DOE SSL Program
PNNL Advanced Lighting Team

Emerging Technology Primer: Networked Outdoor Lighting Control Systems
Fall 2014

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Introduction

The ongoing transition of outdoor lighting to LED technology is poised to deliver significant energy savings. The simple replacement of traditional High Pressure Sodium (HPS) sources with today's LED offerings commonly delivers an immediate 50% (or better) reduction in energy consumption. The inherent controllability of LED sources offers an opportunity to achieve even greater energy savings. Unfortunately, taking advantage of this opportunity is presently not straightforward. While LED technology adoption continues to become more viable for more users, and vendors continue to bring new and more mature complimentary networked outdoor lighting control systems to market, the adoption of these systems continues to lag behind. A recent survey of 240 public outdoor lighting owners and operators nationwide found that 62% of respondents had LED lighting somewhere in their system, while less than 5% reported any use of advanced controls to date.[1]

Among the key barriers to adoption of outdoor lighting control systems is a general unfamiliarity with the technology, and lack of understanding of how market-available products work, and differentiate themselves from one other. This emerging technology primer aims to help owners and operators of outdoor lighting systems better understand some key differences in the technology building blocks that comprise market-available outdoor lighting control systems, and better understand how those key differences relate to system features, value propositions, and potential barriers to deployment. This greater understanding should enable owners and operators to better formulate questions to ask when evaluating a market-available system that don't require a complete understanding of the technology building blocks, but effectively uncover how they relate to user needs and concerns (i.e. system features, value propositions, and potential barriers to deployment).

Note that this emerging technology primer is focused on building blocks and features that vary across market-available offerings, and are likely to be key deciding factors in selecting a system ideally suited to meet a given user's needs. Features common to most systems, or whose desirability is primarily a function of user taste (e.g. software Graphical User Interface (GUI) appearance) are not addressed in much detail, if at all. Finally, the scope of this primer is limited to the explanation and characterization of these building blocks and features, rather than the value propositions they offer, which are typically perceived differently by different users. Methods for predicting or measuring the value delivered by this emerging technology, as well as barriers to its adoption are left for another discussion.

[1] Municipal Solid State Street Lighting Consortium Public Outdoor Lighting Inventory: Phase I Survey Results. US DOE. September 2014.

Terminology

The starting point for understanding an emerging technology should always be the terminology used to describe its components and features. A poor understanding, or more commonly, misunderstanding of key terms can be a significant market barrier all by itself.

In North America, two commonly referenced sources of terminology are IES/ANSI RP-16-10 “Nomenclature and Definitions for Illuminating Engineering” and IES TM-23-11 “Lighting Control Protocols”, both available from the Illuminating Engineering Society (IES).

For the purposes of this primer, a networked outdoor lighting control system consists of three types of components: Field Devices (or, taken together, Field Device Networks), Network Infrastructure, and a Central Management System (Figure B-1). These terms are defined below; definitions of terms that are included in IES TM-23-11 contain both the documented definition as well as clarifying points useful for their use in describing networked outdoor lighting control systems.

1. **Field devices**: the entire set of networked Components (hardware and embedded software, consisting of Controllers and possibly Gateways) installed in the field that, following installation, start-up and commissioning, function together to adaptively control and remotely monitor Luminaires.

2. **Controller** (from IES TM-23-11): “the device that originates a command to execute a lighting change. Most commonly associated with a lighting control station or control console, a controller may also be a sensor or other automatic device operating without human interaction”. In most networked outdoor lighting control systems, Controllers physically monitor and control Luminaires installed at Control Points, react and respond to logical and physical inputs, make control decisions using internal algorithmic and logic functions, and communicate via a network protocol.

3. **Gateway** (from IES TM-23-11): “a device designed for interfacing between two communication networks that use different protocols, such as BACnet to DALI, or DMX512 to 0-10VDC. A Gateway may contain devices such as protocol translators, impedance matching devices, rate converters, fault isolators, or signal translators as necessary to provide system interoperability”. In most networked outdoor lighting control systems, Gateways serve (at a minimum) as the interface between one or more Field Devices and a Central Management System, where they aggregate data packets, connect to an external network and typically translate from a wireless Field Device protocol to a standardized Wide Area Network (WAN) protocol, such as WiFi (i.e. IEEE 802.11xx), Ethernet (i.e. IEEE 802.3), or LTE Cellular (i.e. 3GPP Release 8).

4. **Network** (from IES TM-23-11): “a group of systems that function cooperatively and/or interdependently to provide a chain of command for lighting control.”

5. **Field Device Network**: typically a Local Area Network (LAN) that connects and enables communication between (exclusively) Field Devices

6. **Backhaul Network**: typically a Wide Area Network (WAN) that connects and facilitates communication between (at a minimum) one or more Field Device networks with a Central Management System.

7. **Central Management System**: a computer environment that functions as the core of the System by providing all shared System services, and consolidating and storing (or managing the storage of) all System data.

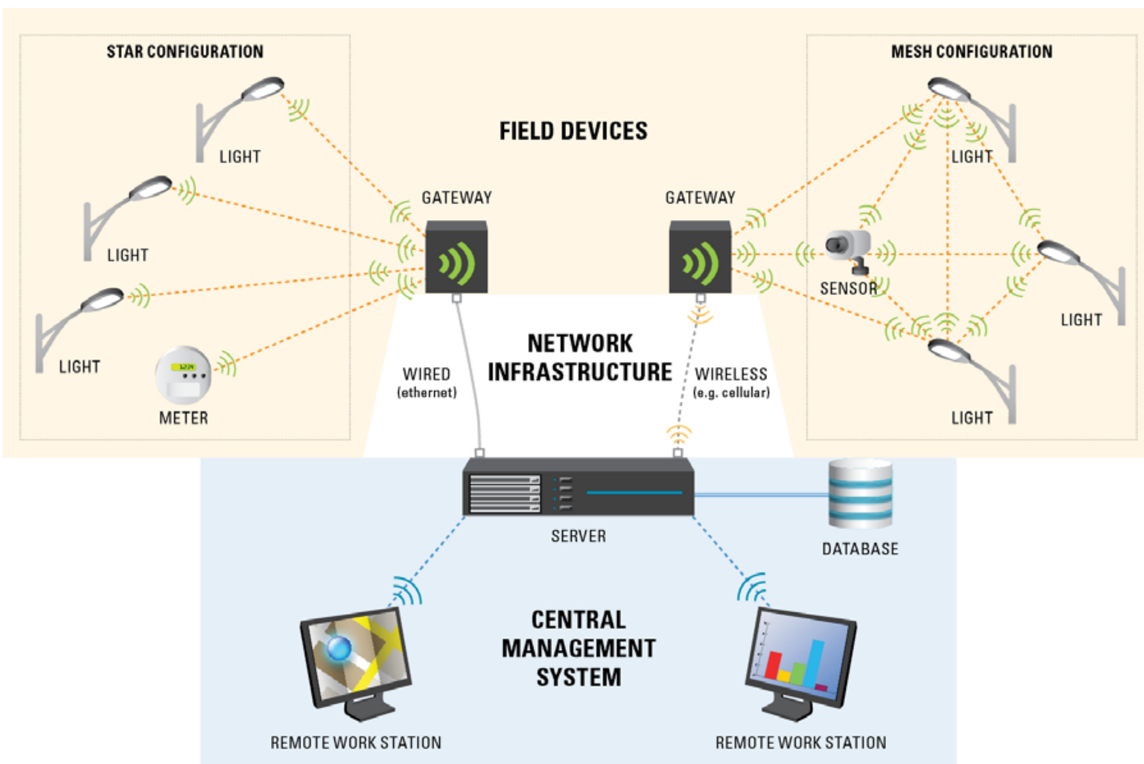

Figure B-1: A networked outdoor lighting control system (Source: CTLC for MSSLC)

Technologies that are new to one application (e.g. outdoor lighting) but mature in another often attempt to bring terms from those other applications. While sometimes this speeds understanding, often it inhibits it – in particular if the terms are understood or used differently in the emerging application. For example, the networking technology utilized in networked outdoor lighting control systems borrows much from product developments for other applications (e.g. home or industrial automation). One approach for exchanging data between system components involves the formation of a communication “mesh” between system components through which an optimal data path can be determined. Those versed in mesh networks often use the term Leaf, Router, and Border Router (defined below) to differentiate between different types of mesh “nodes” (Figure B-2). Note in particular that one term (Border Router) is essentially defined by the same function performed by the (more generic) term “Gateway”.

1. **Leaf**: transmits/receives data packets (messages)

2. **Router**: generates and forwards (i.e. repeats) adjacent node’s data packets (messages)

3. **Border Router**: translates from mesh protocol to a standardized Wide Area Network (WAN) protocol (i.e. a Gateway)

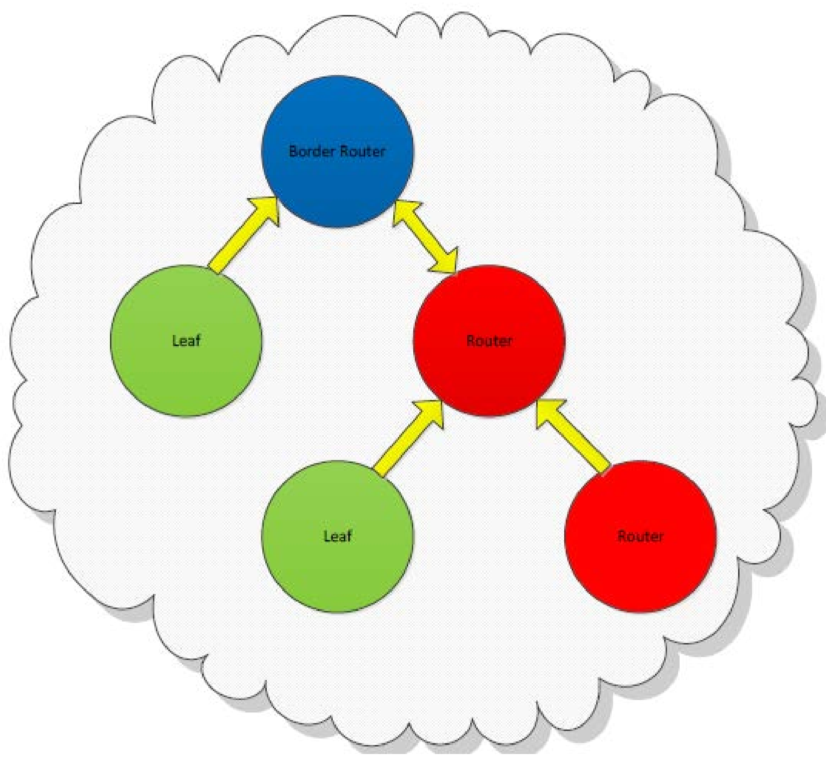

Figure B-2: Mesh terminology diagram.

The deployment of a networked outdoor lighting control system is not as simple as installing a set of components, and applying power. The components in such a system all have specific roles, and must work together to deliver system features. In particular, networked outdoor lighting control systems require the exchange of data between various components in order to enable their full functionality, and deliver their full value. In some ways, the performance (including the potential energy savings) of such systems is directly related to how well (and in some cases how much) data is exchanged between system components.

The deployment of a networked outdoor lighting control system requires the successful execution of a series of activities spanning from mechanical mounting of components to the configuration of software options. Discussion of and differentiation between these activities requires the definition of additional terms. Deployment activities can be broken into three distinct sequential stages, differentiated by both their nature and perhaps the skill sets required for their successful execution: Component Installation, System Start-Up, and System Commissioning (Figure B-1). When planning the deployment of a system, owners and operators should carefully consider who has the necessary skills and is capable of taking responsibility for the tasks required in each stage. In some cases, owner and operator staff may be more than capable. In others, the vendor, a vendor representative, or perhaps a qualified third party may be more suitable.

A sufficient understanding of these deployment stages is presented in a technology primer both to facilitate a greater understanding of the complexity of the technology, and as context for the described building blocks and features – some of which simplify the effort or reduce the time required to successfully execute a particular deployment phase. Each phase is described in more detail below.

1. **Component Installation**: A process that results in a state where all components have been provided the basic necessities required for them to operate as intended. Component installation typically includes mechanical mounting, the establishment of one or more electrical connections, and perhaps some provisioning for network communication or configuration of basic parameters to default or user specified settings. It does not necessarily result in a state where all components are operating as intended or where all System functions and capabilities are available to the user.

2. **System Start-Up**: A process that results in a state where all components are operating as intended and all system functions and capabilities are available to the user. System Start-up typically includes the configuration of system hardware, firmware, and software. It does not necessarily result in a state where all system functions and capabilities are configured according to user desires.

3. **System Commissioning**: A process that results in a state where all System functions and capabilities are configured according to User desires. System commissioning typically includes the modification of system software settings, and should by definition result in a state where all system functions and capabilities are configured according to user desires.

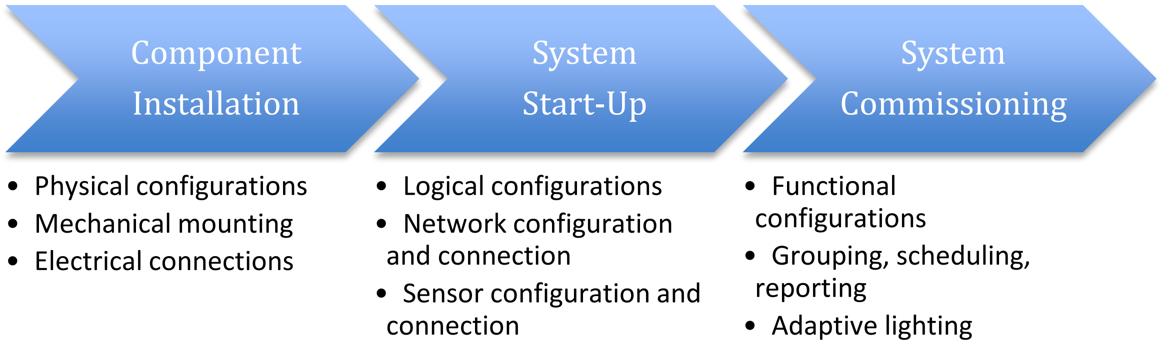

Figure B-1: Deployment process for a networked outdoor lighting control system.

Considerations

Networked outdoor lighting control systems are truly an emerging technology; market-available products currently vary significantly in approach, implementation, sophistication, and maturity. There is no shortage of building blocks and features that could potentially be addressed by technology primer, and no one sub-set of topics that is best suited for all owner and operator types. This version of the emerging technology primer for networked outdoor lighting control systems addresses the following topics in subsequent sections.

1. Interoperability
2. Luminaire integration options
3. Input voltage options
4. Lighting control options
5. Energy metering

1) Interoperability

Interoperability is a key consideration for any system that, initially or as it evolves, is comprised of components that perform different functions, and require the exchange of information to (ideally) perform those functions. The term "interoperability", while widely used, is frequently used inconsistently. Any discussion of interoperability should start with a common definition. Here, interoperability is differentiated from compatibility and interchangeability as follows:

1. **Compatibility**: Two components (or a component and a system) are compatible if they can operate in a system (or in the same physical environment) without corrupting, interfering with, or hindering the operation of the other entity.

2. **Interoperability**: Two components (or a device and a system) are interoperable if they can both operate in a system as intended, typically facilitated by an ability to share a common defined set of information.

3. **Interchangeability**: Two components are interchangeable if they can be physically exchanged for each other, and provide identical (for defined characteristics) operation in a system without additional configuration.

Component interoperability provides many advantages for designers, integrators, owners, and operators of systems. Interoperability facilitates the ability to integrate best-of-breed components (e.g. controllers, sensors, software) from different vendors into a system. Further, component interoperability facilitates the ability to modify and improve an existing system as one learns what features or level of performance is really needed, following real-world (post-deployment) experience, and helps manage the risk of component or manufacturer obsolescence. Perhaps most importantly, however, interoperability facilitates the sharing of data. Interoperable components can share data that they generate or collect, and can use data generated or collected elsewhere. In a networked outdoor lighting control system, the availability of more or better data facilitates more sophisticated adaptive lighting approaches and potentially greater energy savings, as well as a growing array of non-energy benefits.

Interoperability is a nuanced concept, however, in that there can be many types or "levels" of interoperability in a given system (Figure 1-1). For example, interoperability between a controller and a luminaire may facilitate the exchange, comprehension, and use of control signal data between those two components – but nothing more. Similarly, interoperability between a Central Management System and a Communication Network may allow the Central Management to connect to a given (e.g. wired, wireless) network – but doesn't guarantee that any other component or system on the network can understand the data that the Central Management System is able to share. Interoperability between a Central Management System and a Field Device Network is required to ensure that data can be exchanged between the Central Management

System and Field Devices – through their associated Gateway. Finally, full interoperability between Field Devices may facilitate the direct exchange, comprehension, and (ideally) use of data between, for example, a sensor and a luminaire – without the need for the data to traverse a Gateway or Central Management System. Note the differentiation between the ability to exchange, comprehend, and make use of data. This distinction between different structures or statuses of data starts to get to the heart of how one can systematically characterize different levels of interoperability.

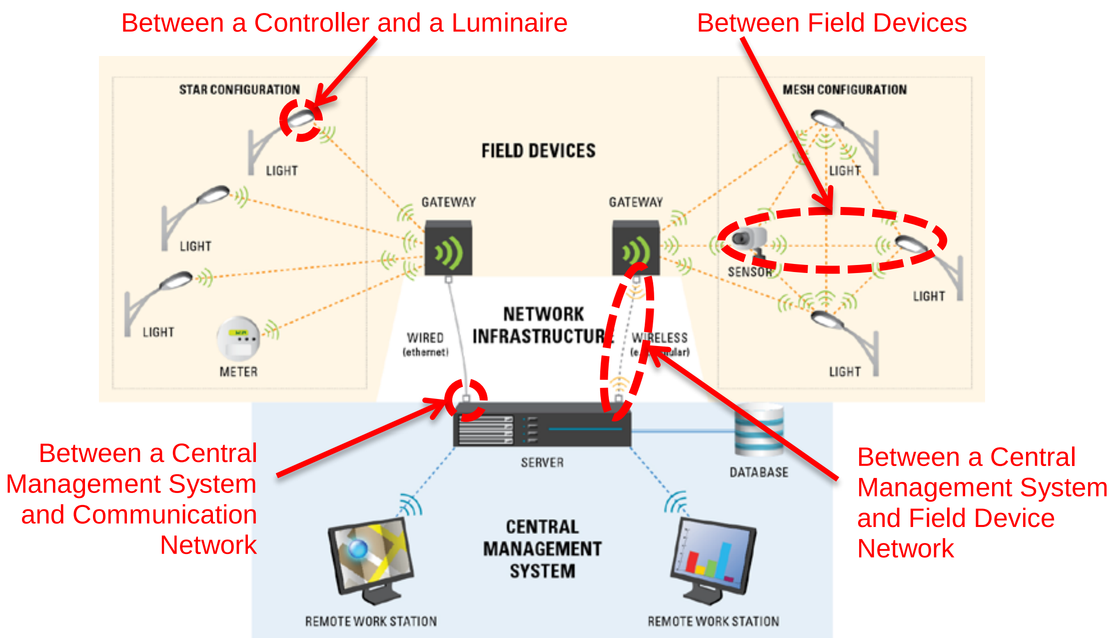

Figure 1-1: Examples of different levels of potential interoperabilitiy in a networked outdoor lighting control system.

One approach to begin to better understand interoperability is to consider how humans exchange data, or communicate (Figure 1-2). Initially, two parties may decide on whether they want to communicate verbally (e.g. face-to-face, or on the phone) or using some written mechanism (e.g. writing a letter or composing an e-mail). For two individuals who do not know each other, however, agreeing upon how to "convey" the information they want to exchange does not necessarily guarantee that they will be able to communicate effectively. A letter may be delivered by various means (e.g. vehicle, airplane) and a telephone conversation may occur over a wired or wireless communication network; these different approaches may result in different transport times or delays, and may degrade the quality of communication in one or more ways (e.g. a letter can get wet, a telephone connection can be noisy). Even agreeing upon or accepting the limitations of how information will be "transported" does not guarantee effective communication. If the two parties speak different languages, or speak to each other using different dialect – communication may be compromised. Finally, consider the topic of discussion; if the parties intend to discuss automobile engines but have different understandings of how fuel injection is accomplished, or one individual does not know what a carburetor is, their communication may not be effective.

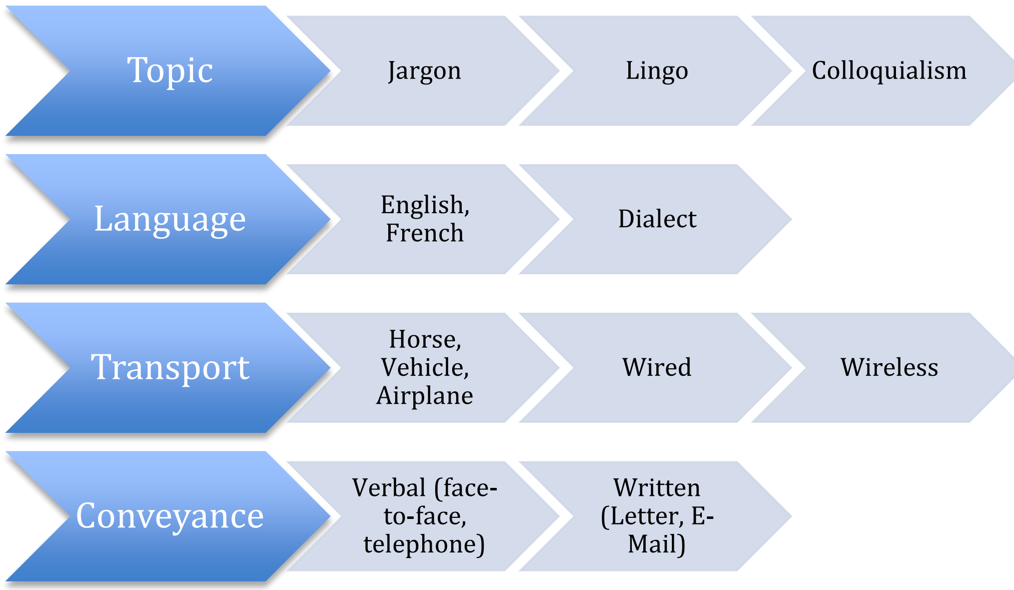

Figure 1-2: Human communication abstract “model”.

Developers of approaches for electronically exchanging data have develop a similar, albeit more precise and sophisticated abstract model for describing the quality or status of data, how it is exchanged in a system, and interoperability. The Open Systems Interconnection model (OSI) is a conceptual model that characterizes and standardizes the internal functions of a communication system by partitioning it into abstraction layers[2]. The model is a product of the Open Systems Interconnection project at the International Organization for Standardization (ISO), and is maintained as ISO/IEC 7498-1. A detailed discussion of the OSI model is beyond the scope of this primer, but the graphical depiction of the model (Figure 1-3, left) conveys some basic concepts, including how data structure or status progresses from bits to usable data, and how a communication network is built up from devices that create a physical (typically electronic or optical) representation of the data to be exchanged, to the creation of network addresses and data paths. Not all communication networks have distinct approaches for achieving all seven OSI layers. Further, not all communication networks even perform the functions described by some of the layers. For example, some communication networks do not have device addresses, and do not manage data paths.

The OSI model may be simplified for the purposes of general discussion and comparison of communication networks (Figure 1-3, right). In particular, this simplified representation is useful for discussing communication protocols:

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[2] http://en.wikipedia.org/wiki/OSI_model

- **Protocol/Communication Mode/Method** (from IES TM-23-11): "a set of standard rules – the syntax, semantics, and synchronization – for communicating over a computer network or a lighting control system or both. The protocol defines the methods for data representation, signaling, authentication and error correction to ensure control or enable the connection, communication, and data transfer between computing or control endpoints. Protocols may be implemented by hardware, software, or a combination of the two. At the lowest level, a protocol defines the behavior of a hardware connection".

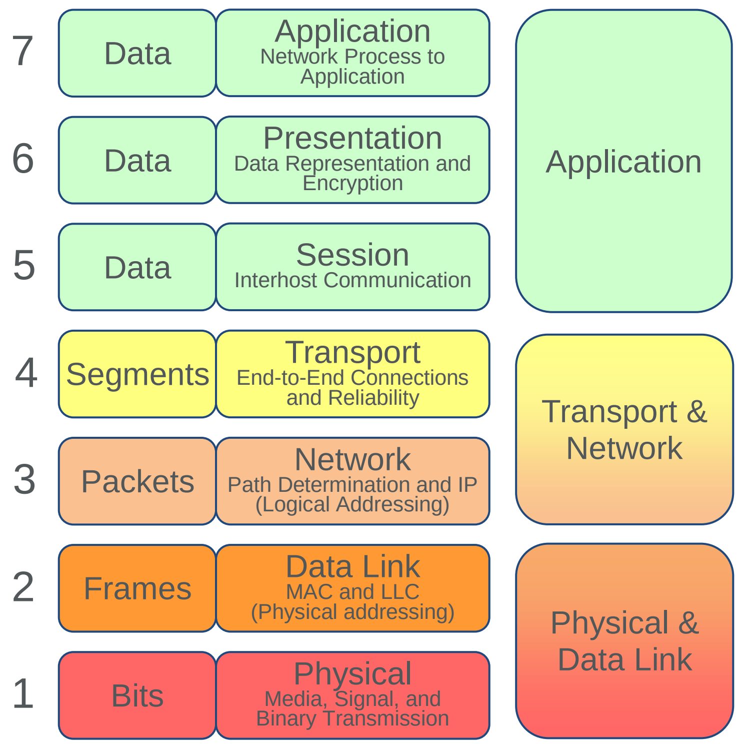

Figure 1-3: The full OSI interoperability abstraction model (left) and simplified version (right)

Protocols are often the most visible face of interoperability specifications. However, a commonly made mistake is the assumption that one protocol guarantees full system interoperability. In reality, protocols typically only define communication at one or a few interoperability levels, and it therefore typically takes many protocols to achieve full interoperability for a given communication network and application.

The "internet" is perhaps the most well-known standardized communication network. It is typically represented abstractly in a slightly modified form of the simplified OSI model (Figure 1-4, left). A wide array of communication protocols were developed and standardized to deliver the interoperable internet system that much of the world has come to rely upon. Figure 1-5, right shows some of these standardized protocols and what interoperability level they operate at.

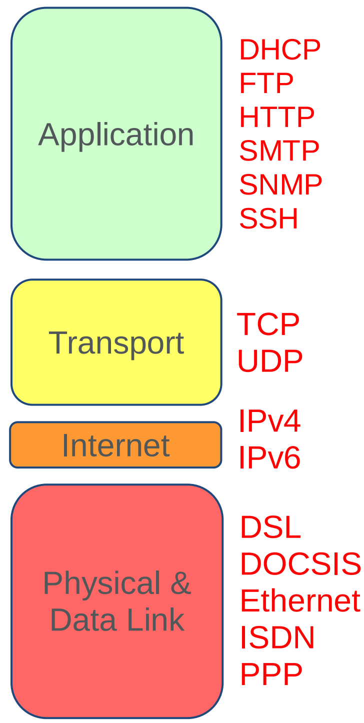

Figure 1-4: The "internet" interoperability abstraction model (left) and common protocols (right) used to communicate at each layer.

It is important to note that, even mature, robust systems like the internet often incorporate devices that utilize different protocols at a given interoperability layer. For example, anyone who has set up a home computer network that connects to the internet is likely familiar with the need for a device that serves as an interface between their Internet Service Provider (ISP) and their home computer network. These devices, among other things, translate between the protocol utilized by the ISP (e.g. DSL, DOCSIS) and the Ethernet protocol that has been adopted as one of the de-facto standards for computers and a wide range of networking equipment. These devices are one form of a Gateway, which, as defined earlier, fundamentally serve as a bridge between systems. As such, Gateways can be used to facilitate interoperability at one or more layers (i.e. Physical & Data Link, Network & Transport, Application) by translating from one protocol to another. The success of any "translation" however, is susceptible to failure if any devices on either side of the Gateway utilize a modified or more recent version of the protocol than the one the Gateway is basing its translation on.

Outdoor lighting system owners and operators have heretofore mostly relied on stand-alone (i.e. non-networked) devices – commonly referred to as photocells – for

controlling their luminaires, and as a result standards development organizations that focus on outdoor lighting are just beginning to think about interoperability.
The ANSI C136 committee, which develops ANSI accredited standards for Roadway and Area Lighting equipment, has however developed two interchangeability standards. ANSI C136.10-2010 contains specifications for "Locking-Type Photocontrol Devices and Mating Receptacles – Physical and Electrical Interchangeability and Testing" (Figure 1-5). The ANSI C136 committee is currently revising this standard. ANSI C136.41-2013 contains specifications for a "Dimming Control Between an External Locking Type Photocontrol and Ballast or Driver" (Figure 1-6). ANSI C136.41 compliant receptacles and contacts are readily available in the component market, and a steady stream of vendors are offering compliant luminaires and lighting control products.

Figure 1-5: An ANSI C136.10 compliant receptacle (left) and controller (right).

Figure 1-6: ANSI C136.41 compliant 5-pin and 7-pin receptacles (left) and 5-pin receptacle-controller combination (right).

Note that both of these ANSI C136 standards primarily only address mechanical and electrical interchangeability; in other words, they ensure that the mechanical mounting and electrical connections of all compliant receptacles and controllers perform at some minimum level, and that the interchange of one receptacle for another, or one controller for another, does not result in a mechanical mount or electrical connection below that minimum level. Neither of these standards addresses the exchange of data from a receptacle to a controller, or vice-versa.

Most market-available networked outdoor lighting control systems are not interoperable. Typically, controllers from one vendor cannot exchange data with a gateway from another vendor, and Field Devices from one vendor cannot exchange data with a Central Management System from another vendor. While the equipment comprising these systems often communicate at the Physical & Data Link layer using standard protocols, communication at higher interoperability layers is accomplished using proprietary protocols (Figure 1-7).

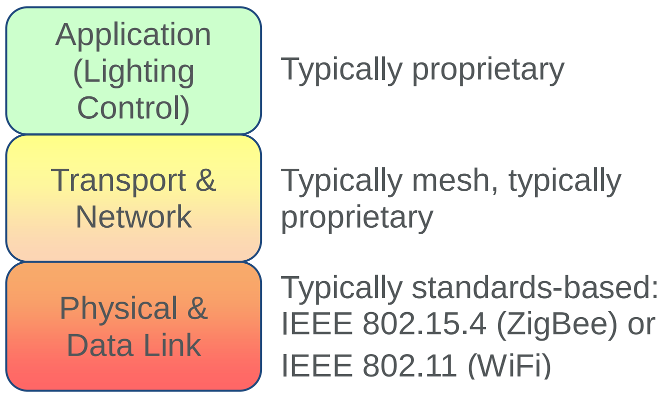

Figure 1-7: Typical market-available networked outdoor lighting control system communication protocols.

Many organizations have developed or are developing open (i.e. available for use by anyone) communication protocols that are intended for or at least capable of being used in networked outdoor lighting control systems. These organizations are typically (but not always) initiated and led by technology vendors, and focused on developing specifications that have broad (i.e. international) applicability. They vary in structure and scope, and the specifications they develop vary in maturity and what interoperability layers they address. It is not uncommon for a given technology vendor to be a member of and contribute to multiple such organizations. Further, knowing that the market success of a given protocol is not easy to predict, some vendors participate in efforts that have overlapping scope. As the specifications developed by these organizations become increasingly adopted by vendors, and thereby established in the marketplace, they are often taken to an accredited Standards Development Organization (SDO), where they become formally standardized using an open and transparent process. SDOs are coordinated and accredited by a national (e.g. the American National Standards Institute (ANSI) in the United States) or international standards body (e.g. the ISO). Some of the currently more prominent or well-known such organizations are briefly discussed below.

LonMark International is a vendor consortium that as of this writing has 14 members developing street lighting products. LonMark International develops full interoperability specifications (including Functional Profiles), for many applications. Many LonMark specifications been standardized, first nationally, and then internationally as the ISO/IEC 14908 series. Table 1-1 contains a list of LonMark supported Device Class categories (i.e. applications) as of this writing. In each category, a number of Device Classes are further defined; Table 1-2 shows the current list of defined Lighting Device Classes. Note that not all Device Classes have associated Functional Profiles; those that do are underlined and hyperlinked. LonMark International develops compliance test procedures for their specifications and manages product certification.

Table 1-1: LonMark Device Class Categories

01.00	Network Infrastructure
04.00	Programmables
05.00	I/O
06.00	Generic Controllers
07.00	Generic Actuators
08.00	Generic Human-Machine Interface
10.00	Sensors
20.00	Energy Management
30.00	Lighting
40.00	Wiring Devices
50.00	Access/Intrusion/Monitoring
60.00	Motor Controls
70.00	Gateways
80.00	HVAC
90.00	Transportation
100.00	Refrigeration
110.00	Fire & Smoke Devices
130.00	Industrial
140.00	Vertical/Conveyer Transportation (Elevator)
150.00	Whitegoods
170.00	Automated Food Service
180.00	Semiconductor Fabrication

Table 1-2: LonMark Lighting Device Classes

30.00	Lighting
30.10	Dimmer 1-10V
30.11	8-Channel dimmer 1-10V
30.12	3-Channel dimmer 1-10V
30.20	Transistor Dimmer

30.30	Thyristor Dimmer
30.40	Lamp Actuator
30.41	ISI Lamp Actuator
30.50	Constant Light Controller
30.71	Occupancy controller
32.00	Switch (Profile-Specific Usage) 00 - Discrete Output (ON/OFF) 01 - Discrete Output (ON/OFF) with Feedback Input 02 - Discrete Output (ON/OFF) with Setting Control 03 - Discrete Output (ON/OFF) with Feedback Input and Setting Control 20 - Variable Output 21 - Variable Output with Feedback Input 22 - Variable Output with Setting Control 23 - Variable Output with Feedback Input and Setting Control
32.01	4-Switch relay
32.02	Multi-switch/multi-sensor
32.03	Switch/sensor
32.50	Scene Panel
32.51	Scene Controller
32.52	Partition Wall Controller
32.53	ISI Keypad
33.00	Real-Time Keeper
33.01	Real-Time-Based Scheduler
34.00	Lighting Controller
34.01	Lighting Panel Controller
35.00	Outdoor Lighting
35.12	Outdoor Luminaire Controller
35.14	Smart Luminaire Controller

The TALQ Consortium is a vendor consortium that as of this writing has 11 regular members, 11 associate members, and 4 partners. The TALQ consortium, which is focused on outdoor lighting, has developed a specification for the interface between Outdoor Lighting Networks (i.e. Field Devices) and Central Management Systems. The TALQ specification covers the Application, Network & Transport layers, but does not specify Physical & Data Link layer protocols. The TALQ Consortium is currently in the process of developing a compliance test procedure for their specification and setting up a product certification program.

The Wi-SUN Alliance is a vendor consortium that as of this writing has 10 promoter members, 44 contributor members, and 2 observer members. The Wi-SUN Alliance, which is focused on Smart Utility Networks, is primarily developing specifications for Physical & Data Link layers based on IEEE 802.15.4g; one or more Network & Transport layer specifications may also be developed as necessary. The Wi-SUN Alliance intends to develop one or more compliance test procedures (as necessary) and manage product certification.

The 3rd Generation Partnership Project (3GPP) unites six national telecommunications SDOs (ARIB, ATIS, CCSA, ETSI, TTA, TTC) to produce the standardized specifications that define 3GPP technologies, including LTE and LTE-Advanced. The growing use of Small Cells to build out 3GPP technology infrastructure and newer efforts such as the standardization and incorporation of LTE-Direct may influence the design and deployment of networked outdoor lighting control systems in the near future.

The AllSeen Alliance is a vendor consortium that as of this writing has 11 premier members, 60 community members, and 9 sponsored members. The AllSeen Alliance, which is focused on enabling the much-discussed future "Internet-of-Things", is primarily developing Application layer protocols that would enable a wide range of devices to exchange usable data without the use of translators (i.e. Gateways).

Other efforts of note include the growing set of National Transportation Communications for ITS Protocol (NTCIP) standards that are the result of a joint standardization project of AASHTO, ITE, and NEMA, and the ZigBee Neighborhood Area Network (NAN) project recently announced by the ZigBee Alliance. NTCIP is planning to update its Object Definitions for Electrical and Lighting Management Systems (ELMS) standard, last published in 2011. The ZigBee NAN is intended to connect smart meters and distribution automation (i.e. SCADA) devices to Wide Area Network gateways.

2) Luminaire integration options

A variety of approaches have been and/or are currently being used to integrate Controllers with luminaires. Most vendors offer an external module that looks like a common photocell and mounts similarly to the luminaire (Figure 2-1). If on/off control is all that is required (no dimming), then integration can be accomplished by either a 3-prong (ANSI C136.10) or a 5-7 prong (ANSI C136.41) luminaire receptacle. If dimming is required, then a means for communicating the dimming control signal from the external Controller to the luminaire ballast or driver is required. Most early market products leveraged the ubiquitous ANSI C136.10 receptacle for mechanical mounting and electrical power (Figure XX), and incorporated some novel approach for delivering the dimming control signal to the luminaire ballast or driver, such as one of the following:

- Drilling a hole in the luminaire to pass a pair of wires compatible with the implementation of a common lighting control protocol (e.g. 0-10V).
- Installing a module in the luminaire to both decode a power-line carrier (PLC) signal generated in the Controller (and communicated over one of the 3 ANSI C136.10 prongs) and generate a common lighting control protocol signal (e.g. 0-10V).
- Installing a module in the luminaire to both decode a wireless signal generated in the Controller and generate a common lighting control protocol signal (e.g. 0-10V).

ANSI C136.41 was developed specifically to offer a standardized option for communication between the external Controller and luminaire. The additional 2-4 prongs available in a ANSI C136.41 compliant receptacle and plug provide a simple means for delivering the dimming control signal from the external Controller to the luminaire ballast or driver that does not require modification of the luminaire or installation of other components.

Figure 2-1: Example of a Controller intended for external luminaire integration, side-view showing the photocell window (left), and mounted on a luminaire (right).

Some vendors offer Controllers designed to be installed inside the luminaire. While such integral approaches offer a number of compelling advantages, they also present some significant potential issues. Internal mounting allows for simple direct control signal wiring between the Controller and the luminaire ballast or driver, eliminating the need to pursue one of the approaches described previously. However, few luminaires have a specified or ideally-suited internal location for mounting a Controller, a problem exacerbated by varying Controller shapes and sizes. This results in the need to identify who will take responsibility for installing the Controller in the luminaire in a manner that does not degrade the performance or void the warranty of either, and does not result in a safety issue. For example, if mounting the controller on or adjacent to the luminaire ballast or driver results in increased operational temperature for either component, then the component lifetime and reliability may be degraded, or worse yet, the luminaire safety rating may be compromised. Finally, most integral Controllers still require the installation of an external antenna (Figure 2-2). The ANSI C136 committee has not yet specified a standardized antenna connector, and most luminaires do not have a specified or ideally-suited external location for mounting an antenna. While the installation of an antenna does not present much potential for compromising the performance of the luminaire, it still demands the time and cost required to modify the luminaire.

In the near future, it is likely these issues will be overcome by the design of luminaires with specified locations and interfaces for mounting controllers and/or antennas (possibly facilitated by a standardized specification), and the design and development of luminaires with integral control, facilitated by Controllers that are internal to the luminaire ballast or driver.

Figure 2-2: Example of a Controller integrated internal to a luminaire; note the small protruding antenna.

Some owners and operators of outdoor lighting systems currently find themselves in the predicament of being ready to convert their lighting infrastructure to LED sources, and interested in deploying a networked outdoor lighting control system, but for one reason or another not ready or able to do so at the same time. Such owners and operators are encouraged to install so-called “control-ready” luminaires that minimize the time, effort, and cost required to integrate them into a networked control system in the future. An ideal “control-ready” luminaire should contain a dimmable ballast or driver, and a means for integrating a Controller that requires low to negligible additional up-front material cost for the luminaire, and low future upgrade labor cost. These conditions can be met in a number of ways, most of which require re-visiting the luminaire in the field:

- Luminaires with an ANSI C136.41 compliant receptacle can be integrated by installing an external Controller with an ANSI C136.41 compliant plug.
- Luminaires with an interior plug/receptacle can be integrated by installing an internal Controller with a matching plug/receptacle (and likely an external antenna).
- Luminaires with a field replaceable power-door can be integrated by installing a new power-door with a Controller installed on the door or integral to the new ballast or driver, and an antenna installed on the door.
- Luminaires with a field replaceable ballast or driver can be integrated by installing a new ballast or driver with an integral Controller (and likely an external antenna).
- Luminaires with a ballast or driver that has an integral Controller can be integrated by a firmware upgrade and/or installing an external antenna.

It is likely that, at present, the ANSI C136.41 approach will result in the lowest combined additional up-front material luminaire cost and future upgrade labor cost for most owners and operators. As luminaires with internal or integral (to the ballast or driver) Controllers and pre-installed antennas become more widely available, the firmware upgrade approach may become more viable.

3) Input voltage options

The installed base of outdoor luminaires are powered by a wide range of electrical infrastructure; in North America this infrastructure may deliver RMS input voltages of 120, 240, 277, 347, and 480 to the luminaire. Many outdoor lighting control system vendors do not yet provide Controllers or other Field Devices that cover this entire range (Table 3-1). The integration of a Controller with a luminaire that operates at a higher input voltage requires the installation of a transformer in the luminaire, which again presents the need to ensure that doing so does not degrade the performance or void the warranty of the luminaire or Controller, as discussed earlier.

In the future, it is likely that such input voltage issues will dissipate as vendors fill out their product offering (likely based on market demand). Emerging luminaire ballasts and drivers are starting to offer additional low-voltage outputs for powering other devices (besides the light-emitting components). The ability to power an internal Controller from a low-voltage input both eliminates the need for Controllers to be compatible with multiple line-voltages, and reduces Controller cost, as the circuitry for converting external line-voltage to the internal low-voltage(s) is no longer required.

Table 3-1: Controller input voltage offerings, based on informal survey of eight vendors

Vendor	120 Volt	240 Volt	277 Volt	120 – 277 Volt	347 Volt	480 Volt
A				X	X	X
B				X	X	X
C				X		X
D		X				
E				X		
F				X		
G		X				
H		X				

4) Lighting control options

One of the key features offered by all networked outdoor lighting control systems is the ability to adjust luminaire light output. In North America, market-available dimmable luminaires predominantly utilize either the 0-10V specification (very common) or some implementation of the DALI specification (less common) for the exchange of light level data. Most vendors offer Controllers that support one or both specifications.

The 0-10V specification consists of protocols for only one-way analog communication of a single piece of data between a Controller and a luminaire. It does not describe a required relationship between its Physical layer representation of this data (i.e. the 0-10V signal) and any Application layer representation (e.g. power or relative light level). As a result, different luminaires that comply with the 0-10V specification may (and in the market, do) produce different power and relative light levels in response to the same 0-10V control signal.

The DALI specification consists of protocols for two-way digital communication of a number of data types between a Controller and luminaire. In addition, it also specifies a required relationship between its Application Layer representation of light level data and luminaire relative light output (Figure 4-1). The DALI Application layer protocol allows for the definition of a limited number of custom data types, which theoretically facilitates the communication of luminaire characteristics (e.g. make/model, power profile, ballast or driver temperature) to the Central Management System, potentially simplifying the completion of an asset management database.

At present, many owners and operators of outdoor lighting systems who are interested in deploying a networked outdoor lighting control system are understandably leery of taking advantage of the ability to adjust the light output of their luminaires. While "adaptive lighting" approaches hold the potential for delivering improved lighting and significantly reducing energy consumption, a number of practices must be established, or re-established:

- When light level adjustments are not possible, nominal light levels in many environments are often designed for worst-case conditions. Taking best advantage of the ability to adjust light levels may require the re-establishment (i.e. lowering) of nominal light levels, with the expectation that light output will be raised when conditions require it.
- Identifying conditions that warrant different (from nominal) light levels.
- Identifying when those conditions occur.
- Establishing target light levels for different conditions.

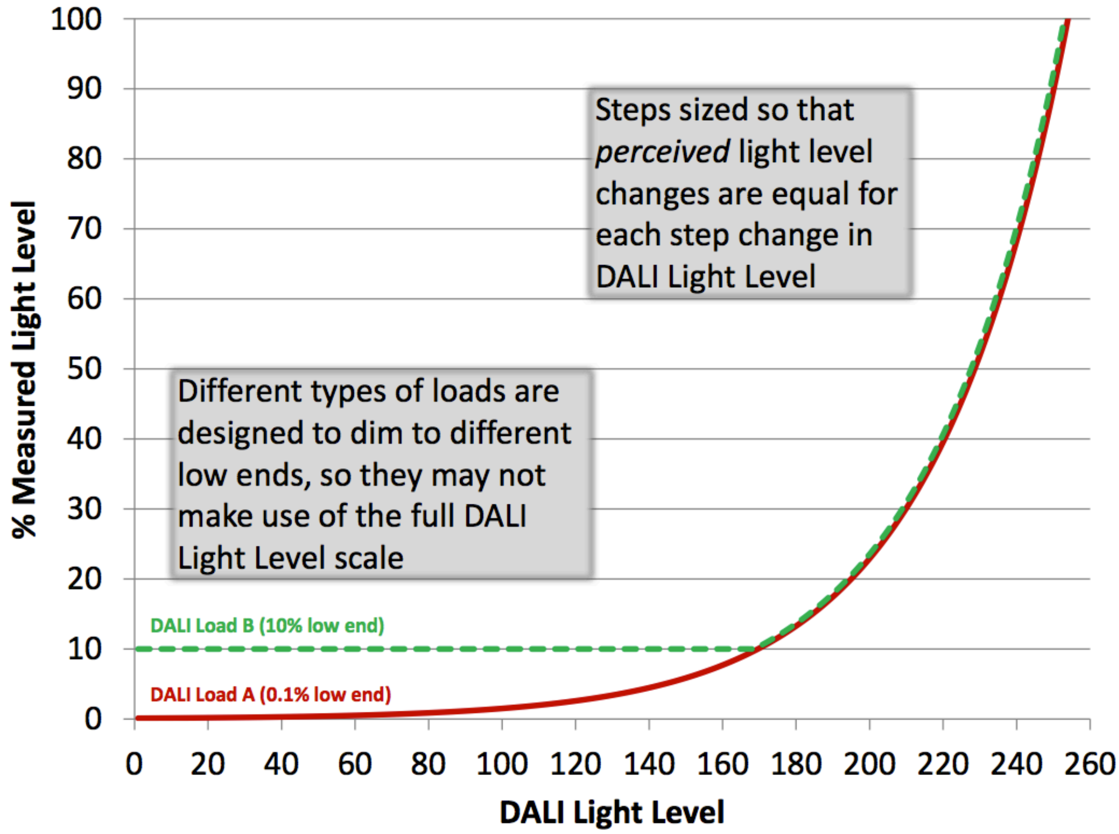

Figure 4-1: Specified relationship between a DALI digital control signal and luminaire relative light output.

Lighting owners and operators that are interested in pursuing adaptive lighting approaches, and looking for guidance on determining appropriate lighting levels for varying conditions are encouraged to review publication number FHWA-HRT-14-050 "Guidelines for the Implementation of Reduced Lighting on Roadways" recently (June 2014) released by the US Department of Transportation Federal Highway Administration.

5) Energy metering

Lighting system owners and operators are rarely just interested in saving energy; they are also interested in reducing operating costs. In North America, the electric energy consumption of most outdoor lighting systems is not metered. Rather, luminaires are billed for energy according to a fixed tariff, based on some determination of nominal power draw and expectation of hours-of-operation, typically under control of a dusk-to-dawn photocell.

Adaptive lighting approaches facilitated by the installation of a networked outdoor lighting control system directly enable energy savings. Operating costs are only reduced, however, if the energy savings can be monetized. Many market-available networked outdoor lighting controls systems have the ability to directly measure and report the energy consumption of all integrated luminaires. However, the measurement accuracy and precision of today's commercial offerings varies, sometimes significantly.

The ANSI C12 committee has over the years developed and revised two standards for characterizing electric meter accuracy and precision:

- ANSI C12.1 – 2008 "American National Standard for Electric Meters, Code for Electricity Metering"
- ANSI C12.20 – 2010 "American National Standard for Electric Meters, 0.2 and 0.5 Accuracy Classes"

These standards were developed for building meters, however, and are not directly applicable for use in evaluating the ability of Controllers to measure the electric energy consumption of a single luminaire. Many vendors are attempting to adapt one or both of these standards for use in evaluating their products, resulting in varying market claims (Figure 5-1).

The ANSI C136 committee has begun work on a new standard specifically for devices intended for use in characterizing the energy measurement of outdoor lighting equipment. This standard is tentatively referred to as ANSI C136.50 – TBD (Revenue Grade Energy Measurement).

- Delivers revenue grade energy data with 0.5% accuracy per ANSI C12.20

Features:
- +/- 2% accuracy (per ANSI C12.1 & C12.20)

Q5. What is the accuracy and resolution of the power monitoring?
A5. Better than 1% non-revenue-grade reporting, with a resolution of watt- seconds (Ws).

- Utility-grade metering means you pay for actual energy use, with measurement accuracy of ± 2%

- Energy metrology at 1 % accuracy, with per day, per hour, or per minute records and robust utility billing integration

Figure 5-1: Energy metering claims, based on informal survey of five vendors.

Some lighting system owners and operators are pursuing the development of new "adaptive lighting" tariffs with their electric utilities. These tariffs are modeled after those recently developed for LED luminaires, which unlike the High Pressure Sodium (HPS) incumbents they are replacing, are available in the market with a wide range of nominal power draws. HPS technology is relatively mature, and there is little variation in source efficacy across otherwise equivalent products. As a result, market-available HPS sources can effectively be characterized by their nominal power draw, and only a limited number of sources serve the needs of most outdoor lighting systems (e.g. 100W, 150W, 200W, 250W), a result which greatly facilities the simple fixed tariff model.

LED technology, on the other hand, is still evolving. Increasing source efficacies and varying luminaire design approaches have resulted in a market where currently there are no typical power draws. In order to limit the number of tariffs – each with its own nominal power draw assumption – most utilities have adopted a binning approach, whereby a limited number of power bins are defined (e.g. 61-80W, 81-100W, 101-120W etc.) and LED luminaires are assigned to the appropriate bin according to their nominal power draw. Luminaires in each bin are billed according the mid-bin power level (e.g. luminaires in the 61-80W bin are billed according to an assumed nominal power draw of 70W).

This approach can be easily modified to support adaptive lighting tariffs. Rather than binning luminaires according to nominal power draw, and independently assigning an hours-of-operation to each luminaire to estimate annual energy consumption and the associate tariff rate, power draw and hours of operation can be binned together. Two examples are shown in Figure 5-2. In the first bin model, luminaires turn on at dusk, turn off at dawn, and dim from 100% to as low as 50% for a maximum of 4 hours. Luminaires whose operation falls in this "bin" would be billed according to the assumption that they are dimmed to 75% for 2 hours each night. In the second bin model, luminaires turn on at dusk, turn off at dawn, and dim from 100% to as low as 0% for a maximum of 4 hours. Luminaires whose operation falls in this "bin" would be billed according to the assumption that they are dimmed to 55% for 4 hours each night.

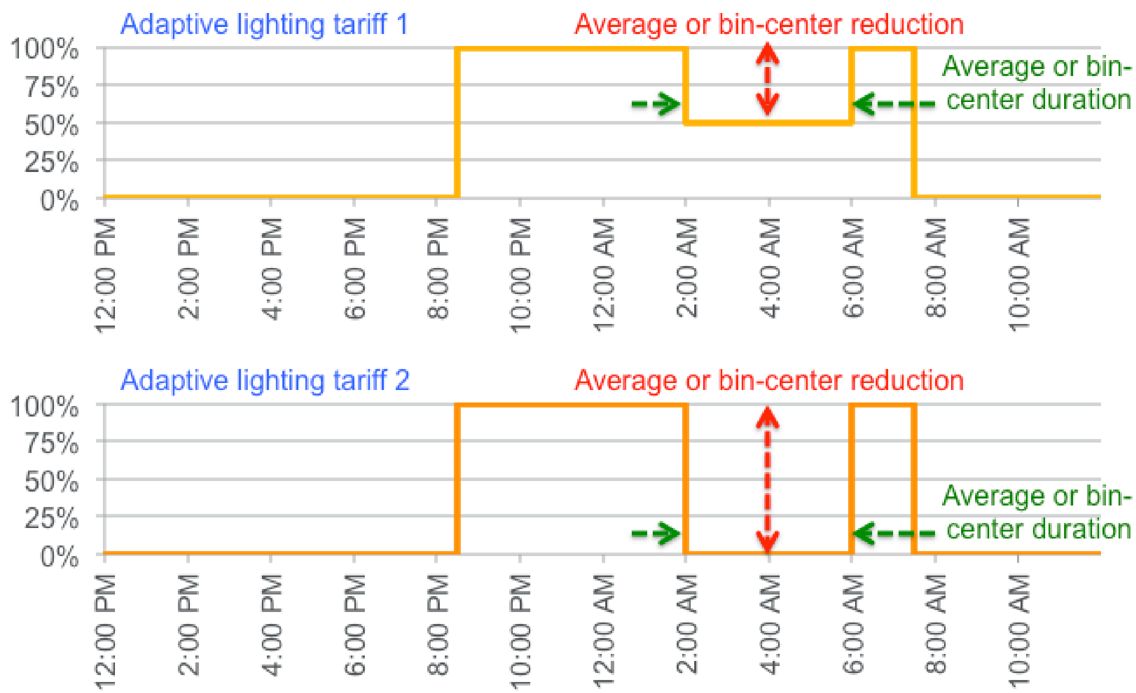

Figure 5-2: Example "fixed" adaptive lighting tariff alternatives to energy metering.

Next Steps

Future revisions or updates to this technology primer will describe and discuss additional outdoor lighting control system considerations, perhaps including one or more of the following, as applicable:

1. Location commissioning
2. Sensor options
3. Network architecture
4. Wireless spectrum
5. Backhaul selection
6. Software
7. Security
8. Data access
9. Business models
10. Integration with other (non-lighting) systems

Lighting owners and operators who are interested in learning more about this emerging technology and are encouraged to explore other resources offered by the DOE and elsewhere:

1) Education
    a. What to Look for Today in Control Systems (Presentation at the IES Street & Area Lighting Conference), U.S. Department of Energy (2014)
    b. Networked Outdoor Lighting Control System Fundamentals (Workshop at Lightfair), U.S. Department of Energy, Philips Lighting and GE Lighting (2014)
    c. Potential Energy and Cost Savings Offered by Today's Networked Outdoor Lighting Controls, and the Obstacles Currently Limiting Their Deployment (Presentation at Strategies in Light), U.S. Department of Energy
    d. Technology and Market Assessment of Networked Outdoor Lighting Controls (Report, NEEA, 2011)

2) Significant municipal pilot projects and deployments
    a. LED Street Light Conversion Project (including networked outdoor lighting control), San Francisco Public Utilities Commission (2014)
    b. LED Street Light Wireless Control Pilot Project, San Francisco Public Utilities Commission, 2014
    c. Street Light Monitoring System, Glendale, AZ

3) Significant utility pilot projects and deployments
    a. Florida Power & Light Selects Silver Spring Networks for North America's Largest Networked Street Light Deployment (Press Release), Florida Power & Light (2014)

4) Significant standards development organizations and relevant documents
    a. ANSI C136 committee, which develops standards for Roadway and Area Lighting
        i. C136.10—Locking-Type Photocontrol Devices and Mating Receptacles—Physical and Electrical Interchangeability and Testing
        ii. C136.41—Dimming Control Between an External Locking Type Photocontrol and Ballast or Driver
        iii. C136.48 – TBD (Remote Monitoring and Control)
        iv. C136.50 – TBD (Revenue Grade Energy Measurement)
    b. ANSI C137 committee, which develops standards for Lighting Systems
    c. National Transportation Communications for ITS Protocol, which develops standards for electronic traffic control equipment
        i. 1213 - NTCIP Objects for ELMS
    d. 3rd Generation Partnership Project, which develops standards that define 3GPP technologies
        i. LTE
        ii. LTE-Advanced

5) Significant industry consortiums
    a. LonMark International
    b. TALQ Consortium
    c. Wi-SUN Alliance
    d. ZigBee Neighborhood Area Network (NAN)
    e. AllSeen Alliance

6) Design Guidance
    a. Guidelines for The Implementation of Reduced Lighting on Roadways, U.S. Department of Transportation (2014)
    b. Public Streetlight Design Guide, City of San Jose, CA (2011)

7) Specification Guidance
    a. Model Specification for Networked Outdoor Lighting Control Systems, U.S. Department of Energy (last updated 2014)

DOE SSL Program
PNNL Advanced Lighting Team

Emerging Technology Primer: Networked Outdoor Lighting Control Systems Fall 2014

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