Basic Elements of a Wireless Mesh Lighting Network

Wireless lighting control systems are a long-awaited advancement in the lighting controls world, replacing the obtrusive and increasingly complex control wiring with a secure and reliable wireless signal. While there are many benefits to this swap, the fundamental shift from wired to wireless brings with it a new world of features and functionalities that designers will need to familiarize themselves with to compare the capabilities of different systems and select the right wireless lighting control solution for the project.

This application note will explore the basic elements and technology behind new wireless lighting control systems and highlight some important points of differentiation found in the wireless solutions available today.

Basic Elements of a Wireless Lighting Control System

A wireless lighting control system is comprised of three fundamental elements: the wireless lighting control devices, the wireless communication standard, or protocol, upon which the devices talk, and the wireless network topology, which describes how the wireless system is organized and how communications flow from one device to another.

Wireless Devices

Wireless devices refer to the lighting control equipment that operates on the wireless network. In today's code-compliant commercial lighting control system, typical devices in a wireless lighting control system include, but are not limited to, light fixtures or luminaires, various configurations of occupancy and daylighting sensors (fixture-integrated, external, battery-powered), wallstations, controlled receptacles, relay switchpacks, and a central area controller (often called a gateway) that will manage the devices installed in its dedicated area. The depth and breadth of the device offering supported by a wireless control system can differ dramatically from one manufacturer to the next, as can the performance of the individual devices, applications they can meet, and the capacity and range of the area controllers, which directly affects the number of area controllers necessary for a project and the overall system cost.

Wireless Communication Standard

The wireless communication standard identifies the language the wireless devices will use to speak to one another and the radio frequency band or wavelength at which they will speak it. There are two important characteristics that should be explored when evaluating different wireless lighting control systems. The first is whether the wireless communication standard is open or proprietary. The second is the frequency band in which the communication standard operates.

Open vs. Proprietary

Wireless standards can be categorized as open or proprietary. Open standards are developed by a team of industry experts and interested parties. The standards are publicly published and available for all product manufacturers to use, allowing devices from different manufacturers to be qualified and incorporated into one wireless system. Proprietary standards are privately developed and privately owned. Wireless lighting control systems using a proprietary communication standard are restricted to include only the few available components that have been specifically developed to speak this privately-owned wireless language.

Frequency Band

Wireless networks use radio frequency waves, sometimes generically referred to as RF, for the communication medium to transmit data and signals through the air. Radio waves can be transmitted at different frequencies and the transmission and performance characteristics can vary significantly. In fact, the general spectrum of the radio wave frequency band ranges from 9 kHz to 275 GHz. The frequency of the radio wave describes the number of waves that are completed over a certain period of time. Radio waves with a lower frequency are longer; higher frequency radio waves are shorter. Different frequencies of radio waves have different characteristics in terms of their transmission range and ability to penetrate or reflect off different materials.

In terms of using radio waves to transmit lighting control signals wirelessly, the frequency of the radio wave can determine import aspects of system performance and component cost. The longer wavelengths present at lower frequencies can often travel longer distances and more successfully travel through barriers, such as concrete walls. However, lower frequency/longer wavelength radio waves require more power and much larger, often more expensive, antennas to receive and transmit the information signal. The radio wave frequency is also a factor that determines available bandwidth and how much information can be transmitted. Lower frequency signals deliver less bandwidth than their high frequency counterparts. While lower frequencies are capable of transmitting the basic low data rate signals communicated through a lighting control system: turn on, dim, turn off; systems that operate on lower frequencies can be limited in their ability to transmit the type of detail-rich data now being requested in IoT (Internet of things) applications. In that regard, lighting control systems that operate at a higher frequency can offer a lower cost solution for transmitting basic lighting control signals and are better equipped to meet the emerging higher-data demands of the connected building.

A Note About Channels

The communications standard or protocol determines how each frequency band is sub-divided into channels to further organize and manage wireless communications traffic. Wireless devices in a system must be tuned to the same specific frequency and channel to transmit and receive signals from one another.

Introducing IEEE 802.15.4—The Open Wireless Lighting Control Communication Standard

The Institute of Electrical and Electronic Engineers (IEEE) develops open wired and wireless communication standards to ensure the interoperability of products and systems developed by different manufacturers. The IEEE created standard 802.3 to define wired Ethernet communications. Their standard 802.11 was developed for wireless LANs and is more commonly referred to as Wi-Fi. Standard 802.15 includes subcategories that define open standards for how different wireless personal area networks communicate. For example, IEEE 802.15.1 is the low power short range protocol initially used to define Bluetooth communication, 802.15.3 defines a communication standard for high-data-rate, ultra-wideband (UWB) technologies, and 802.15.4 was developed for low-data-rate monitor and control applications that needed to offer extended battery-life, low power consumption, and longer range data communications. The IEEE 802.15.4 standard can be used as the open communication standard for wireless lighting control systems, enabling the system to be readily expanded to include components or systems from other qualified manufacturers to further improve energy savings and meet flexible building management applications.

Layers, Frequencies, and Channels

The open IEEE 802.15.4 standard communication protocol contains two basic layers: the physical (PHY) layer and the media access control (MAC) layer, which provide a foundation upon which other protocols and features can be added with other layers. The PHY layer defines the radio frequencies upon which the network operates, power level, type of modulation, and other important parameters of the link. The MAC layer manages communication traffic and defines the format of data handling.

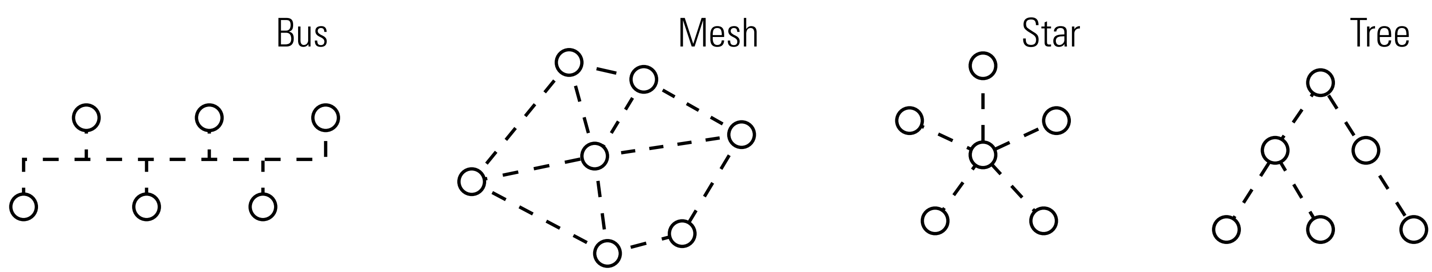
The standard allows for three license-free frequency assignments. The 2.4 GHz band is available worldwide and is the most widely used.

	Europe	Americas/Australia	Worldwide
Frequency Assignment	868-868.6 MHz	902-928 MHz	2.4-2.4835 GHz
Number of Channels	1	10	16
Channel Bandwidth	600 KHz	2 MHz	5 MHz

The 2.4 GHz frequency is used by building devices and systems employing both the 802.15.4 (also used as a basis for Zigbee), 802.15.1/Bluetooth and 802.11/Wi-Fi communication standards. Certain available channels will minimize the overlap of these various networks and enable the larger system to avoid interference. To minimize any possible interference or contention in the USA, channels 15, 20, 25, and 26 are used for the wireless devices on the IEEE 802.15.4 network and channels 1, 6, and 11 are used for 802.11/Wi-Fi devices.

Wireless Network Topology

The network topology describes the architecture of the wireless network and the way in which the messages travel through the system. While there are many common wireless system topologies, including, but not limited to, bus, star, tree, and mesh, the decision between systems based on a linear or mesh structure can impact the overall scalability, robustness, design complexity, latency (the time it takes for a message to travel from a node to an area controller), power consumption, and cost of the system.



Performance Comparison: Linear vs. Mesh Topologies

Most typical system topologies feature a linear structure that transmits messages from one device to another in an established and sequential order. Examples of linear topologies include: bus, where every device is linked to a central backbone; a star network, where every device has a direct connection to the central controller; and a tree topology, which combines bus and star configurations, where the system is organized into various star clusters connected by a linear bus backbone.

In a mesh topology, there is no singular, pre-defined communication path through the system. The wireless devices act as nodes that send, receive, and retransmit messages, passing a message across multiple devices to the dedicated area controller. The devices and the many potential communication paths between them form an interwoven, albeit wireless, mesh structure. There are several different ways that a message can navigate through the network, using any combination of devices, and the system is able to determine and use the most direct and efficient route that exists at any moment.

The mesh topology creates a stronger and more reliable wireless network structure than its linear counterpart. Linear systems can be compromised when a single device in the system fails or cannot transmit messages successfully, as there are no alternative paths available. As mesh structures expand and more devices are added, the network is strengthened and reinforced, creating redundancy and offering alternative routes to ensure messages can be reliably carried throughout the system, even if devices within the network fail, are busy or offline.

This fluid and flexible mesh structure offers two distinct benefits to the wireless system using it. The network is able to detect when a specific component is having issues and will re-route messages accordingly to protect the performance of the system. This ability to self-diagnose and remedy potential problems before the integrity of the system is compromised explains why mesh networks are often referred to as self-healing.

Beyond adjusting the system to accommodate malfunctioning devices, these mesh networks are equipped to identify and incorporate new devices into the system map or recognize and re-establish devices that have been moved. When a new device is added, the network automatically determines what type of device it is, locates neighboring devices and maps optimal pathways to communicate with the newly added component. The network's ability to auto-configure the devices it contains enables the system to stay current in its configuration and maintain efficient communication patterns, although the physical structure and make-up of the wireless system may evolve over time.

These self-healing and auto-configuring capabilities enable a wireless mesh network to more readily accommodate noise in the RF environment and, ultimately, provide a more reliable wireless communication solution than linear network topologies.

Wireless Lighting Control Systems: The Perfect Match for Mesh

Lighting control systems have some unique qualities that lend themselves to using a wireless mesh network. As previously mentioned, today's code-mandated commercial lighting control system is comprised of a number of devices: daylighting sensors, occupancy sensors, wallstations, relay switchpacks and controlled receptacles that are incorporated throughout the entire built space with a grid-like consistency. The prevalence of the lighting control system components throughout the interior space offers a sufficient device density to generate a robust and reliable wireless mesh structure.

The importance of operational lighting and lighting control systems is another factor that supports the use of a mesh topology, over a linear alternative. The mesh structure is less vulnerable to the failure or malfunction of any individual lighting control device. Control signals simply re-route around any off or non-working items, allowing the broader system to continue functioning, even if devices within the system experience difficulties. The singular path in linear systems can cause a substantial disruption in the function of the lighting system when components within the system fail or go offline.

Introducing the WaveLinx Lighting System

The WaveLinx Lighting system from Cooper Lighting Solutions was developed to be the most cost effective, best performing, highly secure and most flexible wireless lighting control solution available. This system offers designers and building owners the low installation cost and on-going flexibility benefits of wireless lighting controls, without the limitations of proprietary systems or linear topologies. Each individual device was designed to provide superior lighting and control performance, and the breadth of available WaveLinx-integrated and WaveLinx-enabled lighting devices and luminaires allows designers to create a comprehensive and cost-effective WaveLinx lighting control solution for any application. The system is built upon the IEEE 802.15.4 wireless communication standard and is organized into a mesh topology to provide a robust, reliable, and interoperable wireless lighting system.

In addition, WaveLinx daylighting and occupancy sensors, available in fixture-integrated or external configurations, collect and share data about the use and performance of the built environment over the wireless network, enabling designers to create lighting systems that are both code-compliant and IoT-ready.

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