Wireless Lighting Control: The Bright Road Ahead
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As efficient and cost-effective solutions make their way to the market, wireless lighting control continues to increase in popularity, offering new growth models and consumer experiences. A key advantage of radio frequency (RF)-based lighting control is that eliminates the need to run expensive copper wire to every control point, sensor and lamp in order to enable advanced and flexible control of the lights. Today’s low-power wireless system-on-chip solutions are low enough in cost to be inserted in every lamp or light bulb. They also consume low enough power to enable lamps to meet AD-DC offline standby standards, and allow sensors and remote controls/switches to run for years on a single battery or energy harvesters. This article discusses the design considerations for a low-power RF (LPRF) lighting control system, and describes some benefits and limitations of today’s openly available technologies.

What makes wireless control attractive?
The main advantage of wireless lighting control is the cost reduction that comes from not having to put in any cabling associated with the control of the lights. Adding to this, the flexibility that comes from advanced control and the energy savings from connecting to sensors and smart grid makes an attractive from return on investment. With the new user interfaces and functionality made possible by connecting the wireless lighting control network to smartphones, tablets, remote controls and other devices, it is also gaining momentum in the home and self-installed markets.

Figure 1: Low-power wireless lighting control
**Advanced control**

Wireless control of lights enables the lights to be grouped independently of wiring. This can lead to more intuitive control that can be adapted to changes in the lighting needs. Imagine the process of moving a wall in an office environment. After the move, in order to allow the switch in one room to control the lights in that room, the wiring would have to be re-done to the affected lamps and if the switch was located on the wall to be moved, it would also have to be re-wired. With wireless control of the lights and wireless switches, a simple re-grouping of the lights would be all that is needed. In a home setting, colored LED lamps and pre-set scenes can be used to easily create the right ambiance with lighting. For rooms with multiple entrances, several switches can be used to control the same group of lights. Switches can be moved around freely, and be supplemented with portable remote controls to allow easy-access to advanced features.

**Connecting to sensors**

Adding sensors to the wireless lighting control network enables truly intelligent lighting solutions – unleashing great benefits in energy consumption and user experience. Passive infra-red sensors can be used to switch lights off in unoccupied rooms or dim lights when available sunlight only requires a low-intensity light supplement. Low-power wireless sensors are now efficient enough to run on a single battery for years, or even from energy harvesters in some cases. Wireless technology enables sensors to be placed in the ideal location, irrespective of lamps or wiring.

**High-efficiency power conversion for lighting and control**

Unlike incandescent filaments, energy-efficient lighting technologies such as LED and CFL require power conversion from AC, DC or battery sources. The efficiency, power factor, ripple current and other power conversion parameters affect the overall value proposition of energy efficient lighting. Imagine installing efficient lighting but throwing the efficiency gains in lighting drivers with poor quality power conversion.

**Connecting to Smart Grid**

Lighting typically accounts for more than 25 percent of the energy consumption of a commercial building. With the proliferation of ZigBee® Smart Energy enabled electricity meters, the real-time information on consumption and pricing can be used to cut peak consumption by dimming lights almost unnoticeably for a period. The financial benefits will be ensured through dynamic pricing of electricity, and the environmental benefits are significant.

**Connecting to the Internet, phones, tablets and other devices**

Smartphones and tablets are becoming omnipresent, and there is rapid growth in user acceptance of using these devices as our interface to anything electronic. This makes smartphones and tablets a natural extension of a lighting control system. A simple Ethernet/WiFi/USB to low-power wireless gateway can ensure that users have access to all features of their lighting control system through their Smartphone/tablet. This was demonstrated by TI at Mobile World Congress this year with the Android-based ZigBee Home Automation-based lighting application, running on a mobile platform. [Click here](#) for more information.

Apart from being a very capable and intuitive remote control for lighting, such a gateway can enable homeowners to set up lights to turn on and off at specific times of day when they are absent, for
increased security. Imagine that all your outdoor lights turn on the second your smartphone comes within range of your home WiFi.

Network considerations

Mesh networking and range
Due to the low power requirements of the network and regional RF regulations, it is not ideal to make a wireless lighting network topology that requires all nodes (lights, switches, sensors and remotes), to be in RF range of a single coordinating node in the network. The solution is an even distribution of routing nodes throughout the building to extend range without increasing power – mesh networking.

Lamps make up the ideal backbone for a wireless mesh network. They are distributed evenly throughout the house and have available a stable supply of electricity that can be used to route packets around the house or building. This enables the sensors, switches and remotes to be able to have very long battery life with little radio use, as there is always a light nearby that is listening when it sends its data. Key characteristics of a good mesh network are that it is self-forming and self-healing and can deal effectively with a high number of nodes in diverse topologies.

As compared to a radio at 2.4 GHz, sub-1 GHz radios give longer range and better penetration for the same amount of power. For this reason, sub-1 GHz solutions are often preferred for outdoor applications such as street and city lighting. There is also generally less interference to deal with in the sub-1 GHz bands as WiFi and microwave ovens are not present there. However, radio interference is present in all the open ISM bands, and it is important that the radio has sufficient output power and a receiver with good selectivity (ACR) and blocking to filter out unwanted signals (see this previous EE Times educational piece for more information). However, there is no globally available sub-1 GHz frequency band. This forces regional specific end-products – for example 868 MHz in Europe and 915 MHz in the US.

Commissioning
Commissioning with traditional lighting is intuitive, but expensive – which ever lights are connected after a breaker switch will be controlled by that switch. Wireless adds flexibility to which switches and remote controls control which lights, but this adds complexity in the installation process that has to be mitigated by offering an intuitive procedure for connecting lights, sensors and switches.

For systems targeting professional installations, a USB dongle and a good graphical PC software tool can be a good way of enabling complex connections to be made in an intuitive manner. However, the use of a PC and software requires a trained installer in the general case. For self-installed systems off the shelf of a supermarket, a simpler and intuitive method must be applied. One approach is to use proximity-based commissioning. Holding the switch or remote control close to the light(s) it is to control while pressing a button. The radio signal receive strength (RSSI) of the packets sent from the light to the switch or remote control is used to determine proximity and qualify the commissioning. A successful implementation of this can for example be found in the Philips SmartLink™ system, here.
Security
Wireless lighting control systems require different levels of security depending on the purpose and location of the system. A home lighting system used mainly to set the correct ambiance easily will have less strict requirements than city lighting or a building’s security lighting. Most low-power wireless chipsets today support 128-bit AES encryption of the packets sent over the air, which is generally sufficient to avoid sniffing or injection. Authentication and key-exchange when new devices are to enter the network are more challenging and are handled differently depending on the level of security needed and the mechanisms available.

Designing LPRF into lamps
With the decreasing solution size, increasing integration and low cost of low power wireless chipsets, it is now viable to include them in a wide range of lamps to provide direct control of each. With the long lifetime of LED and fluorescent-based lighting, it is natural to integrate the wireless functionality with the light source itself.

High temperature
Although modern and more efficacious light sources generate less heat than traditional light sources (such as incandescent and HID), LED- and CFL-based lamps contain driver and control electronics and still create high temperature environments. This becomes particularly challenging in compact designs such as compact fluorescent where the cooling situation surrounding the lamp is generally not controlled.

Also, LEDs must conduct their heat away (as opposed to radiation of heat in the case of incandescent and gas discharge technologies). This compounds the problem of keeping the heat away from the driver and control electronics. The low power wireless and driver control ICs will sustain high temperatures during operation of the lamp. It is important that the IC’s support operation at high temperature to ensure correct operation, good RF and high power quality performance. Chipsets qualified at 85°C are typically not an option, 125°C is sufficient for most applications, unless a very compact fluorescent designs exposes the electronics to even higher temperatures. However, it is also important that the devices and related external components are qualified for a lifetime at that high temperature that is as long as the expected lifetime of the bulb.

Energy Efficiency
Standby current consumption of electronic devices has been a much discussed topic over the last years. There is a continued tightening of the requirements in regional legislation, which also apply to wirelessly controlled lamps. When the lamps are in standby with the light turned off, the radio is in receive mode all or a duty cycled portion of the time. Although low-power wireless radios regardless of technology typically consume less than 10 mW in receive mode, there can be substantial loss in the power supply. Care should be taken to design a power supply to the wireless device that meets the desired targets for standby current consumption. The lamp or luminaire must also meet a minimum lumens/watt requirement, so the efficiency of the lighting driver is critically important.
Small solution size
Like everything else in the electronics components segment, low-power wireless chipsets are shrinking
every day. SoCs like TI’s CC2530 with integrated radio, microcontroller, flash, RAM and peripherals for
lighting systems fit in a tight, 6x6 mm package to meet this growing trend. Apart from the high
frequency crystal and decoupling capacitors, the balun and antenna is all that is required for a complete
solution. The balun transforms the RF signal between balanced and unbalanced, and can take the form
of a network of passives, PCB microstips or a small chip.

The antenna represents the widest range of design choices and the size of the solution can vary greatly.
Antennas can take the form of PCB traces, whips, wires or integrated chips with associated solution size,
cost, efficiency and directionality. It should be noted that the lower the RF, frequency, the longer the
antenna. For applications with restrictions on solution size, this can be an important factor in choosing
between sub-1 GHz and 2.4 GHz frequency bands.

Figure 2 - CC2531 2.4 GHz complete USB nano-dongle for IEEE 802.15.4 (1.65 x 0.95 cm)

The small solution size also makes it important to make sure that both MCU system and radio are robust
with respect to noise so that they can operate well even in the close presence of switching power
supplies. The power converter switching frequency will also affect the size of the power magnetics.
Higher switching frequency will result in a smaller size of the lighting driver (power converter). However
higher switching frequencies come at the cost of lower efficiency and potentially higher undesired
electromagnetic emissions.
Designing LPRF into sensors and remote controls
To take advantage of freedom of placement and mobility – and to avoid pulling wires – sensors, switches and remote controls in a lighting control system are generally battery or energy-harvesting powered. To maximize battery life or enable them to run off energy harvesting sources, the radio should be used as little as possible, and should stay in a low-power sleep mode the majority of the time. Remote controls and switches typically only wake up on key presses and perform the required transaction before going back to sleep. Sensors typically wake up periodically using a low-power timer in order to perform sensor measurement using its internal ADC or they use an internal low-power comparator to be awakened only when a certain threshold value is reached. The system should be designed such that the reporting of these values over the radio is done as seldom as possible. The current consumption in these sleep modes will generally dominate the energy consumption of these devices and be the determining factor for battery lifetime.

Available technologies
ZigBee and 6LoWPAN are two publically available low power radio standards supporting the widely available 2.4 GHz IEEE 802.15.4 radios. These IEEE 802.15.4 radios have been shipped in the 10s of millions since the first radio was launched in 2004. Its robustness, low power and simplicity have driven it into applications such as metering (ZigBee Smart Energy), consumer remote controls (ZigBee RF4CE) and industrial control (Wireless HART and ISA 100).

ZigBee technology
ZigBee is a mesh network software stack based on IEEE 802.15.4 radios, with a set of application layer profiles on top.
These profiles ensure that there are standard devices defined with standard telegrams to send commands such as “on” or “off” in the case of a light. The profiles also provide standard solutions to aspects like commissioning and security. This ensures that lights from one vendor, for example, will interoperate with switches from another vendor. The ZigBee Alliance has a certification process to ensure specification compliance and interoperability between different vendors. This enables you to attain a ZigBee enabled wall-plug or PIR sensor from another vendor if needed. Currently, the Home Automation and Building Automation profiles are the ones most relevant for lighting applications, but other profiles are under development to cover other aspects of lighting control.
6LoWPAN

6LoWPAN is a header compression scheme for IPv6 packets. In combination with the RPL mesh network routing protocol, it provides an efficient IP-based stack for low power wireless networks. These open standards are defined by the IETF and promoted by the IPSO Alliance. 6LoWPAN also forms the basis for the ZigBee IP stack on which the Smart Energy 2.0 profile specification is built.

![6LoWPAN Architecture Diagram]

Due to its native IP addressing, gateways from a 6LoWPAN network to the internet can be made simple and transparent. This can provide a reasonably seamless interface to internet/tablet/phone or existing IP-based lighting/building control solutions.
The challenge with 6LoWPAN in lighting control solutions today is that there is currently no application layers defined. This means that though the networking is well-defined and based on open standards, standards-based solutions for aspects such as commissioning and security are yet to be developed. As there is no application layer specification, and no standards body certifying solutions, there is currently no clear path to make products which are interoperable with those of other vendors.

**A bright road ahead**

With falling cost, and availability of suitable hardware and software solutions, the wireless lighting control market is ready for prime time. Design choices such as frequency band and protocol stack can vary based on the type of lighting system being implemented. However, range, commissioning, security and interoperability should be considered in any and all systems. When integrating drivers and control into a lamp, engineers must keep key parameters in mind, including: size, efficiency, operating temperature and lifetime of the electronics. Following these parameters and the discussed design considerations will lead to successful, innovative lighting products that will undoubtedly light the way for all-new use cases and business models. It’s surely a bright road ahead!

**About the author**

_Peder Rand leads strategic marketing efforts for TI’s low power RF IEEE 802.15.4 and ZigBee products._

(For more information on these and other TI lighting products, visit [www.ti.com/lprf](http://www.ti.com/lprf) and [www.ti.com/lighting](http://www.ti.com/lighting).) Peder has worked for Chipcon/TI since 2005, holding positions as digital designer, project manager and systems engineer. He holds a Masters’ Degree in Computer Science from the Norwegian University of Science and Technology.