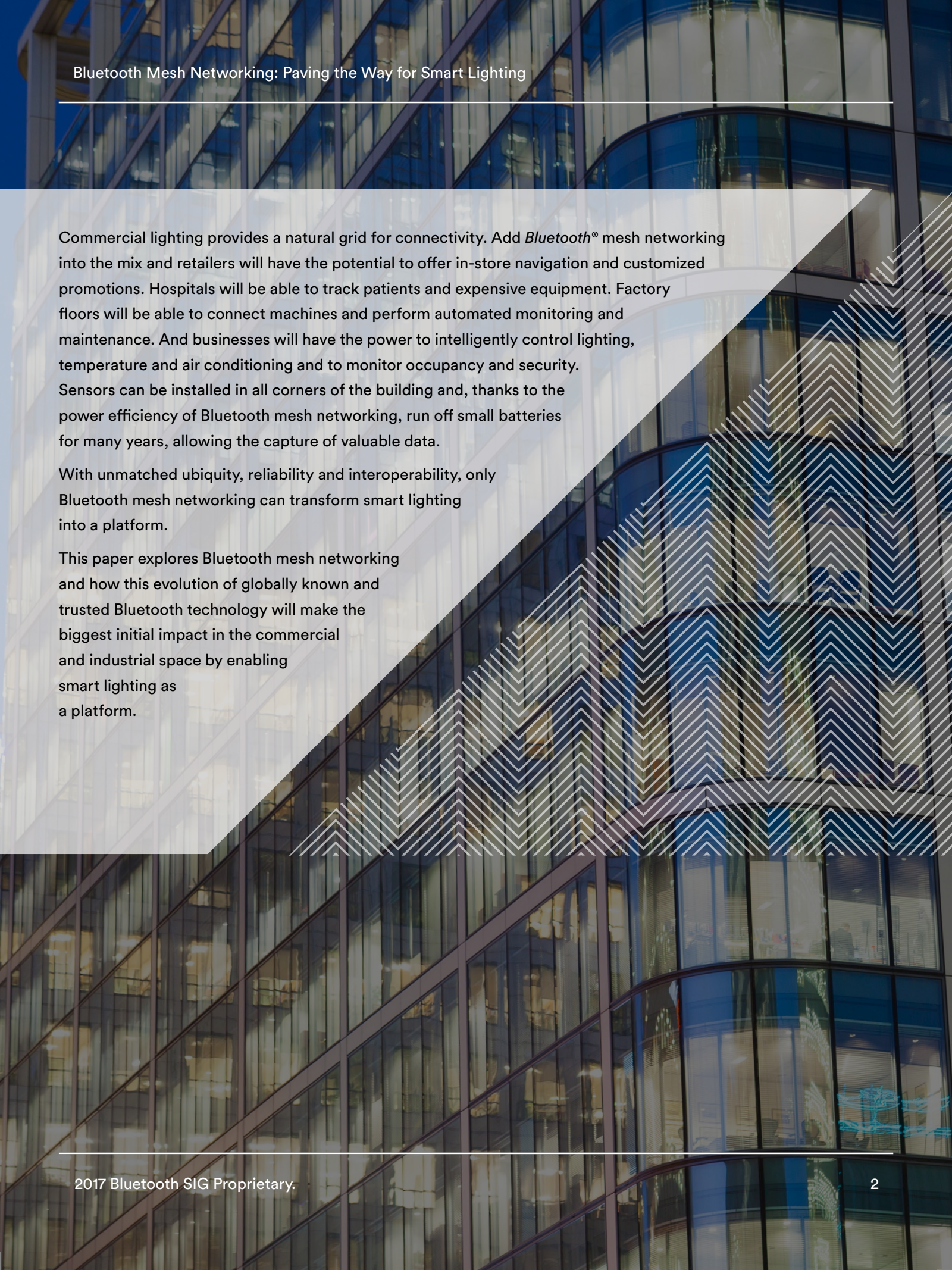
Bluetooth®

# Bluetooth mesh networking: paving the way for smart lighting



Commercial lighting provides a natural grid for connectivity. Add *Bluetooth*® mesh networking into the mix and retailers will have the potential to offer in-store navigation and customized promotions. Hospitals will be able to track patients and expensive equipment. Factory floors will be able to connect machines and perform automated monitoring and maintenance. And businesses will have the power to intelligently control lighting, temperature and air conditioning and to monitor occupancy and security. Sensors can be installed in all corners of the building and, thanks to the power efficiency of Bluetooth mesh networking, run off small batteries for many years, allowing the capture of valuable data.

With unmatched ubiquity, reliability and interoperability, only Bluetooth mesh networking can transform smart lighting into a platform.

This paper explores Bluetooth mesh networking and how this evolution of globally known and trusted Bluetooth technology will make the biggest initial impact in the commercial and industrial space by enabling smart lighting as a platform.

# table of contents



## Contributors


**Martin Woolley**
*Author*

**Sarah Schmidt**
*Graphic Designer*

# 1.0 introduction

## 1.0 Introduction

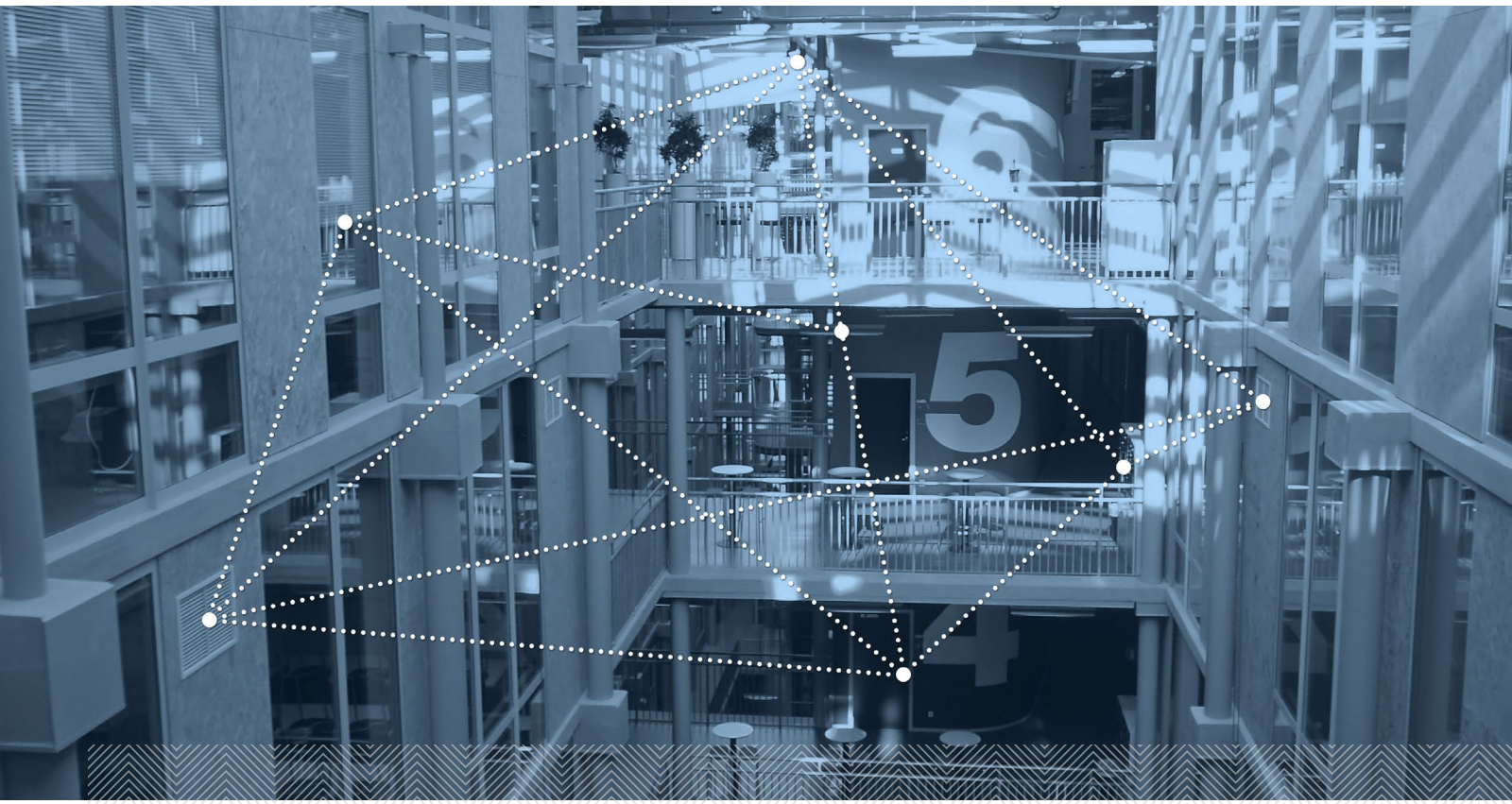
The chances are, you've heard of Bluetooth. The trademark is recognised by over 92% of people around the world, and it's a technology which is familiar to billions of consumers and loved by developers.

Bluetooth has enabled wireless communication between a myriad of types of devices for seventeen years, since the initial version was released in 2000. But what does Bluetooth have to offer the world of commercial lighting? And how can a technology, originally designed to replace serial cables and support applications like wireless audio, satisfy the demanding requirements of complex wireless lighting and building automation systems?


*Bluetooth Brand Equity Study 2016, Lux Insights.

# 2.0 systematic evolution

## 2.0 Systematic Evolution




Bluetooth has not stood still since its initial incarnation. It's been continuously and systematically developed to keep pace with market demands and to enable innovation.

Bluetooth Basic Rate/Enhanced Data Rate (BR/EDR), the original flavour of Bluetooth, was released in 2000. It quickly became the dominant technology for wireless audio products.

In 2010, Bluetooth Low Energy (LE) provided the next major step forward. Its impact has been substantial and widely felt, most notably in smartphones and tablets, as well as in health and fitness, the smart home and wearables categories.

The summer of 2017 brought the addition of mesh networking support to Bluetooth. This is a major step forwards for Bluetooth technology, positioning it for use across a range of new applications and industry sectors, including commercial lighting.

# 3.0
# a tale of topologies

## 3.0 A Tale of Topologies

The evolution of Bluetooth is, in some ways, a story about topologies.

Bluetooth BR/EDR allows one device to communicate with another, using a simple point-to-point connection between the two devices. It's like having an invisible serial cable. We call this a point-to-point topology.

Bluetooth LE supports point-to-point topologies, but it also allows a device to broadcast data so that one broadcasting device can communicate with many listening devices, supporting one-to-many device communications. Bluetooth beacons operate in this manner.

*Figure 1 - Bluetooth BR/EDR supports a point-to-point topology*

Bluetooth mesh supports complex, many-to-many communication between devices so that any device in the mesh network can communicate with any other device in the network. Furthermore, devices do not have to be in direct radio range of each other. Messages are relayed across the network in a series of "hops", and networks can therefore span very large physical areas.

*Figure 2 - Bluetooth LE and one-to-many device communication*

The mesh protocol stack uses Bluetooth LE for radio communications and inherits its power efficiency, low latency and other traits that have made Bluetooth LE so popular.

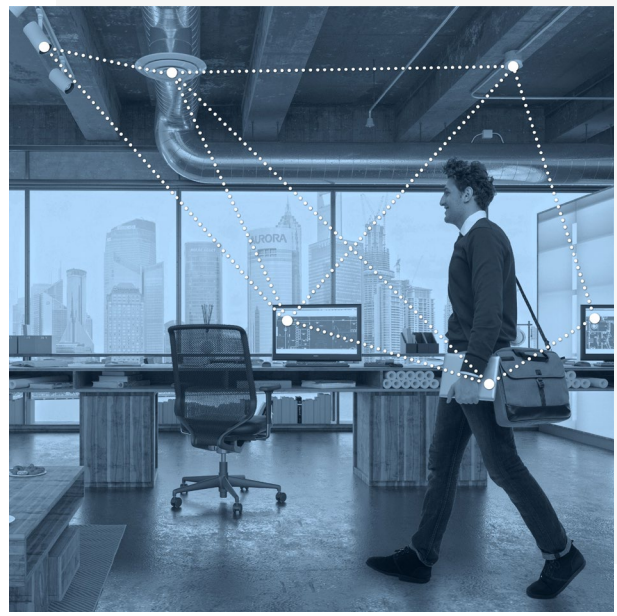


*Figure 3 - Bluetooth mesh and many-to-many device communication*

# 4.0 Bluetooth mesh and lighting

## 4.0 Bluetooth Mesh and Lighting

What does Bluetooth mesh offer the world of lighting? For that matter, what does any wireless technology offer with respect to lighting?

### The Case for Wireless Commercial Lighting Systems

The basic business case for wireless commercial lighting systems is well understood and has been written about extensively. Amongst the most fundamental arguments for wireless lighting systems in commercial buildings are several key points:

**Wired Systems are Expensive**

Both the cost of materials and labour can be significantly higher when installing a wired system rather than a wireless one. There's likely to be more disruption to business operations too, especially if the installation takes place in an office that is already up and running.

**Wired Systems are Inflexible**

In buildings where tenants and their requirements change frequently, it's more difficult to respond to those changes with wired systems and certainly more difficult to respond quickly, which in today's business environment is essential and may even act as a differentiator for a landlord seeking to entice dynamic businesses as tenants.

**Wired Systems have Limited Extensibility**

Lighting systems often do more than just provide basic lighting capabilities. For example, it may be necessary to integrate the lighting system with various types of sensors in the building. Sometimes this is a requirement of the applicable building regulations or energy efficiency standards. It's possible to achieve this with wired systems, but often this requires separate control equipment to orchestrate sensor and lighting behaviours.

Wireless systems have the potential to turn lighting systems into much more than just a lighting system. We'll examine that statement below.

## The Value of Bluetooth

So, what's the advantage of using a wireless lighting system supported by Bluetooth technology? There are a range of issues to consider, including some which are purely technical, some which concern features of the technology specifically included to support lighting products and there are a variety of business issues too.

**Wireless Lighting is Technically Challenging**

Creating a wireless communications technology which can support reliable, responsive, secure and scalable wireless lighting systems requires a number of challenging problems to be solved. Bluetooth mesh was designed to address problems of this sort, and to a significant extent, specifically with commercial lighting systems in mind.

Life gets particularly challenging for the wireless protocol designer when multicast operations involving groups of devices need to be supported. Consider a wireless light switch which operates a set of a dozen lights. Each one of the lights controlled by the switch must come on when the switch is flicked by the user, with no discernible delay, and they must turn on at exactly the same time. This is easy to say but harder to achieve, especially when walls and other environmental factors can attenuate signals or cause interference. It gets even harder when we replace the light switch in our scenario with a wireless dimmer switch, which must provide smooth, responsive and precisely synchronised control of the lights in a way which feels natural and pleasing to the user. Wireless technologies, originally designed for much simpler use cases, such as so called smart thermostats, will struggle to meet these requirements.

When Bluetooth mesh was designed, reliability and support for multicast operations involving groups of

devices operating in harmony were top of the list of requirements (alongside others, such as security).

**Bluetooth Mesh Lighting Features**

Bluetooth mesh is a full stack solution, spanning radio communications at the bottom of the stack and application-specific behaviours at the top. Lighting is regarded as an application in the world of Bluetooth mesh. By including features specifically for lighting systems, as well as other applications, Bluetooth mesh is far more than just a wireless data communications system. It supports common lighting requirements "out of the box" and ensures interoperability across products from different vendors. All mesh application behaviours are implemented using software modules known as models. A series of standard models have been defined by the Bluetooth SIG, and these are selected from to meet a product's distinct requirements. This makes it easy for lighting products to include other non-lighting features, such as support for sensors, and for those features to work directly with the light's primary features in a fully integrated manner, without the need for external controllers.

### The Value of Bluetooth: It's a Standard and a Global Brand

Bluetooth technology is a standard which spans all layers of a full protocol stack. Furthermore, it's a standard which is formally supported by over 32,000 companies, all of whom joined the Bluetooth SIG to express their support for the standard and, in many cases, to get involved and contribute their expertise. The number of companies supporting a standard is one measure of a standard's value.

Standardisation and widespread adoption of a standard has immediate business value. One of the primary drivers behind a standard like Bluetooth is to foster interoperability across manufacturers at every level, from radio communications right up to the specific application behaviours that a given type of product must exhibit. This degree of interoperability produces a "just works" experience for users and generates confidence in products.

The benefit of Bluetooth technology being a full stack standard should not be underestimated. Wireless technologies that comprise some layers from one standard and others from another can find themselves constrained by one of the standards they are dependent upon and unable to progress their roadmap. Bluetooth has no such constraints.

The development of Bluetooth mesh has further advanced the Bluetooth tools, standards definition and testing processes developed over the last 20 years. All new developments in Bluetooth technology benefit from this heritage. And Bluetooth mesh sits on top of Bluetooth LE. Bluetooth LE is already mature and well tested.

## The True Wireless Lighting Opportunity - Lighting as a Platform

A Bluetooth mesh wireless lighting system will yield the business and technical benefits described above. But the more interesting and potentially substantial opportunity, which a Bluetooth mesh lighting system offers, is that installing such a system equips the building with a wireless network and creates a distributed platform for other wireless building services. Lights and switches are microcontrollers with a Bluetooth mesh communications capability and software which controls what those devices can do. Software can be upgraded and added to so new capabilities, which exploit Bluetooth, can reside within the lighting system.

Imagine lights which can act as Bluetooth beacons, allowing smartphone applications to help visitors find their way around a building. Imagine a lighting system which can pinpoint the location of people and physical assets within the building. Imagine an automation system which can use occupancy data and personal preferences to orchestrate changes across multiple systems, creating an optimised and personalised building environment. Imagine a lighting system which can collect a vast range of types of data from building sensors and make it available for analysis and exploitation. These are a few of the possibilities that stem from installing a Bluetooth mesh lighting system and using it as a platform for other services.

# 5.0 Bluetooth mesh technology overview

## 5.0 Bluetooth Mesh Technology Overview

In this section, we'll explore the most fundamental aspects of Bluetooth mesh and gain an understanding of the technology's most important characteristics and terminology.

*Figure 4 - Lighting Node consisting of three Elements*

### Devices, Nodes, Elements and Provisioning

Devices which are part of a mesh network are called nodes, and those which are not are called unprovisioned devices. The process which transforms an unprovisioned device into a node is called provisioning. Provisioning is a secure process that typically involves a smartphone application which will issue the unprovisioned device with a series of security keys that allow it to participate in the network. Once a device has those keys, it becomes a node.

Some nodes are more complex than others and may have more than one independently controllable part. Such parts are called elements. A lighting unit with four independent LEDs is an example of a node comprising four elements.

### Messages

Nodes in the mesh network communicate and interact with each other using messages. Elements contain

state values, which reflect or allow the control of some physical aspect of that element, such as whether it is currently switched on or off. Messages allow state values to be queried by another element or changed. Changing a state value is often accompanied by a change the user can observe, such as a light switching on. Messages therefore represent various types of operations a node may initiate.

## Addresses

Messages are sent from and to an address of some kind. Bluetooth mesh defines three types of addresses.

A unicast address uniquely identifies a single element. Unicast addresses are assigned to devices during the provisioning process.

A group address is a multicast address which represents one or more elements. Group addresses will be established by the primary user via a configuration application and usually reflect the physical arrangement of a building and perhaps correspond to each of its rooms.

A virtual address also identifies a collection of elements, but acts much like a label which has been associated with an element. Virtual addresses will often be assigned in advance by manufacturers and might be used for scenarios, such as sending a message to all vending machines in the building, regardless of the room they are in.

## Publish and Subscribe

Bluetooth mesh uses a message-oriented communication pattern known as publish-subscribe.

The act of sending a message is known as publishing. Elements are configured to select messages sent to specific addresses for processing, and this is known as subscribing.

Typically, published messages will be addressed to group or virtual addresses.

The use of group and virtual addresses with the publish/subscribe communication model has the benefit that removing, replacing or adding new nodes to the network does not require reconfiguration of other nodes. Imagine we have a group address for all lights on the third floor of our building called “Third Floor Lights”. Each light on the third floor has been configured to subscribe to this address. We also have a switch in the reception area which publishes ON and OFF messages to the Third Floor Lights address. Consider what would be involved in installing an additional light on the third floor. The new light would be added to the network using the provisioning process and configured to subscribe to the Third Floor Lights address. No other nodes would be affected by this change to the network. The switch will continue to publish messages to Third Floor Lights as before and the new light will respond alongside the other lights.

## Models

Models define and implement the message types, state values and associated behaviours governing a particular aspect of a device. A device’s total set of capabilities and behaviours is a consequence of the collection of models it implements. There are three categories of model types, namely client models, server models and controller models (which contain both client and server parts). Server models contain state values, whereas client models do not. In all cases, models publish and respond to a variety of defined message types, which act upon or report server state values.

There are currently four classes of models, including lighting, sensors, “timing and scenes” and generics. The lighting models support sophisticated, modern lighting systems. Sensor models support all manner of sensor type and allow the building of sensor networks. Timing and Scenes models are used in automation scenarios. Generic models are the basic building blocks and define the most fundamental types of functionality that a

device might have, such as the ability to have a simple on/off state or the ability for a state (e.g. brightness) to be set to a certain level.

**Generic Models**

Examples of generic server models include the Generic OnOff Server and the Generic Level Server.

As suggested by the name, the Generic OnOff Server includes a state value which indicates whether the host element is currently on or off and defines messages which can both get and set that state value. In other words, it allows other mesh nodes, like light switches, to send messages which cause the light to switch on or off.

The Generic Level Server allows the representation and control of continuous level quantities, such as, but not limited to, brightness levels in lights. To reinforce the point of generic models, these common concepts apply to numerous types of devices, not just lights, and therefore can be used to meet the requirements of a great many product types.

**Lighting Models**

The various lighting server models provide access to and control of a range of lighting product capabilities and characteristics, such as on/off, level, colour, temperature, lightness, lightness range, hue, saturation, chromaticity coordinates and more. The states representing these concepts have defined state transitions, which may be triggered by messages received from clients. States can be bound to other states so that a change in one produces a change in the other. Complex lighting behaviours may be supported in this way.

## Bluetooth Mesh in Action

**Message Publication and Delivery**

A network which uses Wi-Fi is based around a central network node called a router, and all network traffic passes through it. If the router is unavailable, the whole network becomes unavailable.

In contrast, Bluetooth mesh uses a technique known as managed flooding to deliver messages. Messages, when published by a node, are broadcast rather than routed directly to one or more specific nodes. All nodes receive all messages from nodes in direct radio range and, if configured to do so, will relay received messages. Relaying involves broadcasting the received message again, so that other nodes, more distant from the originating node, receive the message broadcast.

**Multipath Delivery**

An important consequence of Bluetooth mesh's use of managed flooding is that messages arrive at their destination via multiple paths through the network. This makes for a highly reliable network, and it is the primary reason the Bluetooth mesh networking design uses a flooding approach rather than routing. Multipath delivery is inherent in the design of Bluetooth mesh and requires little effort to plan and set up.

**Managed Flooding**

Bluetooth mesh networking leverages the strengths of the flooding approach and optimises its operation, such that it is both reliable and efficient. The measures which optimise the way flooding works in Bluetooth mesh networking are behind the use of the term "managed flooding". Those measures are as follows:

**Heartbeats**

Heartbeat messages are transmitted by nodes periodically. A heartbeat message indicates to other nodes in the network that the node sending the heartbeat is still active. In addition, heartbeat messages contain data which allows receiving nodes to determine how far away the sender is, in terms of the number of hops required to reach it. This knowledge can be exploited with the time-to-live (TTL) field.

**TTL**

TTL is a field which all Bluetooth mesh Protocol Data Units (PDU) include. It controls the maximum number of hops over which a message is relayed. Setting the TTL allows nodes to exercise control over relaying and conserve energy by ensuring messages are not relayed further than required. Heartbeat messages allow nodes to determine what the optimum TTL value should be for each message published.

**Message Cache**

A network message cache must be implemented by all nodes. The cache contains all recently seen messages and if a message is found to be in the cache, indicating the node has seen and processed it before, it is immediately discarded.

**Friendship**

The most significant optimisation mechanism in a Bluetooth mesh network is provided by a concept known as friendship. Nodes with a plentiful supply of power may form a partnership with nodes which are highly constrained with respect to power (e.g. they run off small batteries which must last for years). The former is termed a friend node and the latter a low power node. Friend nodes provide a message store and forward service to associated low power nodes. This allows low power nodes to operate in a highly energy-efficient manner with minimal use of the radio required for their operation.

## Security

Security in Bluetooth mesh networking is concerned with the security of more than just that of individual devices or connections between peer devices; it's concerned with the security of an entire network of devices. Consequently, security in Bluetooth mesh networking is mandatory.

The following fundamental security statements apply to all Bluetooth mesh networks:

| | |
|---|---|
| **Encryption and Authentication** | All mesh messages are encrypted and authenticated. |
| **Separation of Concerns** | Network security, the security of individual applications and device security are addressed independently. |
| **Area Isolation** | A Bluetooth mesh network can be divided into subnets, each cryptographically distinct and secure from the others. |
| **Key Refresh** | Security keys can be changed during the life of the mesh network via a Key Refresh procedure. |
| **Message Obfuscation** | Message obfuscation makes it difficult to track messages sent within the network and, as such, provides a privacy mechanism to make it difficult to track nodes. |
| **Replay Attack Protection** | Mesh security protects the network against replay attacks. |
| **Trashcan Attack Protection** | Nodes can be removed from the network securely, in a way which prevents trashcan attacks. |
| **Secure Device Provisioning** | The process by which devices are added to the mesh network to become nodes is itself a secure process. |

## Smartphones and Tablets

It's hard to find a smartphone or tablet which does not support Bluetooth LE. Bluetooth mesh, which uses Bluetooth LE as its underlying radio communications component, makes it possible for current in-market smartphones and tablets to securely interact with mesh nodes. Mobile devices are used in the provisioning process to add new nodes to the network, but may also be used to provide user interfaces for monitoring and controlling nodes from anywhere in the building.

# 6.0 conclusions

## 6.0 Conclusions

Bluetooth mesh networking brings the multi-vendor interoperability, low power and low latency pedigree of Bluetooth LE to the world of commercial lighting. It's designed to allow the creation of reliable, responsive, secure and scalable wireless lighting systems. These systems can evolve to act as a platform for distributed wireless building services that will deliver business benefits by helping establish efficient and thoroughly understood building environments.

## References

[1] Bluetooth Mesh Technology Overview
See https://www.bluetooth.com/~/media/files/marketing/mesh%20technology%20overview.ashx

[2] Bluetooth Mesh Specifications
See https://www.bluetooth.com/specifications/mesh-specifications