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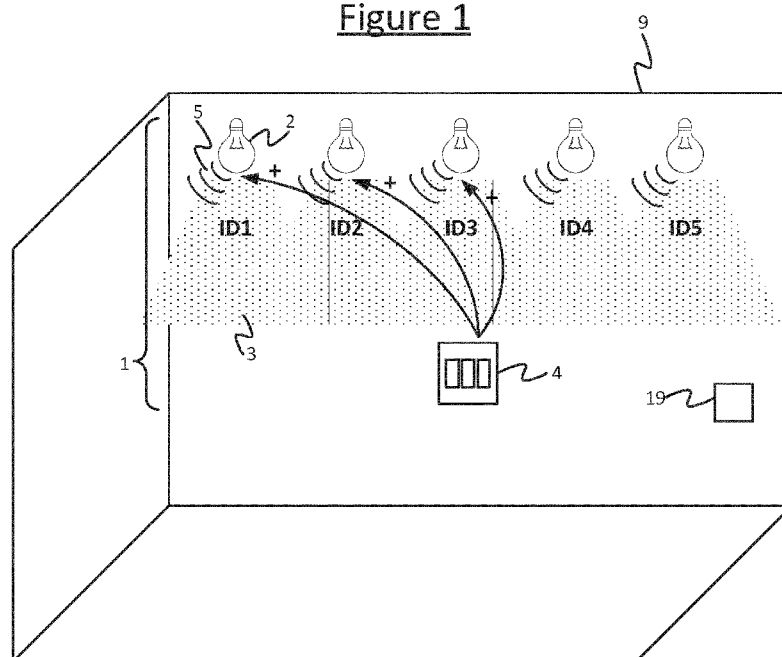
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Figure 1



(57) **Abstract:** An illumination source for emitting visible illumination, and arranged to include a VLC signal comprising an ID of the illumination source modulated into the illumination. A separate control device is able to control the illumination source, and a light sensor is comprised by or placed substantially collocated with the control device. A VLC decoder is configured to detect the ID from the sensed VLC signal. The illumination source is further configured to transmit to the control device an indication of at least one capability of the illumination source in the form of at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application. Based on the supplied indication, it is determined whether the control device can support the indicated capabilities, and on condition thereof, an association is formed between the control device and the illumination source based on the ID received in the VLC signal, thereby enabling the control device to control the illumination source.



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COMMISSIONING OF ILLUMINATION SOURCES

TECHNICAL FIELD

The present disclosure relates to forming an association such as a ZigBee binding between a control device and an illumination source in order to enable the control device to control the illumination source.

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BACKGROUND

Lighting systems are known that use visible light based wireless communication to communicate with other devices, e.g. US patent application US2010/0209105 A1 discloses a wireless lighting system wherein Visible Light Communication (VLC) is used to enable light sources to communicate with VLC terminals. More particularly it discloses a medium access technique that allows a plurality of VLC terminals to access the VLC channels using slotted access that ensures efficient and stable communication. In addition lighting systems are known that use radio based wireless communication rather than VLC based communication.

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A wireless lighting system enables the control and automation of lighting operations via control devices such as sensors and switches which control the lighting devices (e.g. individual lamps) by communicating over a wireless network such as a ZigBee or Thread network. For example, ZigBee devices are characterized by reduced power consumption and cost, together with mesh networking capability, which make them suitable to be used in wireless lighting systems, particularly in retrofitting applications whereby existing lighting devices are replaced with LED lighting devices equipped with ZigBee radio chips.

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In order to properly control the lighting devices in a wireless lighting system, it is required to configure the application-level relationships between the controlling devices (e.g. switches, sensors or room controllers) and the controlled devices (i.e. lighting devices). For example, to enable an on/off switch to send the on/off light command to a light (or a group of lights), an application-level connection needs to be made from the application controlling the on/off switching on the switch to the application implementing the on/off

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function on the lighting device (or group of lighting devices). This application-level connection is usually called “binding” or “pairing”.

Many wireless control network protocols provide a specific commissioning procedure for binding devices to each other. For example, ZigBee specifications define the “finding & binding” flow, described in ZigBee 3.0 Base Device Specifications [BDS] (sections 8.5 and 8.6), which allows devices in the network to discover other devices implementing specific application capabilities (i.e. Clusters) and to bind to them. A similar concept has been described in the specifications of ZCL over IP [ZCLIP].

This type of procedure usually requires that a “special commissioning mode” is invoked on the devices and/or that a trigger such as a push button action is performed on each of the devices that the commissioner wants to bind to each other.

In addition, to enable the sending of control commands to a group of lighting devices (e.g. multiple lights in the same area to be controlled jointly), groups need to be created and associated with the controlling device. Also this procedure requires that a commissioner selects and assigns devices manually to a specific group, based on pre-defined criteria.

The creation of a group in such a system is accomplished by sending an application command (e.g. ZCL Add Group) to one or more interfaces (e.g. endpoints in ZigBee) on receiving devices. This assigns a Group identifier (Group ID) to the intended members of a group. When an interface on a device has been added to a group, it starts processing all the commands addressed to the group, which are identifiable via the Group ID. As an example, if a controlling device such as a switch or a sensor is to control a group of lighting devices, it sends an add group command to the interfaces on the lighting devices it intends to control. Following the successful group creation, all the lighting devices that are part of the group will process the commands addressed to the group.

The application-level configurations (such as binding and group creation in ZigBee) require information related to the controlled device to be delivered to the controlling device, such that the latter can properly set-up the proper configuration. This information includes a unique identifier (ID) for the device such as its network address and the application-layer components implemented (e.g. clusters in ZigBee). For example, a controlling device would need to know the identifiers of the devices to be added to the group and the application-layer components to be bound. Additionally, information on how to create the groups (i.e. which lighting devices belong to which group and which controlling device controls the group behaviour) is required in the system.

Due to the complexity of the process, the application-level configurations described above are typically set-up at system configuration time based on pre-configurations created by the installer of the wireless lighting system. For example, an installer of a ZigBee wireless lighting system would set up each binding and group configuration by going to each single device and providing the application-level configurations required described above.

SUMMARY

This pre-configuration process is conventionally performed manually by a commissioner and involves selection of devices one by one. The procedure of selecting the devices and their configuration is therefore time and resource consuming, particularly for large-scale wireless lighting systems.

In addition to communication via radio signals (such as ZigBee), lighting devices can also leverage visible light communication (VLC) to communicate using optical wireless communication. That is, a lighting device can configure its lighting element (e.g. a string or array of LEDs) to manipulate the emitted light in order to encode digital data which can be received by a device with a VLC decoder.

Given that often the controlling device is found in proximity of the controlled devices (e.g. a switch on a wall below the lights to control), the present disclosure introduces a method to perform automatic configuration of groups and bindings in wireless lighting networks by exploiting the proximity between the devices and visible light communication (VLC) in order to send configuration information via VLC, wherein this configuration information comprises at least an ID of the illumination source, which is needed to form the association (e.g. ZigBee binding). Further the VLC can be used to signal one or more application capabilities of the illumination source, or at least to trigger the control device to query the one or more capabilities from the illumination source. Based on the knowledge of the one or more capabilities obtained in this way, the control device can then determine whether it can support the capability or capabilities in question, and in dependence on this decide whether to form the association or not. Thus VLC can be used to facilitate a more efficient lighting application commissioning process that mitigates the resource-consuming pre-configuration stage discussed above.

According to one aspect of the present disclosure, there is provided a lighting system comprising an illumination source, the illumination source comprising an illumination element for emitting visible illumination to illuminate an environment, and modulator circuitry arranged to include a VLC signal comprising an ID of the illumination source

modulated into the illumination emitted by the illumination element. The system further comprises: a separate control device comprising a controller for controlling the illumination source; a light sensor for sensing the VLC (visible light communication) signal, the light sensor being comprised by or placed substantially collocated with the control device; a VLC decoder configured to detect the ID from the sensed VLC signal; and association-forming logic for determining whether to form an association between the control device and the illumination source enabling the controller of the control device to control the illumination source. The illumination source is further configured to transmit to the control device an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application, and the controller is further configured to receive the transmitted indication and supply the received indication to the association-forming logic. The association-forming logic is configured to determine, based on the supplied indication, whether the controller of the control device can support the indicated capabilities, and on condition thereof, to form said association between the control device and the illumination source based on the ID received in the VLC signal in order to enable said control device to control the illumination source by means of the association.

Said at least one capability may be an optional feature or a requirement, e.g. a requirement in order to work at all, or a requirement with respect to a given specification such as ZigBee.

By way of example, said at least one capability of the illumination source may comprise any one or more of:

- supporting on/off switching control enabling the illumination to be switched on and off by the controller,
- supporting tri-level switching enabling the illumination to be switched between three discrete levels by the controller,
- supporting dimming functionality enabling a dim level of the illumination to be controllable by the controller,
- supporting colour control enabling a colour of the illumination to be controllable by the controller,
- the illumination source having a specified type of sensor operable to send sensor readings to the controller,
- the illumination source having a temperature sensor operable to send sensed temperature readings to the controller,

- the illumination source having a presence sensor operable to send indications of sensed person presence events to the controller,
- a maximum luminous flux of the illumination,
- a maximum or typical power consumption of the illumination source,
- 5 - a luminaire type of the illumination source,
- a lamp type of the illumination source,
- a direction at which the illumination sources is capable of emitting the illumination or range of directions over which the illumination source is capable of emitting the illumination,
- whether the illumination source is capable of moving the direction of the emitted
- 10 illumination,
- the ability to join a group of light sources whereby the group can be controlled jointly by the controller by reference to a common group ID,
- ability to render a respective part of a scene based on an identifier of the scene supplied by the controller,
- 15 - a list of supported light scenes,
- whether the illumination source is capable of being configured with new scenes,
- whether the illumination source has capacity to accept a new scene configuration and/or
- whether the illumination source currently has capacity to accept any more control associations.

20 In embodiments the illumination source comprises an embedded memory storing an application, and an embedded processor arranged to run said application; and said at least one capability may be at least one capability of the application.

In embodiments the controller may be implemented in the form of code stored on storage of the control device and arranged to run on a processor of the device. In

25 embodiments the association-forming logic may be implemented in the form of code stored on storage of the control device or external device and arranged to run on a processor of that device.

Preferably VLC is also exploited as the means by which to send the capabilities of the illumination source. Hence in embodiments, the modulator circuitry is

30 arranged to use VLC to perform said transmission of the indication of said at least one capability, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application, by modulating said indication into the emitted illumination, the controller being configured to receive the indication via the VLC decoder.

Alternatively, said at least one capability may be sent by another interface using another medium than visible light, e.g. a radio, infrared or ultrasound interface.

Other communications between control device and illumination source, and/or any other nodes, may also be conducted via any suitable communication medium, e.g. a wireless medium such as radio, infrared or ultrasound.

In embodiments the illumination source may be configured to perform said transmission by broadcasting said indication of the at least one capability repeatedly without prompt from the control device. E.g. the repetition may be periodic or random.

In embodiments the illumination source is configured to switch between an uncommissioned mode and a commissioned mode, wherein the illumination source is configured to perform said transmission on condition of being in the uncommissioned mode and to switch to the commissioned mode in response to forming said association.

Alternatively, in response to receiving the ID of the illumination source via said VLC signal, the controller may be configured to control the control device to send a request to the illumination source requesting the indication of the one or more capabilities; and the illumination source is configured to perform said transmission by transmitting the indication of the at least one capability to the control device in response to said request from the controller of the control device.

In embodiments, the controller may be configured to determine a received signal strength of the received VLC signal and to supply the determined signal strength to the association-forming logic, wherein said association-forming logic may be configured to form said association on further condition that the measured signal strength is greater than a threshold.

Thus the association is based not only on knowledge of capability, but on the capability of a node that is known to be within a defined proximity. By a node knowing its own capabilities and knowing the capabilities of another node in proximity, this advantageously allows the device to make an inference as regards the application context and to act thereupon. For instance if the user introduces a new switch device into a particular room and there is a VLC-emitting lamp in that room, the proximity and the VLC signal enable a determination, on the basis of the introduction into the room, to determine that the switch device can control the lamp in that room. Then the next time the user actuates the switch, this toggles the lights in the relevant room. As another example, consider a system where the lighting device is a first (smart) lamp capable of detecting VLC signals from other lamps, and the control device (e.g. switch) is configured to return a confirmation back to the

first lamp via another channel (e.g. RF) in event that the association is formed. If the first lamp detects the VLC from another lamp but does not detect the confirmation from the control device, i.e. so no control device has been detected within proximity but another lamp has been, then the first lamp may determine that it should instead form an association with the other lamp enabling it to be controlled by that lamp as part of the same group, such that when the other lamp is controlled then the first lamp is controlled together with it (e.g. they are switched on/off or dimmed together). Thus spatial proximity in combination with knowledge of the capability may make all the difference.

In embodiments, the association-forming logic may be comprised by the controller on the control device, and may be configured such that said association comprises one or both of: controlling the control device to transmit an ID of the control device to the illumination source such that the control device and illumination source exchange IDs with one another so as to record one another as having said association, and/or engaging in an authentication process with the illumination source such that the illumination source and the control device authenticate one another.

Alternatively the association-forming logic may be comprised by an intermediate device housed externally to the illumination source and the control device, and may be configured such that said association comprises one or both of: controlling the control device to transmit an ID of the control device to the intermediate device such that the intermediate device records the IDs of the illumination source and the illumination source as having said association, and/or the intermediate device authenticating the control device and the illumination source.

Either way the association forming logic may be implemented in the form of software stored on a memory of the relevant device and arrange to be run on a processor of that device. Alternatively a hardware implementation is not excluded.

In embodiments, said association may comprise an application-layer association. For instance said association may comprise one of: a ZigBee binding, a Bluetooth pairing, an allocation to a ZigBee group, a configuration of a ZigBee scene, or a configuration of an Open Interconnect Consortium (OIC) scene. Alternatively said association may comprise a network layer association such as forming or joining a Wi-Fi, ZigBee, Thread or Bluetooth network.

In further alternative or additional embodiments, the association-forming logic may be configured such that said association comprises adding the illumination source to a

group of multiple illumination sources under a common group ID, enabling the controller to control the group of illumination sources together as a group by reference to the group ID.

In embodiments, the association-forming logic may be configured to add the illumination source to a first group of illumination sources under a first group ID, to be controlled together by reference to the first group ID, on condition that the determined signal strength falls between a first and a second threshold; and to add the illumination source to a second group of illumination sources under a second group ID, to be controlled together by reference to the second group ID, on condition that the determined signal strength exceeds the second threshold.

In embodiments, the controller may be configured to measure a received signal strength of the received VLC signal and to supply the determined signal strength to the association-forming logic, and the association-forming logic is configured to arbitrate between the control device and another control device so as to only form said association on further condition that the measured signal strength is greater than a received signal strength experienced by the other control device. And/or, the association-forming logic may be configured to arbitrate between the control device and another control device to determine which of the control devices has a capability or capabilities most closely matching the at least one capability of the illumination source, and to only form said association on further condition that the control device is that which has the capability or capabilities most closely matching said at least one capability.

Alternatively the control device and another control device may both be allowed to associate with the illumination source at the same time, e.g. one of the control devices being a mobile device and the other being a static device.

The illumination source may take the form of a luminaire or an individual lamp. The control device may take any suitable form, e.g. a smart light switch, wall panel, or a mobile user terminal such as a smartphone, tablet or wearable device installed with a suitable lighting control application. The association may be stored in the control device, in the illumination source, or elsewhere (e.g. a server), or distributed amongst a combination of multiple of these.

The light sensor and VLC decoder may be comprised by the control device itself. Alternatively the light sensor and VLC decoder may be implemented in a separate commissioning tool, housed separately to both the illumination source and control device, but held substantially co-located with the control device at the time of using the system (i.e. close

enough that it can be taken to be located at approximately the same position for the purpose of commissioning).

The association-forming logic may be comprised by the controller on the control device itself. Alternatively the association-forming logic may be comprised by an external device such as a lighting bridge, gateway, server or commissioning tool housed externally to both the illumination source and the control device.

According to another aspect disclosed herein, there is provided control device for forming an association with an illumination source which emits a VLC signal comprising an ID of the illumination source modulated into illumination emitted by the illumination source, and which transmits an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application; the control device comprising: a light sensor for sensing the VLC signal; a VLC decoder configured to detect the ID from the sensed VLC signal; and a controller configured to receive the transmitted indication and based thereon trigger a determination as to whether the control device can support the indicated capabilities, such that on condition thereof, an association is formed between the control device and the illumination source based on the ID received in the VLC signal in order to enable said controller to control the illumination source by means of the association.

According to another aspect disclosed herein, there is provided an illumination source for forming an association with a control device, the illumination source comprising: an illumination element for emitting visible illumination to illuminate an environment; and modulator circuitry arranged to include a VLC signal comprising an ID of the illumination source modulated into the illumination emitted by the illumination element, for detection by a light sensor of the control device;

wherein the illumination source is further configured to transmit to the control device an indication of at least one capability of the illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application, thereby enabling a determination as to whether the control device can support the indicated capabilities, so that on condition thereof, an association is enabled to be formed between the control device and the illumination source based on the ID received in the VLC signal so that the control device can control the illumination source by means of the association.

According to another aspect disclosed herein, there is provided a method of enabling a control device to control an illumination source, the illumination source comprising an illumination element for emitting visible illumination to illuminate an environment, and modulator circuitry arranged to include a VLC signal comprising an ID of the illumination source modulated into the illumination emitted by the illumination element; wherein the method comprises: using a light sensor to sense the VLC signal, the light sensor being comprised by or placed substantially collocated with the control device; detecting the ID from the sensed VLC signal; operating the illumination source to the control device an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application; using the controller to receive the transmitted indication and supply the received indication to the association-forming logic; and determining whether to form an association between the control device and the illumination source enabling the controller of the control device to control the illumination source; wherein said determination comprises, based on the supplied indication, whether the controller of the control device can support the indicated capabilities, and on condition thereof, forming said association between the control device and the illumination source based on the ID received in the VLC signal.

According to another aspect disclosed herein, there is provided a method of operating a control device to form an association with an illumination source which emits a VLC signal comprising an ID of the illumination source modulated into illumination emitted by the illumination source, and which transmits an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application; the method comprising: using a light sensor of the control device to sense the VLC signal; decoding the sensed VLC signal in order to detect the ID of the illumination source; receiving the transmitted indication and based thereon determining whether the control device can support the indicated capabilities; and on condition that said determination determines that the control device can support said at least one capability, forming an association between the control device and the illumination source based on the ID received in the VLC signal in order to enable the control device to control the illumination source by means of the association.

According to another aspect disclosed herein, there is provided a method of operating an illumination source to form an association with a control device, the method comprising: including a VLC signal comprising an ID of the illumination source in

illumination emitted by the illumination source, for detection by a light sensor (12) of the control device; and transmitting to the control device an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application, thereby causing a determination as to whether the control device can support the indicated capabilities, wherein on condition thereof, an association is formed between the control device and the illumination source based on the ID received in the VLC signal in order to enable the control device to control the illumination source by means of the association.

According to another aspect disclosed herein, there is provided a computer program product comprising code embodied on computer-readable storage and configured so as when run on a processing apparatus (of the relevant device or devices) to perform the method of any of the embodiments disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

To assist understanding of the present disclosure and to show how embodiments may be put into effect, reference is made, by way of example only, to the accompanying drawings in which:

Figure 1 is a schematic illustration of a lighting system installed in an environment, and

Figure 2 is a schematic block diagram of a VLC transmitter and receiver.

DETAILED DESCRIPTION OF EMBODIMENTS

The set-up of a wireless lighting system comprises configuring an association enabling the lighting devices to be controlled by one or more controlling devices such as switches and/or sensors. This process is typically performed via a system pre-configuration, which requires the addition of application-level configurations (e.g. group membership of a device, binding relationship of a device in ZigBee networks) to possibly multiple nodes in a network. The pre-configuration process, usually done manually by a commissioner, can involve selection of devices one by one. The selection procedure of the devices and their configuration is time and resource consuming, particularly for large-scale wireless lighting systems.

The following describes a mechanism to efficiently and automatically select and configure devices such as wireless switches and sensors (e.g. occupancy sensors) to

control wireless lighting devices (e.g. LED luminaires or LED lamps) by leveraging configuration information transmitted via optical signals emitted by the lighting devices.

In embodiments, during the configuration phase, a lighting device advertises its application-level configuration which includes both a unique identifier (e.g. network

5 address) and its application-scenario capabilities (e.g. supported ZigBee clusters). In embodiments both of these pieces of information may be advertised from the lighting device by encoding and periodically transmitting the data via VLC. A device such as a switch or a sensor, which is to control the lighting behaviour of the lighting device, implements an embedded VLC decoder to receive the advertisement messages from the lighting devices in
10 its proximity. The controlling device evaluates the advertised capabilities, and based thereon decides whether to set up an association to control the lighting device. The decision may be further based on the intensity of the VLC signal received (possibly in combination with the intensity of the RF signal received), given that it successfully decoded the data transmitted via VLC. As a consequence of the decision to control a lighting device in its proximity, the
15 controlling device sends an application message via its wireless (mesh) network to set-up the lighting control configuration for the lighting device, based on the ID as received via VLC.

Thus the disclosed system and method provide automatic commissioning of a light source based on visible light communication. In embodiments the method is performed when the light source is fresh out of the box. At this point in time the light source broadcasts
20 its identifier (ID) and, either periodically or on request, transmits its application capabilities (e.g. needs). As a result a controller in proximity can receive the ID and can receive (either as broadcast or on request) the application capabilities of the new device. If the control device is capable of controlling this fresh-out-of-the-box product it can select to associate with the lighting device. E.g. the broadcast of application information is used by a VLC ID receiving
25 controller in the commissioning of the lighting device by matching its control capabilities with the lighting device control needs (or more generally capabilities).

The association may be registered locally in the controller, in the lighting device, and/or in another component such as the backend or bridge. The association may also be registered in multiple such locations.

30 In embodiments, the association may comprise forming groups of lighting devices, e.g. which allow group control whereby the lighting devices of the group can be controlled jointly. In embodiments, a measure of received signal strength such as RSSI (received signal strength indicator) may be used to limit the devices to associate with. The RSSI or other such measure may further also be used to prioritize between controllers when

multiple are found. Also controllers might be fixed or mobile, which might result in both getting associated; or control devices may coordinate amongst themselves if there are multiple recipients of the ID in order to determine which one is most suited, e.g. which is closest and/or which best suits the advertised application needs or capabilities. In another example, a central coordinator (e.g. bridge, gateway or server) decides on what associations are made (and in embodiments performs the application-level commands needed to make these associations active).

Figure 1 illustrates an example environment 9 equipped with a lighting system 1 according to embodiments of the present disclosure. The environment 9 is a space occupiable by one or more users. It may comprise an indoor space such as one or more rooms of a building, or an outdoor space such as a garden or park, or a partially covered space such as a stadium or gazebo, or a combination of such spaces such as a campus, or even the interior of a vehicle such as a ship or train. The lighting system 1 comprises a plurality of lighting devices (i.e. illumination sources) 2 installed or otherwise disposed at a plurality of different respective positions throughout the environment 9. Each lighting device 2 may take the form of a luminaire (comprising at least one lamp plus any associated housing, socket and/or support), or an individual lamp within a luminaire. Either way, the lamp or lamps comprised by each lighting device 2 may take any suitable form such as an LED-based lamp, a traditional incandescent lamp, or a gas discharge lamp. The luminaires in which the lamps are mounted may take any of a variety of traditional or non-traditional forms, e.g. mounted on the ceiling or wall of a room, a free-standing luminaire, a luminaire embedded in a surface or item of furniture, or an outdoor light pole.

The lighting system 1 further comprises at least one control device 4 for controlling the lighting devices 2. The control device may take the form of a dedicated control unit such as a smart light switch or wall panel, a dedicated sensor unit such as a presence sensor, or a general purpose user terminal installed with a suitable lighting control app. Such a user terminal may take the form of either a static user terminal (e.g. a desktop computer) or a mobile user terminal (e.g. laptop, tablet, smartphone, or wearable device such as a smartwatch or smart-glasses).

Each lighting device 2 is configured to emit visible illumination 3 for illuminating the environment 9, enabling the one or more occupants to see clearly and find their way about within the environment. This may be referred to as ambient illumination. Further, as will be discussed in more detail shortly, each lighting device 2 is configured to embed a signal into the illumination it emits. This signal comprises at least a unique identifier

(ID) of the respective lighting device 2, and preferably also an indication of one or more application capabilities of the respective lighting device 2. Moreover, each lighting device 2 is configured to be able to communicate over a wireless channel 5 based on a medium other than visible light, preferably a radio channel (though the possibility of other media such as ultrasound or infrared are not excluded). For instance the radio channel may be based on a radio access technology such as ZigBee, Bluetooth, Wi-Fi, Thread, JupiterMesh, Wi-SUN, 6LoWPAN, etc. The radio channel 5 can be used by the control device 4 to control the lighting devices 2. In some embodiments, the radio channel 5 may also be used to communicate the application capabilities of the lighting device 2, instead of using the visible light 3 for this.

The control performed by the control device 4 via the radio channel 5 may comprise controlling the illumination emitted by the respective lighting device, such as to turn the illumination on and off, dim the intensity of the illumination up and down, change its colour, set a new scene, and/or set a dynamic (time-varying) effect. In embodiments, the control may also comprise controlling other aspects of the lighting device's functionality, such as to request a status report (e.g. burning hours, energy consumption, fault reports, etc.) or set it to a power saving mode. As another example, the control may comprise changing the ID of the lighting device 2.

As an aside, note also therefore that the concept of "ID" may extend to a built-in unique ID of the lighting device 2, which can be in some embodiments changed by the control device 4. For example: the control device 4 detects ten luminaires via its RF network, then asks each of these one by one over RF to transmit code X as VLC. Then its decoder 14 is configured to look specifically and only for code X. This may help to detect weaker and further away VLC signals, e.g. putting in a 1024-bit CDMA code and using powerful correlation techniques at a backend server allows detection of this VLC signal even when it is "buried" beneath noise. As another example, the control device 4 can first try short ID codes and if it doesn't detect enough devices 2, it starts configuring longer ID codes on devices that it can discover over its RF network. Longer codes can help to detect weaker (further-away) VLC signals.

In order to be able to control the lighting devices 2, the control device 4 must first form an association with each lighting device 2 it is to control. This is sometimes called a binding or a pairing in the art. This association may comprise the control device 4 and lighting device 2 exchanging IDs with one another, so as to set up a connection with one another via the radio communication medium 5. The association may also comprise the

control device 4 and lighting device 2 authenticating one another based on a cryptographic authentication procedure. In one example implementation, the light source 2 may embed a specific ever-changing random code or token in the VLC that can be picked up by the control device 4, so the control device 4 can use it for the authentication. The control device 4 can thus prove that it is sufficiently in the neighbourhood of device 2 and is present in the same room.

In embodiments the association is an application-layer association such as a ZigBee binding, Bluetooth pairing, an allocation to a ZigBee group, a configuration of a ZigBee scene, or a configuration of an OIC scene. Alternatively or additionally the techniques disclosed herein can also be extended to forming a network-layer association such as creating or joining a Wi-Fi network, creating or joining a ZigBee network creating or joining a Thread network, or creating or joining a Bluetooth network

In particular embodiments disclosed herein the radio channel 5 is a ZigBee channel and the association comprises forming a ZigBee binding. Embodiments may be described in terms of ZigBee but it will be appreciated this is not limiting.

In embodiments, the association may further comprise forming a group of lighting devices 2. In this case the control device 4 associates a group ID, e.g. a ZigBee Group ID, with a plurality of the lighting devices. This then enables the control device 4 to control the group of lighting devices 2 together as a group by reference to only the single group ID.

Figure 2 gives a schematic overview of a system for transmitting and receiving signals via visible light. The system comprises a transmitter in the form of one of the lighting devices 2, and a receiver in the form of the control device 4.

The lighting device 2 comprises a light-emitting element 10, a modulator-driver circuit 8 connected to the light-emitting element 10, and an encoder 6 coupled to the modulator-driver circuit 8. The light-emitting element 10 is the component that emits the visible illumination 3 for illuminating the environment 9. For example this may take the form of a string or array of LEDs, or a filament bulb (though in the latter case only relatively slow modulation rates would be achievable). The modulator-driver circuit 8 is arranged to drive the light-emitting element 10 to emit the visible illumination 3, and also to modulate the intensity of the illumination 3 under the control of the encoder 6, so as to thereby embed a visible light communication (VLC) signal into the emitted illumination 3. To this end, the encoder 6 is coupled to an input of the driver-modulator 8, for controlling the light-emitting element 10. Particularly, the encoder 6 is configured to control the lighting element 10, via

the driver 8, to modulate the illumination it emits in order to broadcast a repeated coded light message comprising at least the unique ID of the respective lighting device 2. Preferably the repetition is periodic, but other possibilities are not excluded, e.g. randomly timed repetitions.

In embodiments the encoder 6 is implemented in the form of software stored
5 in memory and arranged for execution on a processor (the memory on which the software is stored comprising one or more memory units employing one or more storage media, e.g. EEPROM or a magnetic drive, and the processor on which the software is run comprising one or more processing units). Alternatively it is not excluded that some or all of the encoder
10 6 could be implemented in dedicated hardware circuitry, or configurable or reconfigurable hardware circuitry such as a PGA or FPGA. Whatever form it takes, in embodiments the encoder 6 may be implemented internally in a single lighting unit 2 (luminaire or lamp) along with the light-emitting element 10 and modulator-driver circuit 8, i.e. in the same housing. Alternatively the encoder 6 could, partially or wholly, be implemented externally such as on a lighting bridge server comprising one or more server units at one or more geographic sites
15 (not shown).

The lighting device 2 further comprises a local control application 16 responsible for performing the overall control of the lighting device 2 in response to commands from the control device 4. This may include the control of one or more lighting properties such as the on/off state of the illumination, the intensity level of the illumination,
20 its colour, setting it to form part of a scene, and/or setting any dynamic effects. In embodiments the control may also include controlling other functions such as responding to status requests from the control device 4, or switching to a power-saving mode. The local control application 16 takes the form of software (e.g. firmware) stored on an embedded memory of the lighting device 2 and arranged to run on an embedded processor of the
25 lighting device 2 (again the memory may comprise one or more memory units employing one or more storage media, e.g. EEPROM or a magnetic drive, and the processor may comprise one or more processing units). This may be the same memory and/or processor by which the encoder 6 is implemented or separate. In embodiments the encoder 6 forms part of the local control application 16, though it is not excluded that they could be implemented in separate
30 applications (the encoder 6 is shown in Figure 2 as a distinct block purely for schematic illustrative purposes). In embodiments the local control application 16 is also operable to control the encoder 6 in order to control the information being transmitted via the VLC signal.

Furthermore, the lighting device 2 comprises a wireless transceiver 11 for communicating via a medium other than visible light, e.g. a radio transceiver for communicating via the radio channel 5 (though other forms are not excluded, e.g. an ultrasound or infrared transceiver). For instance this may be a transceiver 11 capable of communicating according to ZigBee, Bluetooth, Wi-Fi, Thread, 6LoWPAN, JupiterMesh or Wi-SUN standards, etc. The application 16 is operatively coupled to the radio transceiver 11 and arranged to be able to communicate over the radio channel 5 via the radio transceiver 11, thereby enabling the local control application 16 to be controlled by the control device 4 via the radio channel 5 (such as to perform those control functions discussed above).

Note also, in variants the application 16 may be replaced wholly or in part by dedicated hardware circuitry or configurable or reconfigurable circuitry such as a PGA or FPGA.

The control device 4 comprises a light sensor 12 and a decoder 14 coupled to an input from the light sensor 12, in order to receive samples of the illumination 3 emitted by one or more of the light sources 2 and captured by the light sensor 12. The light sensor 12 may take the form of a dedicated photosensor, e.g. a point-sensor such as a single photocell. Alternatively the light sensor 12 may take the form of a camera, either a global-shutter camera or a rolling-shutter camera, for capturing the modulated illumination via images captured by the camera. Whatever form it takes, the light sensor 12 is arranged to capture samples of the illumination 3 from one or more of the lighting devices 2, including the VLC signal, and to pass these samples to the decoder 14 which is configured to decode the VLC signal based on the received samples. This decoding comprises at least extracting the ID of the respective lighting device(s) 2 from the VLC signal. The decoding may also comprise extracting any other relevant data, such as the advertised capabilities of the respective lighting device 2.

The decoder 14 may take the form of software stored in memory and arranged to run on a processor (the memory on which the software is stored comprising one or more memory units employing one or more storage media, e.g. EEPROM or a magnetic drive, and the processor on which the software is run comprising one or more processing units).

Alternatively it is not excluded that some or all of the decoder 14 could be implemented in dedicated hardware circuitry, or configurable or reconfigurable hardware circuitry such as a PGA or FPGA. Whatever form it takes, in embodiments the decoder 14 may be implemented internally in a single control unit 4 (e.g. switch, sensor, wall panel or user terminal) along with the light sensor 12, i.e. in the same housing. Alternatively the decoder 14 could, partially

or wholly, be implemented externally such as on a lighting bridge or a server comprising one or more server units at one or more geographic sites (not shown).

The control device 4 further comprises a controller in the form of a controller application 17, operatively coupled to the decoder 14. The controller application 17 takes the form of software stored in memory and arranged to run on a processor (again the memory may comprise one or more memory units employing one or more storage media, e.g. EEPROM or a magnetic drive, and the processor may comprise one or more processing units). This may be the same memory and/or processor by which the decoder 14 is implemented or separate. In embodiments the decoder 14 forms part of the controller application 17, though it is not excluded that they could be implemented in separate applications (the decoder 14 is shown in Figure 2 as a distinct block purely for schematic illustrative purposes). Also, like the decoder 14, while in embodiments the controller application 17 is integrated into a single control unit along with the light sensor 12 (i.e. in the same housing), it is not excluded that the controller application 17 could instead be implemented partially or wholly at a remote location such as a server comprising one or more server units at one or more geographic sites (not shown).

The control device 4 also comprises association-forming logic 18, e.g. ZigBee logic, for forming the association (e.g. ZigBee binding) with the illumination source 2. In embodiments the association-forming logic 18 is part of the controller 17 and is implemented in the same form, preferably in software (note therefore that the term “logic” herein does not limit to hardware logic). However it is not excluded that the association-forming logic 18 may be implemented in a different form, e.g. the controller 17 being implemented in software and the association-forming logic 18 being implemented in hardware or vice versa.

Furthermore, the control device 4 comprises a wireless transceiver 13 for communicating via a medium other than visible light, e.g. a radio transceiver for communicating via the radio channel 5 (though other forms are not excluded, e.g. an ultrasound or infrared transceiver). For instance this may be a transceiver 13 capable of communicating according to ZigBee, Bluetooth, Wi-Fi, Thread or 6LoWPAN standards, etc. The controller application 17 is operatively coupled to the radio transceiver 13 and arranged to be able to communicate over the radio channel 5 via the radio transceiver 11, thereby enabling the controller application 17 to control the local control application 16 on one or more of the lighting devices 2 via the radio channel and radio transceiver 11 on the lighting device(s) 2, in order to perform the control of the lighting devices(s) according to any of the embodiments as discussed herein (e.g. on/off, dim up/down, change colour, set to form part

of a scene, set a dynamic effect, request status report, go to power saving mode, etc.). Note that this communication may involve one or more hops. In general reference to communication, transmission or such like herein does not exclude indirect communication or transmission over multiple hops via one or more intermediate nodes, such as in a wireless mesh network. The intermediate node or nodes could take any of a variety of forms, such as a server, gateway, router, repeater, bridge and/or one or more peers in a mesh network.

The encoder 6, modulator-driver 8 and lighting element 10 operate together to emit a VLC (visible light communication) signal to be detected by the light sensor 12 and decoder 14 operating together on the control device 4. According to the present disclosure, VLC is used to facilitate the forming of a control association (e.g. binding, pairing or forming of groups) between the control device 4 and one or more lighting devices 2.

Visible light communication (VLC) refers to techniques whereby information is communicated in the form of a signal embedded in the visible light emitted by a light source. VLC is sometimes also referred to as coded light. The signal is embedded by modulating a property of the visible light, typically the intensity, according to any of a variety of suitable modulation techniques. In some of the simplest cases, the signalling is implemented by modulating the intensity of the visible light from each of multiple light sources with a single periodic carrier waveform or even a single tone (sinusoid) at a constant, predetermined modulation frequency. If the light emitted by each of the multiple light sources is modulated with a different respective modulation frequency that is unique amongst those light sources, then the modulation frequency can serve as an identifier (ID) of the respective light source or its light.

In more complex schemes a sequence of data symbols may be modulated into the light emitted by a given light source. The symbols are represented by modulating any suitable property of the light, e.g. amplitude, modulation frequency, or phase of a carrier waveform modulated into the light. For instance, data may be modulated into the light by means of amplitude keying, e.g. using high and low levels to represent bits or using a more complex modulation scheme to represent different symbols. Another example is frequency keying, whereby a given light source is operable to emit on two (or more) different modulation frequencies and to transmit data bits (or more generally symbols) by switching between the different modulation frequencies. As another possibility a phase of a carrier waveform may be modulated in order to encode the data, i.e. phase shift keying.

In general the modulated property could be a property of a carrier waveform modulated into the light, such as its amplitude, frequency or phase; or alternatively a

baseband modulation may be used. In the latter case there is no carrier waveform, but rather symbols are modulated into the light as patterns of variations in the brightness of the emitted light. This may for example comprise modulating the intensity to represent different symbols, or modulating the mark:space ratio of a pulse width modulation (PWM) dimming waveform, or modulating a pulse position (so-called pulse position modulation, PPM). The modulation may involve a coding scheme to map data bits (sometimes referred to as user bits) onto such channel symbols. An example is a conventional Manchester code, which is a binary code whereby a user bit of value 0 is mapped onto a channel symbol in the form of a low-high pulse and a user bit of value 1 is mapped onto a channel symbol in the form of a high-low pulse. Another example coding scheme is the so-called Ternary Manchester code developed by the applicant.

Based on the modulations, the information in the VLC signal can be detected using any suitable light sensor 12. This can be either a dedicated photocell, or a camera comprising an array of photocells (pixels) and a lens for forming an image on the array. E.g. the camera may be a general purpose camera of a mobile user device such as a smartphone or tablet. Camera based detection of VLC signals is possible with either a global-shutter camera or a rolling-shutter camera. E.g. rolling-shutter readout is typical to mobile CMOS image sensors found in everyday mobile user devices such as smartphones and tablets. In a global-shutter camera the entire pixel array (entire frame) is captured at the same time, and hence a global shutter camera captures only one temporal sample of the light from a given luminaire per frame. In a rolling-shutter camera on the other hand, the frame is divided into lines in the form of horizontal rows and the frame is exposed line-by-line in a temporal sequence, each line in the sequence being exposed at a slightly later time than the last. Each line therefore captures a sample of the signal at a different moment in time, and therefore at different phases of the modulation waveform. Hence while rolling-shutter cameras are generally the cheaper variety and considered inferior for purposes such as photography, for the purpose of detecting VLC they have the advantage of capturing more temporal samples per frame, and therefore a higher sample rate for a given frame rate. Nonetheless VLC detection can be achieved using either a global-shutter or rolling-shutter camera as long as the sample rate is high enough compared to the modulation frequency or data rate (i.e. high enough to detect the modulations that encode the information).

VLC is often used to embed a signal in the light emitted by an illumination source 2 such as an everyday luminaire, e.g. room lighting or outdoor lighting, thus allowing the illumination from the luminaires to double as a carrier of information. The light thus

comprises both a visible illumination contribution for illuminating a target environment such as room (typically the primary purpose of the light), and an embedded signal for providing information into the environment (typically considered a secondary function of the light). In such cases, the modulation is typically performed at a high enough frequency so as to be beyond human perception, or at least such that any visible temporal light artefacts (e.g. flicker and/or strobe artefacts) are weak enough not to be noticeable or at least to be tolerable to humans. For example when a modulated signal does not have substantial signal components below 100 Hz the modulation will typically not be visible. Thus the embedded signal does not affect the primary illumination function, i.e. so the user only perceives the overall illumination and not the effect of the data being modulated into that illumination. E.g. Manchester coding is an example of a DC free code, wherein the power spectral density goes to zero at zero Hertz, with very little spectral content at low frequencies, thus reducing visible flicker to a practically invisible level. Ternary Manchester is DC² free, meaning not only does the power spectral density go to zero at zero Hertz, but the gradient of the power spectral density also goes to zero, thus eliminating visible flicker even further.

Based on such technologies, the encoder 6, modulator-driver 8 and lighting element 10 operate together to emit a VLC signal comprising the ID of the respective lighting device 2 and an indication of one or more application capabilities of the local control application 16 running on that lighting device 2. In a variant of this, the VLC comprises as a minimum the ID but not necessarily the capability or capabilities, or at least not initially. Either way, in embodiments, the lighting device 2 is configured so as to begin beaconing this information via VLC when it is newly removed from its store packaging (e.g. box, i.e. it is “fresh out of the box), and is now being turned on for the first time. This means the lighting device 2 has at least two modes, an uncommissioned mode (e.g. ZigBee Factory New mode on) and a commissioned mode (e.g. ZigBee FN mode off). According to the present invention, these modes are adapted such that in the uncommissioned mode the beaconing, including the capability information, is turned on and in the commissioned mode it is turned off. The illumination source 2 is configured to begin in the uncommissioned mode when it is powered up for the first time, and then to switch to the commissioned mode when the association with a control device 4 is formed.

The VLC-encoded ID and capability information are detected by the light sensor 12 and decoder 14 operating together on the control device 4. Or in a variant where the VLC beacon does not contain the indication of the lighting device’s application capabilities, then the controller 14 may be configured so as in response to detecting the

received ID to request the capability information from the lighting device 2 identified by this ID. This request is sent via the radio channel 5 and radio transceivers 13, 11 (again noting that such communication may be direct or via multiple hops). In response to the request, the application 16 on the lighting device 2 returns the requested information on its one or more application capabilities. This response may be sent back to the control device 4 via another VLC signal (using the encoder 6, modulator-driver 8, lighting element 10 and emitted illumination 3); or via a radio signal (via the radio channel 5 and transceivers 11, 13).

According to the present disclosure, the received ID and capability information are used by the association-forming logic 18 running on the control device 4 in order to set up an association between that controller application 17 and the local application 16 running on the lighting device(s) 2. This association enables the control device 4 to control the lighting device(s) 2 with which this association is formed (such as to perform any of the various control functions mentioned previously). The concept of an association in this sense will be familiar to a person skilled in the art, e.g. a ZigBee binding or a Bluetooth pairing. The association may comprise the control device 4 and the target lighting device 2 exchanging IDs. The control device 4 already has the ID of the lighting device 2 from the VLC signal 3, so the association may comprise at least the control device sending its own ID to the lighting device 2 being associated with via the radio channel 5 (using the radio transceivers 11, 13). In embodiments the forming of the association may also comprise the control device 4 and lighting device 2 authenticating one another. Again this may be implemented over the radio channel 5 using the radio transceivers 11, 13 on the respective devices 2, 4.

Subject to any required authentication of the lighting device 2, the controller application 17 of the control device 4 registers the ID of the lighting device 2 as being confirmed as associated with the control device 4. Similarly, subject to any required authentication of the control device 4, the local control application 16 on the lighting device 2 registers the ID of the control device 4 as being confirmed as associated with the lighting device 2. Thus an application-layer connection is set up between the controller application 17 on the control device 4 and the local control application on the lighting device 2. The controller application 17 is configured so as, on condition of this association being formed, to allow itself to communicate with the local control application 16 on the lighting device 2 via the radio channel 5 and radio transceivers 13, 11, in order to perform the control of the lighting device 2 (e.g. turn the illumination on/off, dim it up/down, change its colour, set a dynamic effect, request a status report, and/or set to power saving mode, etc.).

In a variant of the above, the association, including the IDs of the devices, may alternatively be registered with another, centralized network element such as a lighting bridge or server (where again a server may refer to one or more server units at one or more geographic sites). In this case the controller application 17 can control the target lighting device 2 by reference to the association formed in this network element. The lighting device 2 and/or control device 4 may also be authenticated by the centralized network element. In another variant, the association may be registered with the lighting device 2, for instance in a system where the lighting devices 2 are smart devices (and there is not necessarily a bridge device). In general the association (i.e. the IDs of the associated devices and the fact that they are associated in a control relationship) may be registered in the control device 4, the lighting device 2, another element such as a bridge or server, or any combination of these. If the association is registered only locally at the controller 4 or lighting device 2 this enables use in bridge-less scenarios, or if registered only at the bridge this enables lower cost control devices 4 and lighting devices 2. In another example the association may be registered at both locations, though this may involve syncing.

In embodiments, the association may be one step in creating a group of multiple lighting devices 2, e.g. a ZigBee Group. In this case the controller application 17 on the control device 4 creates a group ID, e.g. a ZigBee Group ID, and adds each lighting device with which it associates to the group under this same group ID. The controller application 17 can then control the group as a whole by reference to the group ID instead of the individual IDs of the individual lighting devices 2, e.g. using ZigBee groupcast.

As an optional addition to this, the association comprises the creation of a scene as one of the possible "binding" operations. For example a pushbutton panel that has by default the buttons with text on it "on", "off", "concentration", "presentation" and "relax" written on it will configure these presets as scenes into the controlled lighting devices 2. Then when a user presses the button, it invokes the relevant scene via a "scene change" type command (using e.g. ZigBee scene cluster).

According to the present disclosure, the forming of the association (whether it be an individual or a group association) is conditional on whether the at least one of the application-scenario capabilities of the lighting devices local control application 16, as indicated to the control device 4 from the lighting device 2, match one or more of the capabilities and/or requirements of the controller 17 of the control device 4. Alternatively or additionally, the capabilities of the lighting device 2 upon which this association depends

may comprise one or more lower-layer software capabilities and/or one or more hardware capabilities.

In some embodiments, the association may be conditional on how many of the capabilities the controller 17 can match or how closely it matches it/these. In embodiments, one, some or all of the capabilities in question may be requirements (needs) of the controller 17, i.e. capabilities that must be supported by the lighting device 2 for the control to work, or capabilities that are required according to some standardized specification. Alternatively or additionally, one, some or all of the capabilities in question may be optionally supported features, i.e. functions that are preferable for the controller application to be able to support.

Examples of such capabilities include: (a) maximum output flux level (e.g. in Lumen); (b) maximum or typical (e.g. average) power consumption level (e.g. in Watts); (c) luminaire type (e.g. downlight, desklight, spot, ...); (d) lamp type (e.g. tube, bulb, LED panel, ...); (e) direction (e.g. angle) at which the lighting device 2 is capable of emitting its light (e.g. shining up/down) or range of directions over which it is capable of emitting its light (e.g. a solid angle of its beam); (f) whether the lighting device 2 is on/off capable; (g) whether the lighting device 2 is tri-level capable (full/dimmed/off); (h) whether the lighting device 2 is dimming-capable; (i) whether it is capable of colour control; (j) whether the colour can be controlled on a particular basis such as colour temperature control, RGB control or YUV control; (k) motion (e.g. motor control) capabilities; (l) group membership capabilities; (m) scene support and/or preconfigured scenes list (if any), e.g. is the lighting device able to adopt its respective role in a scene based on a signalled scene ID, is it capable of being configured with new scenes, and/or whether it has capacity to accept any new scenes; and/or (n) information on whether the lighting device is able to accept any further bindings (e.g. in terms of information on existing already-configured bindings).

Further examples of the communicated lighting device capabilities may include: having a particular sensor capable of reporting sensor readings to the controller (e.g., a temperature sensor operable to report temperature readings, or a presence sensor operable to report person(s) presence in a space); and/or being able to notify a defined parameter in a specific format (e.g. a temperature sensor which sends temperature change notifications in degree Celsius).

The association-forming logic 18 compares the one or more capabilities of the lighting device 2 with the control requirements of the controller 17 for the use case in question. E.g. if the controller 17 needs to be able to control devices emitting in a certain direction, or with colour control, etc., in order to create a specified lighting scene, then the

association may be conditional upon the lighting device 2 supporting this capability or capabilities. Or if the controller 17 prioritises connecting to lights that allow both dim level and colour temperature, such as to enable a warm dimming effect whereby colour temperature varies from warm to cool with increasing dim level, then the association may be made dependent on these capabilities.

In some embodiments, the association may be dependent on one or more additional criteria, in addition to the one or more application capabilities of the lighting device 2.

For instance, in embodiments the controller 17 may be configured to determine a measure of the signal strength (e.g. RSSI) of the VLC signal 3 as received at the light sensor 12 of the control device 4, and/or to determine a measure of signal strength (e.g. RSSI) of a radio signal 5 from the lighting device 2 as received at the radio transceiver 13 of the control device. The association-forming logic 18 may compare one or both of these to a respective predefined threshold, and only associate the control device 4 with the lighting device 2 on condition that one or both of these exceeds the respective threshold. Thus RSSI (or such like) may be used to limit the devices 2 with which the control device 4 associates.

In further embodiments, the RSSI may further also be used to prioritize between control devices 4 when multiple are found. In this case there are potentially multiple control devices 4 present in the environment, each of which may be configured in a like manner. In these embodiments the different control devices 4 require some mechanism by which to coordinate with one another. For instance this may be implemented via the radio channel. The association logic 18 of the controllers 17, via the radio transceivers 13, exchange RSSI measurements (or such like) and compare their own RSSI to the received RSSI from the other control device(s) 4. If their own RSSI is the highest, they associate with the lighting device 2 in question; but if not, they do not associate. In a variant of this, the association logic 18 on one control device 4 takes on the role of master for the purposes of the comparison. In this case the corresponding logic 18 on the other control device(s) 4 report their RSSIs to the master (e.g. via the radio transceivers 13), and the master performs the comparison and based thereon instructs the logic 18 on the control device 4 with the highest RSSI to associate with the lighting device 2 (e.g. this instruction may again be implemented via the radio transceivers 13). In another variant, a centralized network element such as a server or lighting bridge may take on the role of arbitrator for the purpose of the comparison. In this case the association logic 18 on all the control devices 4 may report their RSSIs to the centralized network element, which then then performs the comparison and instructs the logic

18 of the control device 4 with the highest RSSI to associate with the lighting device 2 (again the relevant communications may for example be implemented via the radio transceivers 13).

In yet further alternative or additional embodiments, the criteria applied by the association-forming logic 18 for association may include how closely (how well) the

5 controller 17 supports the transmitted capability or capabilities of the target lighting device 2.

This may be especially relevant where there are multiple candidate control devices 4 present in the environment 9, any of which could potentially be able to associate with the given lighting device 2 (because each is in range and supports to some extent at least one of the

application capabilities of the lighting device 2). In this case the controllers 17 on the

10 different control devices 4 are again configured to coordinate with one another, e.g. via any of the mechanisms discussed above. Instead of the RSSI however (or in addition to this), the comparison determines which controller 17 on which control device 4 most closely (best)

matches the signalled capabilities of the local control application 16 on the target lighting device 2. If multiple capabilities are signalled, this may comprise determining which

15 controller 17 on which control device 4 supports the greatest number of the signalled capabilities, and selecting that device 4 to form the association with the lighting device 2. Or

if the support for the feature is a matter of degree, the comparison may determine which control devices most closely supports a given one of the signalled features and select that

device 4 for the association. If multiple factors are taken into account, e.g. RSSI is taken into

20 account as well as suitability, a metric may be designed to weigh up the different factors, e.g.

the relative benefit of RSSI vs. supporting more or fewer features. Whatever the test, if there is a draw then one of the control devices 4 may be selected at random.

In an example use case of the multiple controller scenario, consider the case where at first there is a single control device 4 in a room and then another control device 4 is

25 added rather than another lamp. It might be useful to split the previous group into two, one small, one larger (and for instance have one or two taps to activate them respectively). Hence

in embodiments, when there is a group of multiple lighting devices 2 associated with an

existing control device 4, but then a new control device 4 is introduced and it is determined

by the above process that one is closest or better suited to one or more (but not all) of the

30 lighting devices in the group, then in response to this the group may be split. I.e. these one or

more lighting devices 2 now become associated for control purposes (e.g. bind) with the new

control device 4, whilst the remaining lighting device(s) 2 remain associated (e.g. bound)

with the existing control device 4 for control purposes.

In other embodiments, it is not excluded that multiple control devices 4 may be allowed to associate with a given lighting device 2 or a given group of lighting devices 4 at once. For example this may be desirable if one of the control devices 4 takes the form of a static terminal such as a wall-panel or wall switch and the another of the control devices 4 takes the form of a mobile terminal such as a tablet, smartphone or wearable device. In embodiments the coordination (implemented via any of the above mechanisms) may determine the form of the device (e.g. mobile or static) and, based on this, determine whether or not two control devices 4 are allowed to associate with a given lighting device 2 at once. Or in a variant, at most N (N=1,2,3, ... Etc.) control devices 4 may be allowed can bind to a specific light source. The light source may need to indicate this limit – e.g. in terms of the number of remaining bindings - as one of its capabilities.

In further embodiments, the lighting device 2 may comprise its own light sensor (not shown) and the application 16 (or other logic) on the lighting device 2 may be capable of using this sensor to detect VLC signals from another lighting device 2 (e.g. other instances of the same lighting device 2). Further, the control device 4 (e.g. switch) may be configured to return a confirmation back to the respective lighting device 2 via another channel (e.g. an RF, infrared or ultrasound channel) in event that the association is formed between the control device 4 and that lighting device 2 (e.g. when the ZigBee binding is formed). Thus while the lighting device is the only device that can emit its capabilities, the control device 4 can act on the VLC trigger from the lighting device to perform a handshake with the lighting device 2 to acknowledge that it can control the lighting device 2. The fact that the control device 4 sends an acknowledgement back to the lighting device 2 can be taken by the lighting device 2 as a confirmation that the control device 4 can control (at least one of) the capabilities, and in embodiments that it is also within the predetermined proximity threshold (e.g. RSSI threshold).

This can enable the application or logic 16 in the lighting device 2 in question (the “first” lighting device) to take action to form an alternative association in event that it does not receive the acknowledgment or handshake from the control device 4. For instance the alternative association may be formed with another of the lighting devices 2, such that the first lighting device is controlled by a signal (e.g. RF or VLC signal) from that other lighting device in order to control them together as a group. So when the other lighting device is controlled in a given manner by a control device (e.g. switch, sensor or smartphone app) with which that other lighting device has formed an association (e.g. ZigBee binding etc.), then the other lighting device controls the first lighting device to be controlled in the same manner.

E.g. they are both turned on and off together as a group, or both dimmed up and down together as a group.

For instance consider that the first lighting device is a first smart lamp and the other lighting device is another smart lamp. If the first lamp detects the VLC from another lamp but does not detect the confirmation from the control device (e.g. smart switch or sensor), i.e. so no suitable control device has been detected but another lamp has been, then the first lamp may determine that it should instead form an association with the other lamp enabling it to be controlled by that lamp as part of the same group, such that when the other lamp is controlled then the first lamp is controlled together with it (e.g. they are switched on/off or dimmed together).

Some particular example embodiments are now discussed in more detail. It will be appreciated that the VLC communications may be performed using the encoder 6, modulator-driver 8, lighting element 10 and emitted illumination 3; the radio communications may be performed using the radio transceivers 11 and radio channel 5; the control operations on the side of the lighting device 2 may be performed by the local control application 16 running on the lighting device 2; and the control operations on the side of the control device 4 may be performed by the controller application 17 with the association operations on the control side being performed by the association logic 18, which may be run on the control device 4. For brevity such details will not be repeated each time.

To begin the process, a lighting device 2 that is to be controlled by another device (the control device 4) encodes and transmits application-level configuration information via VLC. As this information is unlikely to change, it may be periodically transmitted according to a configurable duty-cycle. In this way, a receiving device 4 configured with the same duty-cycle can receive the information by being active for no more than the configured duty cycle (for the first time it listens the receiving device 4 would need to listen longer in order to catch up with the luminaire's duty cycle, and then after seeing the code twice it can deduce the duty cycle time). This process can be set up to last only for a determined duration, as it is typically needed only at system configuration time.

The VLC decoder 14 present in the controlling device 4 (such as a switch or a sensor) decodes the application-level configuration data transmitted by the surrounding lighting devices 2 and uses this to configure the interaction between itself and the controlled devices 2. The controlling device 4 may send an application message via wireless communication containing the configuration created for the controlled devices 2.

Groups of lighting devices 2 controlled by a controlling device 4 such as a switch or a sensor can be automatically created and configured as follows.

In a first step, each lighting device 2 encodes and transmits via VLC its unique identifier and its application capabilities (e.g. ZigBee Clusters implemented, etc.).

5 In a second step, the controlling device 4 receives the unique identifier and the application capabilities of the lighting devices 2 in its proximity via VLC. The controlling device 4 evaluates the intensity of the VLC signal received. If the VLC signal received is above a configured threshold, the controlling device 4 compares the list of application capabilities received with its own application capabilities. If the VLC signal received is lower
10 than the configured threshold, the controlling device 4 can immediately ignore the information sent via VLC without processing the application content of the message received.

For all those messages received with a VLC signal strength above a configured threshold, the controlling device 4 compares the received application capabilities
15 with its own application capabilities (e.g. a controller device 4 which implements the client-side of the ZigBee on/off cluster receives information from a controllable device which implement the server-side of the same on/off cluster). In a third step, the controlling device 4 can then decide to send a binding command to those lighting devices 2 with matching application capabilities and perform binding according to the specified procedure of the
20 wireless protocol in use, e.g. ZigBee.

In a further embodiment multiple groups may be automatically created and configured by using a set of multiple thresholds corresponding to different intensities of VLC signal received by the controlling device 4. For example, by using a set of thresholds t_1 , t_2 , t_3 , the following configuration can be set up, based on the intensity of the received signal s .

- 25 • $s < t_1$: device not added to any group.
- $t_1 \leq s < t_2$: device added to group A which controls the lights at distance from the controlling device.
- $t_2 \leq s < t_3$: device added to group B which characterize lights in close proximity of the controlling device.

30 Another example configures the lighting devices 2 belonging to multiple groups by using a set of thresholds t_4 , t_5 as follows.

- $s < t_4$: device not added to any group.
- $s \geq t_4$: device added to group A which is used to set up background lighting in all the lighting devices in a room.

- $\geq t_5$: device added to group B which is used to control the on/off of the lighting devices close to the switch (e.g. lights on a table).

In variants of any of the above embodiments, only the unique identifier is sent via VLC, whereas other information such as application capabilities is sent via RF

5 communication 5. For example a controlling device 4 receives a unique identifier via VLC and then, triggered by this, queries the lighting device 2 via RF communication using the received identifier. Only the device 2 with that unique identifier responds with its application capabilities. Thus the controlling device 4 receives both the ID and the capability information based on the unique identifier as received via VLC. The response from the lighting device 2
10 indicating its application capabilities may be transmitted to the control device 4 via RF or VLC.

The above has been described in terms of a control device 4 forming its own association or binding, with the association-forming logic 18 being implemented on the control device 4, e.g. as part of the controller 17. In an alternative class of embodiments
15 however, the association (e.g. binding) process described above may be governed by an intermediate node 19 such as a bridge, gateway, server or commissioning tool, housed externally to both the lighting device 2 and the control device 4. For instance, the control device(s) 4 such as a smart switch or sensor, and/or one or more new lighting devices 2 such as a new lamp, may be placed in the field and it is the role of the central component 19 (e.g.
20 bridge or commissioning tool) to commission the lot. This might also involve recommissioning existing lamps based on physical proximity. So adding a new control device 4 such as a smart switch could define a new group close to this switch. Alternatively in a “local controllers only” scenario, a control device 4 may form an association so as to control (e.g. switch or dim) lamps 2 within its own proximity only; e.g. such that a sensor
25 only controls a lamp in vicinity of the sensor, whilst a switch-type actuator (e.g. rocker or toggle switch) only controls another lamp in vicinity of that switch, etc.

The following describes a variant of the above described processes in which the association between the control device 4 and lighting device 2 is performed by a third device 19 such as a server, bridge or gateway.

30 In a first step, the control device 4 (e.g. switch or sensor) detects VLC from the lighting device 2 and sends the detected VLC information plus its own control capability into the network, e.g. by RF (via unicast or multicast). In a second step, the bridge, gateway or such like 19 picks up this RF transmission by the control device 4 and looks up (via RF) the lighting device 2 by its ID (e.g. device discovery). In a third step, the bridge/gateway 19

then performs the capabilities matching and then creates the bindings (that in previously-described embodiments the logic 18 in the controller 17 would do). It performs this on all involved devices: the lighting device 2 is bound to the bridge/gateway 19 itself, which will control the light; the control device 4 (e.g. switch or sensor) is bound to the bridge/gateway 19, such that it will report any sensor/button events to the bridge/gateway 19. After this, in a fourth step, the bridge/gateway 19 waits to receive control input (e.g. sensor or button inputs) from the control device 4 and computes which lighting device(s) 2 need to be controlled based on these inputs. It then sends control messages to the relevant one or more lighting devices 2.

In another class of embodiments, the third device 19 takes the form of a commissioning tool, again housed separately to both the lighting device 2 and the control device 4 (e.g. switch or sensor). This tool could be a dedicated commissioning device or a smartphone running a commissioning app. In this case the commissioning tool 19 detects the VLC signal. In such embodiments the light sensor 12 is implemented in the commissioning tool 19. The VLC decoder 14 may be implemented in the commissioning tool 19 or the control device (4), or elsewhere such as on a bridge, gateway or server.

The following describes another variant of the previously described association processes, in which this time the process uses the light sensor 12 of the commissioning tool 19 to detect the VLC (and optionally the commissioning tool also comprises the VLC decoder 14 to decode the VLC and/or the association-forming logic 18 to perform the association between the control device 4 and lighting device 2).

In a first step, a person holds the commissioning tool near the location of the control device 4. In a second step, the same person is pressing a button (e.g. a random button) on the control device 4. In a third step the commissioning tool 19 decodes the VLC signal from lighting device(s) 2 during some time window. This allows the commissioning tool 19, in a fourth step, to create the binding between control device 4 and lighting device(s) 2. The VLC signal will tell it which lighting device(s) 2 are near the control device 4; and the button pressing on the control device 4 will tell the commissioning tool 19 which control device 4 is intended to be bound (assuming the control device 4 by default broadcasts or multicasts an event message into the RF network, when it is not yet bound and a button is pressed, in order to enable discovery of itself).

In yet further embodiments, whilst the various embodiments above have been described in terms of forming an application-layer association between the light source and control device, alternatively or additionally the techniques disclosed herein can also be

extended to forming a network-layer association such as creating or joining a Wi-Fi network, creating or joining a ZigBee network creating or joining a Thread network, or creating or joining a Bluetooth network. In some embodiments the controller 17 may use the received capabilities (whether received by VLC, RF or otherwise) to form a new wireless network
5 with parameters based on the received capabilities.

It will be appreciated that the above embodiments have been described by way of example only. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does
10 not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored and/or distributed on a suitable medium, such as an optical
15 storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A lighting system (1) comprising:
an illumination source (2) comprising an illumination element (10) for emitting visible illumination (3) to illuminate an environment (9), and modulator circuitry (8) arranged to include a VLC signal comprising an ID of the illumination source modulated into the illumination emitted by the illumination element;
a control device (4) comprising a controller (17) for controlling the illumination source;
a light sensor (12) for sensing the VLC signal, the light sensor being comprised by or placed substantially collocated with the control device;
a VLC decoder (14) configured to detect the ID from the sensed VLC signal;
association-forming logic (18) for determining whether to form an association between the control device and the illumination source enabling the controller of the control device to control the illumination source;
wherein the illumination source is further configured to transmit to the control device an indication of at least one capability of said illumination source and wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application;
the controller is further configured to receive the transmitted indication and supply the received indication to the association-forming logic; and
the association-forming logic is configured to determine, based on the supplied indication, whether the controller of the control device can support the indicated capabilities, and on condition thereof, to form said association between the control device and the illumination source based on the ID received in the VLC signal in order to enable said control device to control the illumination source by means of the association.
2. The lighting system of claim 1, wherein the modulator circuitry (8) is arranged to use VLC to perform said transmission of the indication of said at least one capability, by modulating said indication into the emitted illumination (3), the controller (17) being configured to receive the indication via the VLC decoder (14).

3. The lighting system of claim 1 or 2, wherein the illumination source (2) is configured to perform said transmission by broadcasting said indication of the at least one capability repeatedly without prompt from the control device (4).

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4. The lighting system of claim 1, 2 or 3, wherein:

in response to receiving the ID of the illumination source (2) via said VLC signal, the controller (17) is configured to control the control device (4) to send a request to the illumination source requesting the indication of the one or more capabilities; and

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the illumination source is configured to perform said transmission by transmitting the indication of the at least one capability to the control device in response to said request from the controller of the control device.

5. The lighting system of any preceding claim, wherein said at least one capability of the illumination source (2) comprises one or more of:

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- supporting on/off switching control enabling the illumination to be switched on and off by the controller (17),

- supporting tri-level switching enabling the illumination to be switched between three discrete levels by the controller,

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- supporting dimming functionality enabling a dim level of the illumination to be controllable by the controller,

- supporting colour control enabling a colour of the illumination to be controllable by the controller,

25

- the illumination source having a specified type of sensor operable to send sensor readings to the controller,

- the illumination source having a temperature sensor operable to send sensed temperature readings to the controller,

- the illumination source having a presence sensor operable to send indications of sensed person presence events to the controller,

30

- a maximum luminous flux of the illumination,

- a maximum or typical power consumption of the illumination source,

- a luminaire type of the illumination source,

- a lamp type of the illumination source,

- a direction at which the illumination sources is capable of emitting the illumination or range

of directions over which the illumination source is capable of emitting the illumination,

- whether the illumination source is capable of moving the direction of the emitted illumination,

- the ability to join a group of light sources whereby the group can be controlled jointly by

5 the controller by reference to a common group ID,

- ability to render a respective part of a scene based on an identifier of the scene supplied by the controller,

- a list of supported light scenes,

- whether the illumination source is capable of being configured with new scenes,

10 - whether the illumination source has capacity to accept a new scene configuration, and/or

- whether the illumination source currently has capacity to accept any more control associations.

6. The lighting system of any preceding claim, wherein:

15 the association-forming logic (18) is comprised by the controller (17) on the

control device (4), and is configured such that said association comprises one or both of:

controlling the control device to transmit an ID of the control device to the illumination

source (2) such that the control device and illumination source exchange IDs with one

another so as to record one another as having said association, and/or engaging in an

20 authentication process with the illumination source such that the illumination source and the

control device authenticate one another; or

the association-forming logic is comprised by an intermediate device housed externally to the illumination source and the control device, and is configured such that said

association comprises one or both of: controlling the control device to transmit an ID of the

25 control device to the intermediate device such that the intermediate device records the IDs of

the illumination source and the illumination source as having said association, and/or the

intermediate device authenticating the control device and the illumination source.

7. The lighting system of any preceding claim, wherein the association-forming

30 logic (18) is configured such that said association comprises adding the illumination source

(2) to a group of multiple illumination sources under a common group ID, enabling the

controller (17) to control the group of illumination sources together as a group by reference

to the group ID.

8. The lighting system of any preceding claim, wherein the controller (17) is configured to determine a received signal strength of the received VLC signal and to supply the determined signal strength to the association-forming logic (18), and wherein said association-forming logic is configured to form said association on further condition that the measured signal strength is greater than a threshold.

9. The lighting system of claim 7 and 8, wherein the association-forming logic (18) is configured to add the illumination source (2) to a first group of illumination sources under a first group ID, to be controlled together by reference to the first group ID, on condition that the determined signal strength falls between a first and a second threshold; and to add the illumination source to a second group of illumination sources under a second group ID, to be controlled together by reference to the second group ID, on condition that the determined signal strength exceeds the second threshold.

10. The lighting system of any preceding claim, wherein one or both of:
the controller (17) is configured to measure a received signal strength of the received VLC signal and to supply the determined signal strength to the association-forming logic (18), and the association-forming logic is configured to arbitrate between the control device (4) and another control device so as to only form said association on further condition that the measured signal strength is greater than a received signal strength experienced by the other control device; and/or
the association-forming logic is configured to arbitrate between the control device and another control device to determine which of the control devices has a capability or capabilities most closely matching the at least one capability of the illumination source (2), and to only form said association on further condition that the control device is that which has the capability or capabilities most closely matching said at least one capability.

11. A control device (4) for forming an association with an illumination source (2) which emits a VLC signal comprising an ID of the illumination source modulated into illumination (3) emitted by the illumination source, and which transmits an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application;
the control device comprising:

a light sensor (12) for sensing the VLC signal;

a VLC decoder (14) configured to detect the ID from the sensed VLC signal;

and

a controller (17) configured to receive the transmitted indication and based

5 thereon trigger a determination as to whether the control device can support the indicated capabilities, such that on condition thereof, an association is formed between the control device and the illumination source based on the ID received in the VLC signal in order to enable said controller to control the illumination source by means of the association.

10 12. An illumination source (2) for forming an association with a control device (4), the illumination source comprising:

an illumination element (10) for emitting visible illumination (3) to illuminate an environment (9); and

15 modulator circuitry (8) arranged to include a VLC signal comprising an ID of the illumination source modulated into the illumination emitted by the illumination element, for detection by a light sensor (12) of the control device;

wherein the illumination source is further configured to transmit to the control device an indication of at least one capability of the illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application, thereby enabling a determination as to whether the control device can support the indicated capabilities, so that on condition thereof, an association is enabled to be formed between the control device and the illumination source based on the ID received in the VLC signal so that the control device can control the illumination source by means of the association.

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13. A method of operating a control device (4) to form an association with an illumination source (2) which emits a VLC signal comprising an ID of the illumination source modulated into illumination (3) emitted by the illumination source, and which transmits an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application; the method comprising:

30 using a light sensor (12) of the control device to sense the VLC signal;
decoding the sensed VLC signal in order to detect the ID of the illumination source;

receiving the transmitted indication and based thereon determining whether the control device can support the indicated capabilities; and

on condition that said determination determines that the control device can support said at least one capability, forming an association between the control device and the illumination source based on the ID received in the VLC signal in order to enable the control device to control the illumination source by means of the association.

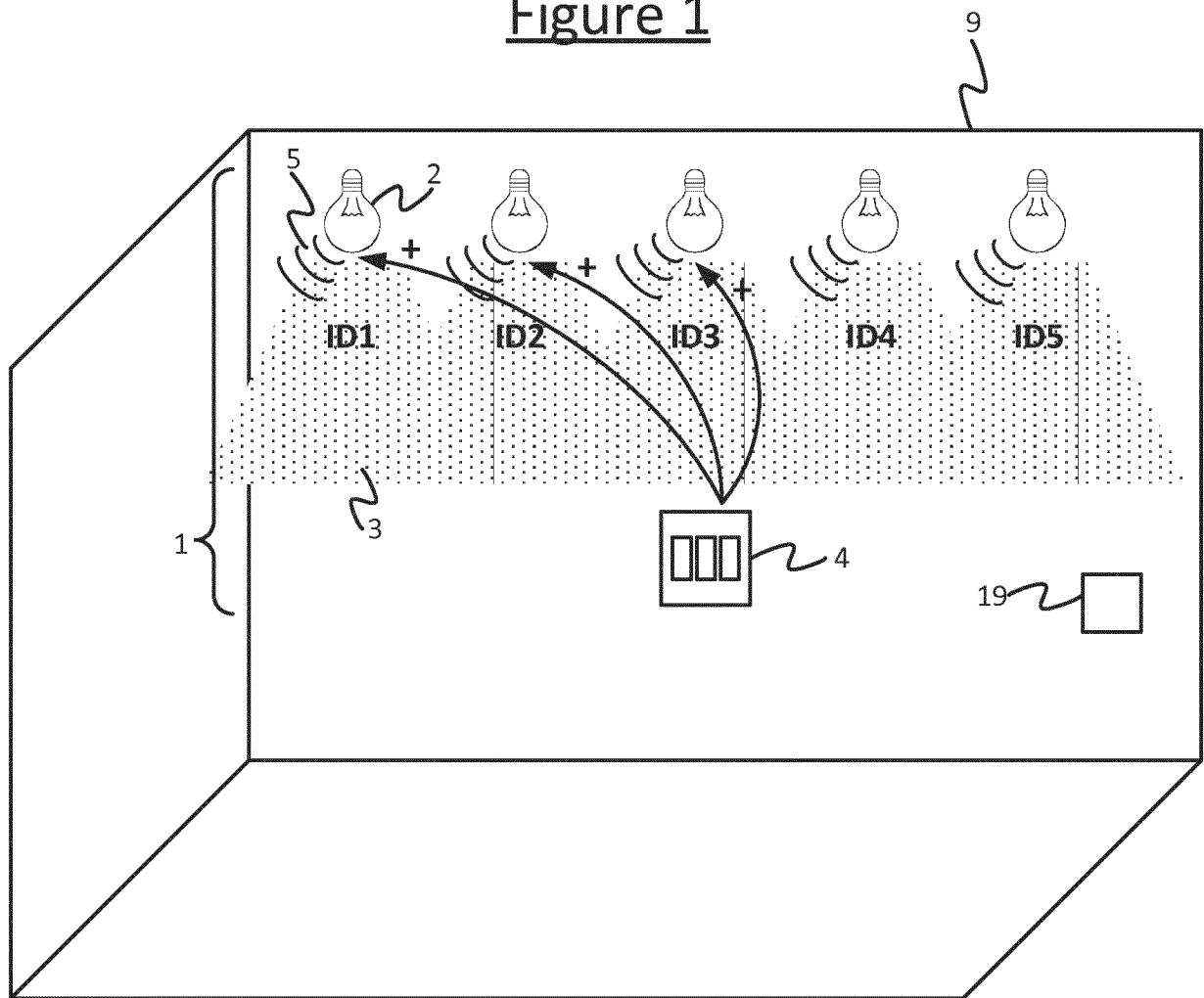
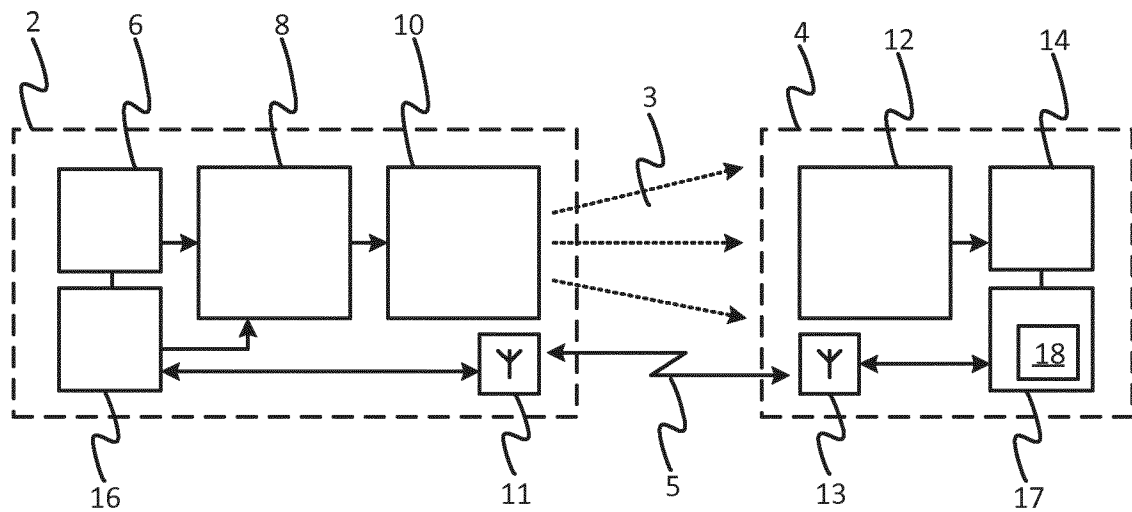
14. A method of operating an illumination source (2) to form an association with a control device (4), the method comprising:

including a VLC signal comprising an ID of the illumination source in illumination (3) emitted by the illumination source, for detection by a light sensor (12) of the control device; and

transmitting to the control device an indication of at least one capability of said illumination source, wherein said capability is at least one of an illumination feature or illumination requirement of the illumination source in an illumination lighting application, thereby causing a determination as to whether the control device can support the indicated capabilities, wherein on condition thereof, an association is formed between the control device and the illumination source based on the ID received in the VLC signal in order to enable the control device to control the illumination source by means of the association.

15. A computer program product comprising code embodied on computer-readable storage and configured so as when run on a processing apparatus to perform the method of claim 13 or 14.

1/1

Figure 1Figure 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/067419

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B10/116
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010/209105 A1 (SHIN HONG-SEOK [KR] ET AL) 19 August 2010 (2010-08-19) paragraph [0026] - paragraph [0030] paragraph [0035] - paragraph [0036] figures 1,2 paragraph [0038]	1-15
Y	US 2016/323035 A1 (JOVICIC ALEKSANDAR [US] ET AL) 3 November 2016 (2016-11-03) paragraph [0055] figure 5	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

14 September 2018

Date of mailing of the international search report

01/10/2018

Name and mailing address of the ISA/

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Inan, Beril

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/067419

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GROBE LIANE ET AL: "High-speed visible light communication systems", IEEE COMMUNICATIONS MAGAZINE, IEEE SERVICE CENTER, PISCATAWAY, US, vol. 51, no. 12, 1 December 2013 (2013-12-01), pages 60-66, XP011534246, ISSN: 0163-6804, DOI: 10.1109/MCOM.2013.6685758 [retrieved on 2013-12-16] page 61, column 2 -----	1-15
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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