DSSS) provides about +8dB of coding gain/diversity.

These capabilities help avoid problems not only with RF interference from other radios, but also with electromagnetic noise from motors, lights, and other sources that are much more common in plant environments. Emerson's wireless devices with these features have been proven in use at many process control plants, demonstrating greater than 99.9% data reliability.

Wireless plant network

The Cisco Wireless Mesh Networking Solution is based on the Cisco Aironet® 1500 Series, an outdoor Wi-Fi mesh access point using Cisco's Adaptive Wireless Path Protocol (AWPP), which forms the basis of the emerging IEEE 802.11s standard. The Cisco Aironet 1500 Series provides route optimization, self-healing for interference or outages, resiliency, and dynamic re-optimization when new sectors are added.

To address the needs of complex and hazardous industrial plant environments, Cisco has designed the Aironet 1520 Series specifically for such plant operations. It supports zero-touch configuration deployment to easily and securely join the mesh network. Flexible, high-powered, high-sensitivity radio options, along with a selection of high-gain antennas, allow coverage to be scaled as capacity needs increase. Cisco Aironet 1520 is managed and monitored by Cisco wireless LAN controllers and the Cisco Wireless Control System (WCS).

Using AWPP, Cisco 1500 access points discover each other automatically and select the best path for maximizing system capacity and minimizing latency by using intelligent wireless routing based on the AWPP. If a link is degraded, the access point will determine whether a better path exists, and will route traffic through a more optimal node.

The standards advantage

Using technologies based on IEEE 802 standards at both levels of the architecture (802.15.4 for field networks and 802.11 for plant networks) provides a significant advantage in managing coexistence. The IEEE coordinates all its 802 wireless activities, and its coexistence technical advisory group (802.19) provides a framework for coexistence among existing standards as well as those under development.

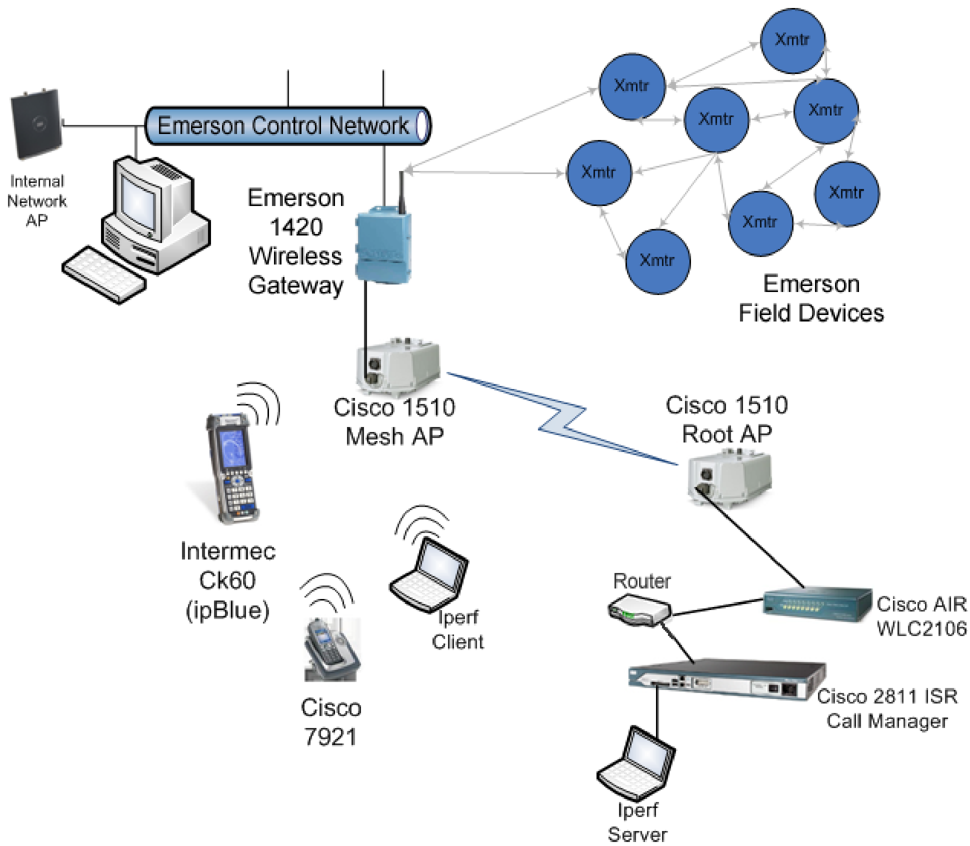
Coexistence testing

Tests were conducted to determine the real-world impact of deploying a Cisco IEEE 802.11b/g plant-level network and associated applications in the same process facility as an Emerson Smart Wireless field network using mesh and IEEE 802.15.4 technology from Dust Networks.

Cisco – IEEE 802.11b/g	Emerson – IEEE 802.15.4
▪ Physical layer o 14 channels, 5 MHz channel spacing, 22 MHz channel width o 54 Mbps max data rate ▪ Only 3 non-overlapping channels o 1, 6 and 11 in North America o 1, 7 and 13 in Europe ▪ Radio Power output o 100mW max indoors o Up to 4W outdoors (Mesh)	▪ Physical layer o 16 channels, 5 MHz channel spacing, 2 MHz channel width o 250 kbps data rate ▪ Physical channel usage o Channel hopping (frequency hopping) permitted o Coordinated channel (TDMA) use permitted ▪ Emerson (and WirelessHART) use channel hopping and coordination o 15 channels used

Test description

The test was conducted in a factory floor environment at an Emerson production facility. The environment consisted of two Cisco 1510 outdoor mesh access points, an Emerson 1420 wireless gateway attached to a Cisco 1510 mesh access point, and a mixture of eight Emerson Smart Wireless field devices. In addition, several Emerson facility Wi-Fi access points were near the test network.



Network performance-analysis tools (an Iperf client and server) were connected to the test access points to provide a load on the Wi-Fi network. To provide voice over Internet protocol (VoIP) traffic, a Cisco 7921 IP phone and an Intermec CK60 mobile worker platform with a voice application were used.

Network statistics were monitored on the 802.15.4 network while Iperf was used to generate traffic on the 802.11b/g network. The Iperf client was connected using 802.11g. The data throughput of Iperf was monitored periodically to determine the overall impact on available bandwidth in the 802.11b/g network.

The selected channel for the 802.11b/g network was varied between 1, 6, and 11 during the test. The 802.15.4 network was running with field device data update rates set to 15 seconds (a typical configuration).

The 802.11b/g mesh access point was approximately 1 meter from the 802.15.4 gateway and anywhere from 30 cm to 1 meter from most of the 802.15.4 devices under test. This was again to create as close to worst-case test environment as possible given known RF characteristics.

Test results

Impact of 802.11b/g on 802.15.4. Overall data reliability of the 802.15.4 field network remained at 100% throughout the testing. Although 802.11b/g interference caused a small amount of packet loss on some of the 802.15.4 devices, the Emerson field network includes several features (such as retries and path diversity) to counter this effect, and the net packet loss was not significant enough to affect overall data reliability.

Impact of 802.15.4 on 802.11b/g. Throughput on the 802.11b/g network (monitored using Iperf) varied from 4 Mbits/sec to 8 Mbits/sec during baseline testing with no 802.15.4 traffic. In the presence of 802.15.4 traffic, the throughput varied in the same range throughout the testing. Based on the test results and known RF interactions (overlapping channels, output power), it is more likely that the other 802.11b/g access points that were in the surrounding environment but not part of the test caused most of the variation in the data throughput of the test 802.11b/g network.

Voice over IP testing was also conducted using the Intermec CK60 handheld computer with an IP voice application and the Cisco 7921 IP phone. In the test environment, no impact could be detected in the voice quality when 802.15.4 traffic was introduced into the environment over the test period.

Implications for wireless deployments

Impact of 802.11b/g on 802.15.4. Any 802.15.4 devices within range of but greater than 1 meter from an 802.11b/g mesh access point will have a path stability impact that is dependent on distance and bandwidth utilization. The impact on packet error rate is

$$\text{Packet Error Rate} = \text{BWU} * 20\%$$

where BWU is the bandwidth utilization of the 802.11b/g mesh access point and the 20% factor comes from empirical data gathered.

For example, if the 802.11b/g average bandwidth utilization is 20% (which is high for a typical Wi-Fi network), then there will be a 4% impact on individual path stability. This level of packet error rate is not large enough to impact the overall 802.15.4 network data reliability. This is because the network protocol has automatic retries built in, allowing some packet loss while continuing to maintain very high data reliability. Also, path diversity and channel hopping help to make the impact of this interference non-existent.

Prior research and testing has showed that static-channel 802.15.4 devices within 10 cm of an 802.11b/g mesh access point are significantly impacted. This is mostly a result of the high power output of the 802.11b/g radio. However, this issue is not seen with the Emerson Smart Wireless solution because it uses channel hopping to move around the interference. A technique not used in this test, "blacklisting" overlapping channels so the devices don't use them, also provides a way to mitigate the problem.

Impact of 802.15.4 on 802.11b/g. The 802.15.4 network will have an impact on the 802.11b/g network in proportion to its channel usage. Channel usage is a function of the total bandwidth utilization in the network and the channel dwell time. This can range from nearly 0% for typical networks to 100% for very large networks of line-powered devices.

For each device present in the range of an 802.11b/g access point, the maximum possible impact on the throughput will be

$$\text{802.11b/g bandwidth decrease} = 25\% * \text{BWU} * 4/15$$

The 25% factor comes from empirical data; the 4/15 comes from the number of 802.15.4 channels that are occupied by one 802.11b/g channel. The bandwidth utilization near an 802.15.4 gateway can approach 41% for large-scale networks. The 41% factor comes from the data rate of the 2.4 GHz 802.15.4 network producing maximum size packets (128 bytes) in 10 mS time slots.

The worst-case impact, assuming the 802.11b/g device is near an 802.15.4/WirelessHART gateway, is therefore 25% * 41% * 4/15 = 2.73%, or a reduction from 20 Mbps (typical throughput) to 19.45 Mbps. A reduction of this magnitude is negligible even in the most extreme time-sensitive applications like VoIP communication, which was tested to prove that no degradation occurs.

This testing was intended to represent near worst-case conditions users will encounter in deploying IEEE 802.11b/g devices alongside IEEE 802.15.4 devices. It is unlikely that a practical installation will ever reach greater than 40% bandwidth utilization on either type of network. Even in this extreme deployment, there was no noticeable impact on either network. And since most traffic into the gateways are communicated at a lower power level (power diversity), it has been shown to not impact the network in practical implementations.

Summary

Advancements in wireless technology have overcome previous concerns about using wireless applications in process operations. In particular, features of the Emerson and Cisco wireless architecture such as channel hopping and mesh networks can reduce or avoid potential coexistence problems between 802.11 and 802.15.4 technologies.

Our tests of this architecture under real-world conditions demonstrate that coexistence issues are in fact minimal, even in an extreme deployment scenario. From these findings we conclude that process industry users can move forward with confidence that these technologies can be used together successfully. In fact, there are probably many reasons to begin planning new wireless implementations.

While this paper addresses RF compatibility, other issues such as security and network management are aspects of network design that also require consideration. Cisco and Emerson offer a range of solutions to address these areas based on individual project requirements. Look for future white papers from Cisco and Emerson documenting best practices for process industry users who are implementing wireless networks in the plant environment. Additional information is also available from www.EmersonProcess.com/SmartWireless or by contacting an Emerson or Cisco salesperson.

References

[1] IEEE std 802.15.4-2006, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)

[2] IEEE Std 802.15.2-2003, Part 15.2: Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Bands, 28 August 2003.

[3] Dust Networks, Technical Overview of Time Synchronized Mesh Protocol (TSMP), June 20, 2006, online at www.dustnetworks.com/docs/TSMP_Whitepaper.pdf.

[4] WirelessHART™ Specifications

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