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CROSS PERSONAL AREA NETWORK COMMUNICATION BY CONNECTED GRID MESH NETWORK IN LIGHTING AREA

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ABSTRACT

Techniques are described herein for broadcast and unicast mechanisms to perform cross Personal Area Network (PAN) communication in a Connected Grid Mesh (CG-Mesh). Neighboring PAN information (e.g., security, PAN, etc.) is stored in a cross-PAN node. A lighting group Identifier (ID) allocation may be used for the broadcast mechanism, and route table creation may be used for the unicast mechanism. This allows a system to meet any lighting timing requirements.

DETAILED DESCRIPTION

Connected Grid Mesh (CG-Mesh) networks may incorporate Advantage Metering Infrastructure (AMI), Distributed Automation (DA), and street lighting for smart cities. The CG-Mesh may provide connectivity of remote meters for energy enterprises to read data as desired. It may also enable remote controlling of lighting.

Routing Protocol for Low-power and Lossy Networks (LLNs) (RPL) may establish upward and downward routes. The Peer-to-Peer (P2P) traffic path in the same Directed Acyclic Graph (DAG) is usually based on a Destination Advertisement Object (DAO) informed downward route or follows a default route up towards the root in storing mode. Alternatively, the traffic path may follow a default route up towards the Low-power and Lossy Border Router (LBR), which sends the traffic to the destination node by injecting a source route header in non-storing mode. Because of a hardware limitation, the AMI and lighting market adopts non-storing mode.

In the lighting system, CG-Mesh nodes are placed on street lamps to control the on/off status of lights. Street lighting systems need to turn on and off the light with different lighting levels (e.g., 20%, 80%, 100% brightness, etc.) based on different moving speeds of various objects (e.g., pedestrian, bicycle, car, trunk, etc.). Table 1 below illustrates an example number of lights that are turned on or off based on the presence of different types of objects. In the example of an incoming car, four street lights may be turned on near the car, with three of the lights turned on with 100% brightness. The other light may be turned on with 20% brightness. The street lights may be turned on/off in turn as the car moves down the street.

Object Type	Lighting Number 1	Lighting Number 2	Lighting Number 3	Lighting Number 4
car	100% level	100% level	100% level	20%
bicycle	100% level	100% level	20%	-
pedestrian	80% level	80% level	20%	-

Table 1

Figure 1 below illustrates a street lighting system implemented with CG-Mesh with various street lighting characteristics. Special nodes in the cross-street (e.g., nodes a, b, c, and d) have more powerful resources than general nodes (e.g., 1x or 2x) along the street. The special nodes may include more resources than the general nodes, such as external sensors (e.g., a camera or photocell sensor for capturing objects, larger Random Access Memory (RAM) / Flash size, etc.). Each node may have a Global Position System (GPS).

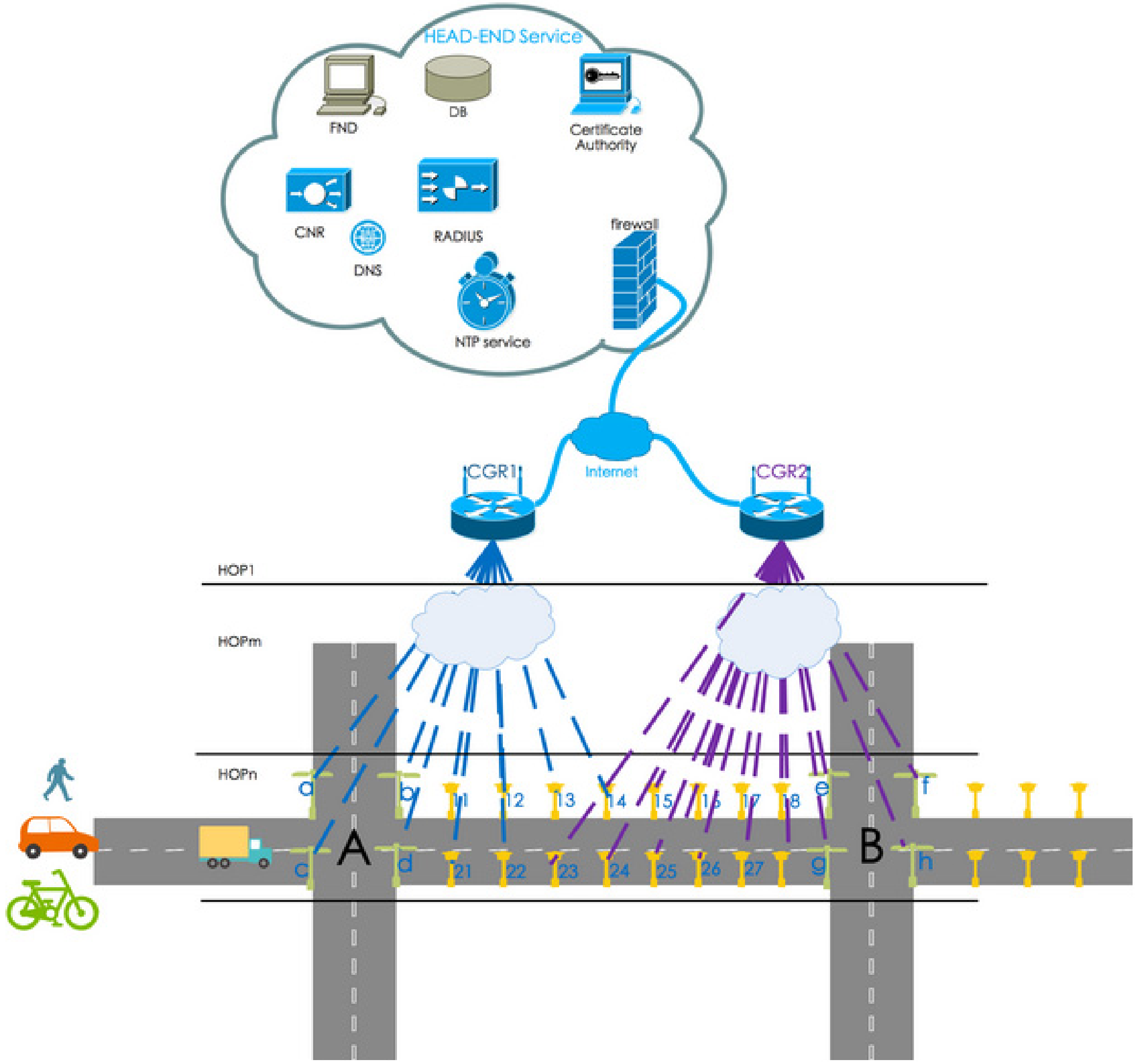

Figure 1

One problem related to the light control timing. Consider an example in which the distance between street lamps varies from 30 to 50 meters due to environment factors (e.g., pole height). Furthermore, the speed of vehicles may vary from 60 to 100km/h. As such, the timing of controlling the lights may vary from 4.3 seconds [= (30 meters * 4) / 100 km/h] to 12 seconds [= (50 meters * 4) / 60 km/h].

In current CG-Mesh networks, the average round-trip timing between two hops is 150ms when the wireless signal is good. But the maximum round-trip timing between two hops may reach up to four seconds when the wireless signal is very bad. In extreme cases, there could be 20 hops or more between nodes in a PAN. For example, in Figure 1, when node b detects a car via its camera, node b turns on its light, and sends a unicast turn-on message to the destination addresses of three nodes (nodes 11, 12, 13). The turn-on message may operate in RPL non-storing mode, and as such may be sent upwards to CGR1. CGR1 in turn sends data to the three nodes separately by injecting a source route header. If node b has 20 hops, the round-trip timing between node b and node 11 can vary from 3 seconds [= HOPn * round-trip timing = 20 * 150ms] to 80 seconds [= HOPn * round-trip timing = 20 * 4 seconds]. In most cases, the timing requirement of 4.3 seconds and 12 seconds cannot be met.

Another problem relates to inter-PAN latency. As shown in Figure 1, when node d detects a car via its camera, node d turns its light on and sends a turn-on unicast message to the destination addresses of three nodes (nodes 21, 22, 23). Because node 23 and node d are in different PANs, the turn-on message is sent upwards to CGR1, crosses the head-end service, and is forwarded to CGR2. At last, CGR2 sends data to nodes 23 by injecting a source route header. Thus, inter-PAN travel takes more latency than intra-PAN travel.

As such, described herein is a mechanism to control light in accordance with timing requirements when triggered by an external event. In view of the existing problems of lighting control in CG-Mesh networks, a broadcast mechanism and a unicast mechanism are described to help meet timing requirements.

In a first example step, each node and Connected Grid Router (CGR) registers basic information with the Field Network Director (FND) when they can communicate with it. The information may be merged into registration message reports sent to the FND. The basic information of each node may include, for example, Service Set Identifier (SSID), PAN ID, Internet Protocol version 6 (IPv6) address, GPS coordinates, route table, node type (e.g., special vs. general), neighbor information (e.g., neighbor Media Access Control (MAC) address, last heard timing, etc.), etc. The basic information of each CGR may include, for example, Operating System (OS) software version, bridge version, SSID, PAN ID, security key, etc.

In a second example step, the FND may push the corresponding information to the node once it has received the registration message from the node. The FND may build unique lighting groups with special nodes and general nodes in one street based on GPS and node type using information from the first example step. The FND may also send the extra lighting control group number to the node for responding to the registration message from the node.

Figure 2 below illustrates a unique lighting group ID allocation. As shown, the street information of a physical map is combined with a lighting location. Group IDs Bf and Br are created automatically with the special node.

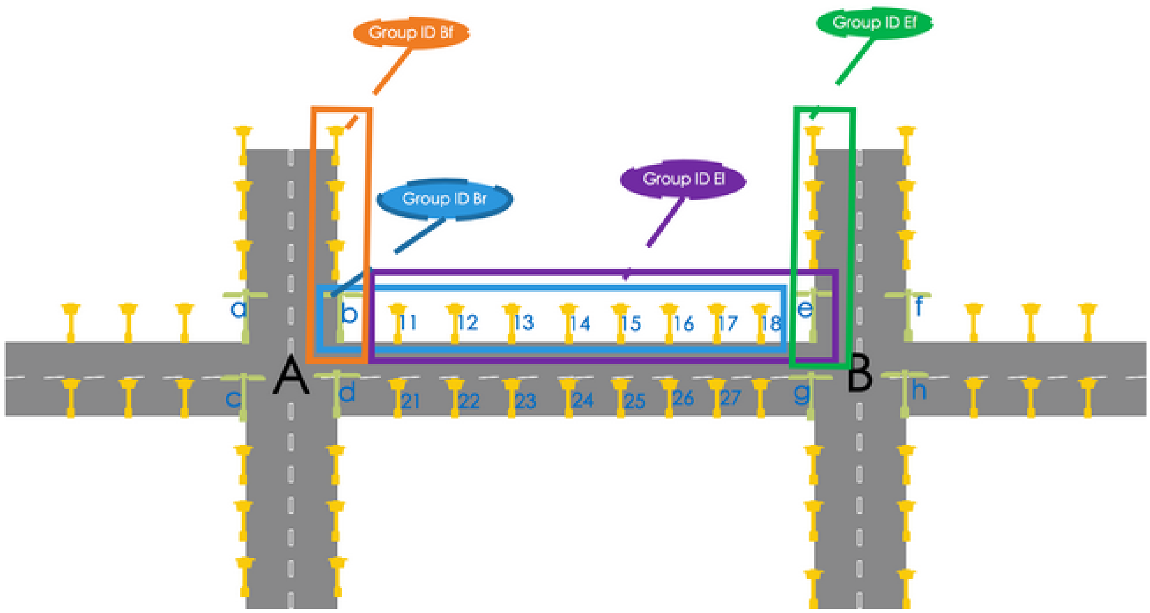

Figure 2

In a third example step, the FND pushes neighbor security information (e.g., security key, etc.) to cross-PAN nodes that are communicable with the neighbor nodes in another PAN. Thus, nodes in one PAN may obtain the corresponding network information (e.g., broadcast schedule, unicast schedule, etc.) from another PAN with the neighbor security information.

Figure 3 below illustrates an example system where cross-PAN information is pushed into a cross-PAN node. For the purposes of this example, consider nodes 15 and 16. Node 15 joined with CGR1 and node 16 joined with CGR2. However, they are also communicable with each other. If the head-end (cloud) service knows that they are cross-PAN nodes it may push CGR2 information into node 15 and push CGR1 information into node 16.

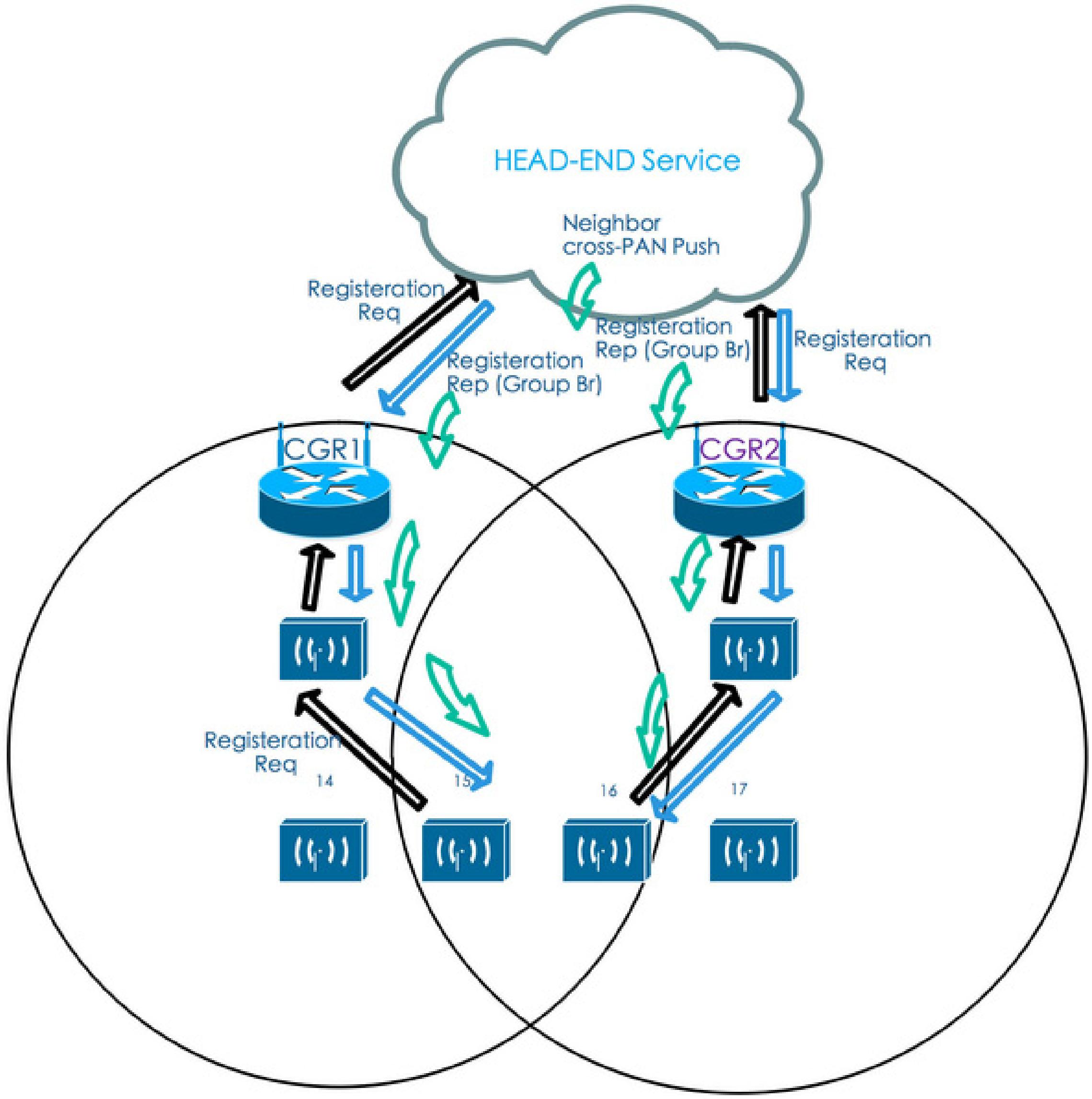

Figure 3

At a fourth example step, a special node may send a broadcast/unicast message to other nodes in same group number to control light when it detects an event such as an incoming car. In order to avoid broadcast flooding, the decision whether to make an automatic transmission with the broadcast mechanism or the unicast mechanism may be determined by a special node based on a created policy. The policy may depend on the node number in one group (e.g., 5, 10, etc.). For instance, when the node number is less than ten lights in one group, the special node may send a lighting message by the broadcast mechanism. Otherwise, it may send the lighting message by the unicast mechanism.

With respect to the broadcast mechanism, if all nodes are in the same group, the special node may directly send the broadcast message to all nodes. But for lighting and wireless PAN migration characteristics, nodes in one group could be in different PANs. The original CG-Mesh mechanism cannot resolve the cross-PAN broadcast communication.

Figure 4 below illustrates the cross-PAN broadcast communication issue.

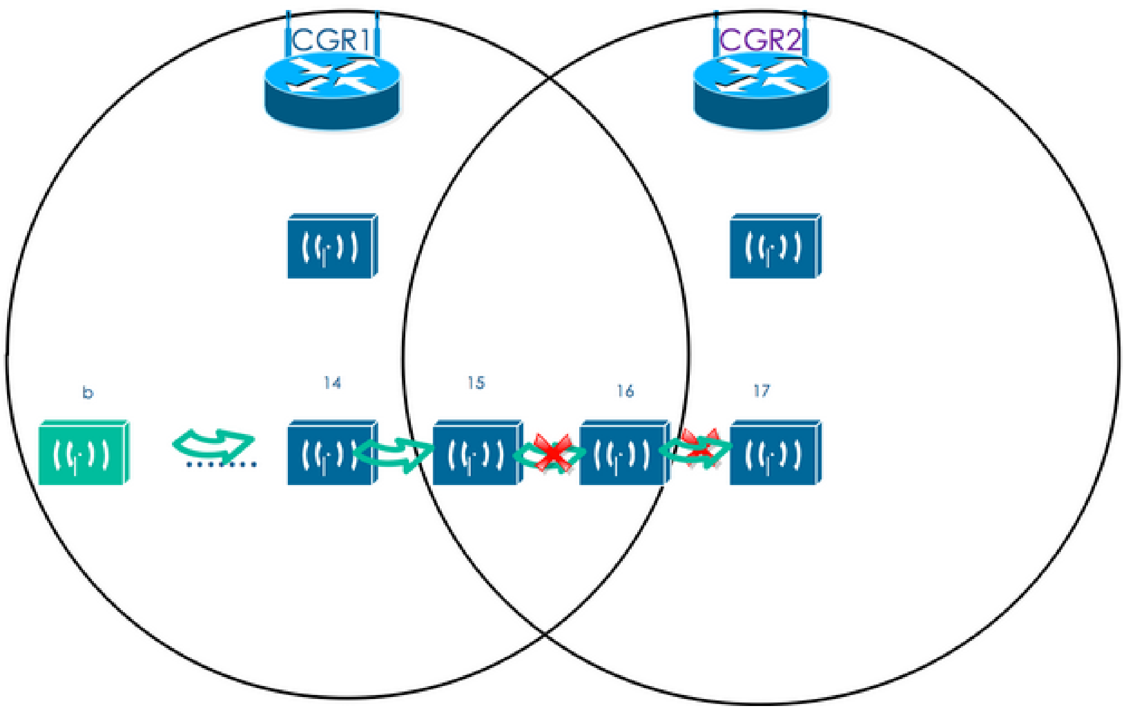

Figure 4

To address these broadcast defects, cross-pan information may be added into the Information Element (IE) field of an Institute of Electrical and Electronics Engineers (IEEE) 154 broadcast frame issued by the special node. The cross-pan IE may include a cross-PAN node 64-bit Extended Unique Identifier (EUI-64), neighbor PAN ID, key index, etc. That node may compute the neighbor cross-PAN node's broadcast schedule based thereon.

Figure 5 below illustrates a cross-PAN broadcast communication solution. In this example, node b, node 15, and node 16 have the same group ID Br in the two PANs. The special node sends only one broadcast message to control light with appended cross-PAN information (e.g., cross-PAN node EUI-64 | PAN 2 | key index = 0 | ...) into the IE field. Once nodes 14 and 15 receive the control message from the special node, they may control their respective lights accordingly. Node 15 checks that the cross-PAN IE is consistent with its own records, and constructs and sends a new broadcast message with other PAN information (e.g., security information, broadcast schedule, etc.). Nodes 16 and 17 receive the control message and control their own lights accordingly.

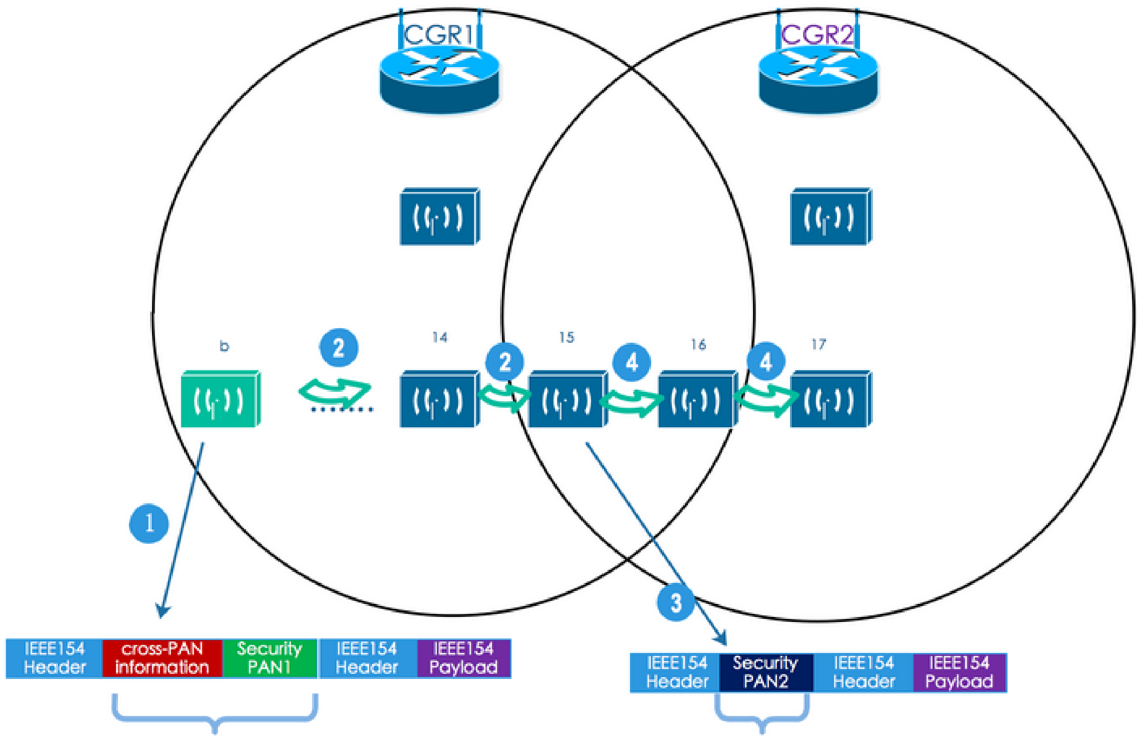

Figure 5

With respect to unicast, if all nodes are in same group, the special node may send unicast messages to all nodes via the border router. If the nodes in the same group are in two PANs, the special node has to cross two border routers to send the unicast message to all nodes. As such, the original CG-Mesh mechanism can take long time to send the unicast message to the destination node.

Figure 6 below illustrates the cross-PAN unicast mechanism issue.

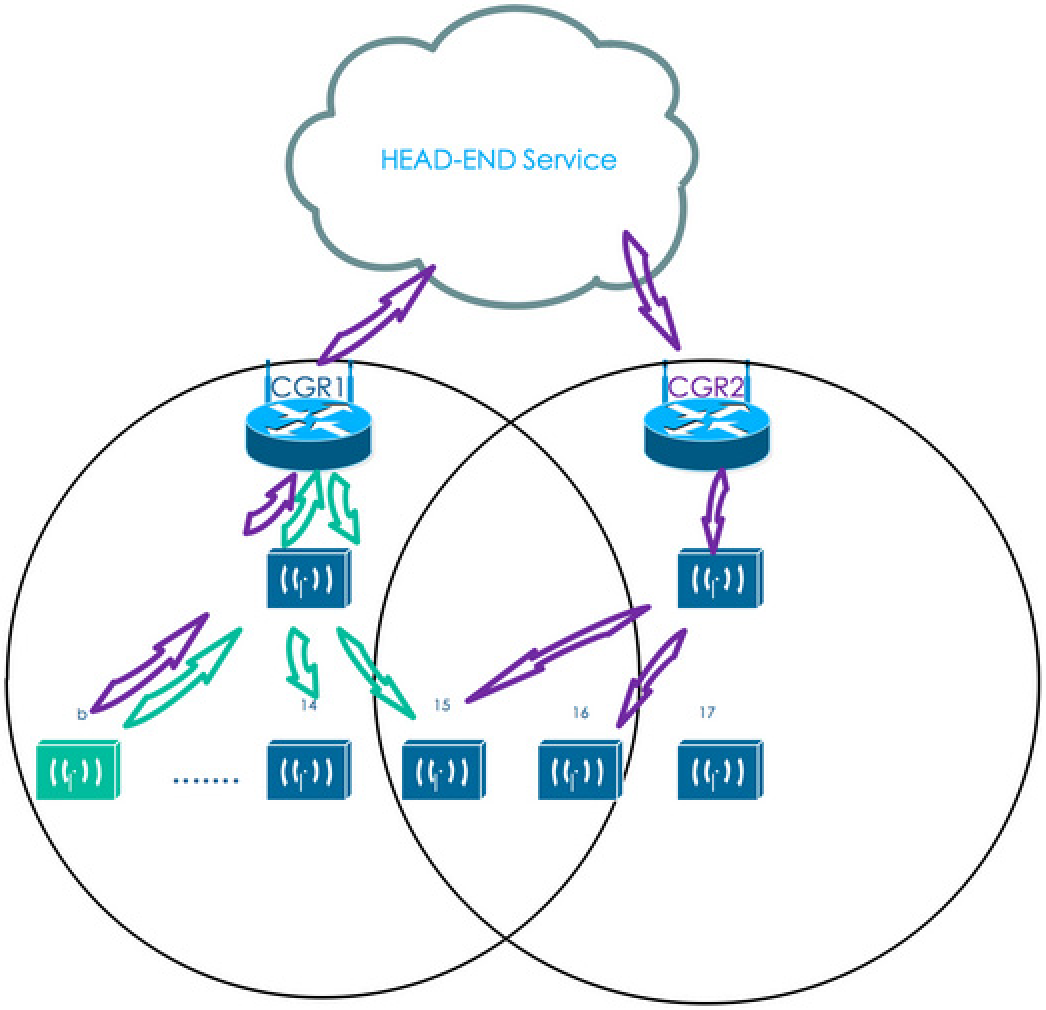

Figure 6

Accordingly, in order to address the aforementioned unicast defects, a route table may be pushed between the special node and the general node in one group into a special node. Figure 7 below illustrates an example cross-PAN unicast mechanism solution. The route table push is labelled with the blue arrows (flow 1). If all nodes in same group are in the PAN, the special node may send unicast messages to the destination nodes (green arrow, flow 2).

However, nodes in the same group may cross two PANs. For example, node b, node 15, and node 16 have the same group ID Br but span two PANs. The special node sends a unicast message to the control light with appended cross-PAN information (e.g., cross-PAN node EUI-64 | PAN 1 | key index = 0 | ...) in the IE field. Once nodes 14 and 15 receive the control message from the special node, they may control their respective lights accordingly. Node 15 checks that the cross-PAN IE is consistent with its own records, and constructs and sends a new unicast message with other PAN information (e.g., security information, broadcast schedule, etc.), labelled with arrow flow 3. Nodes 16 and 17 in the other PAN receive the control message and control their own lights accordingly.

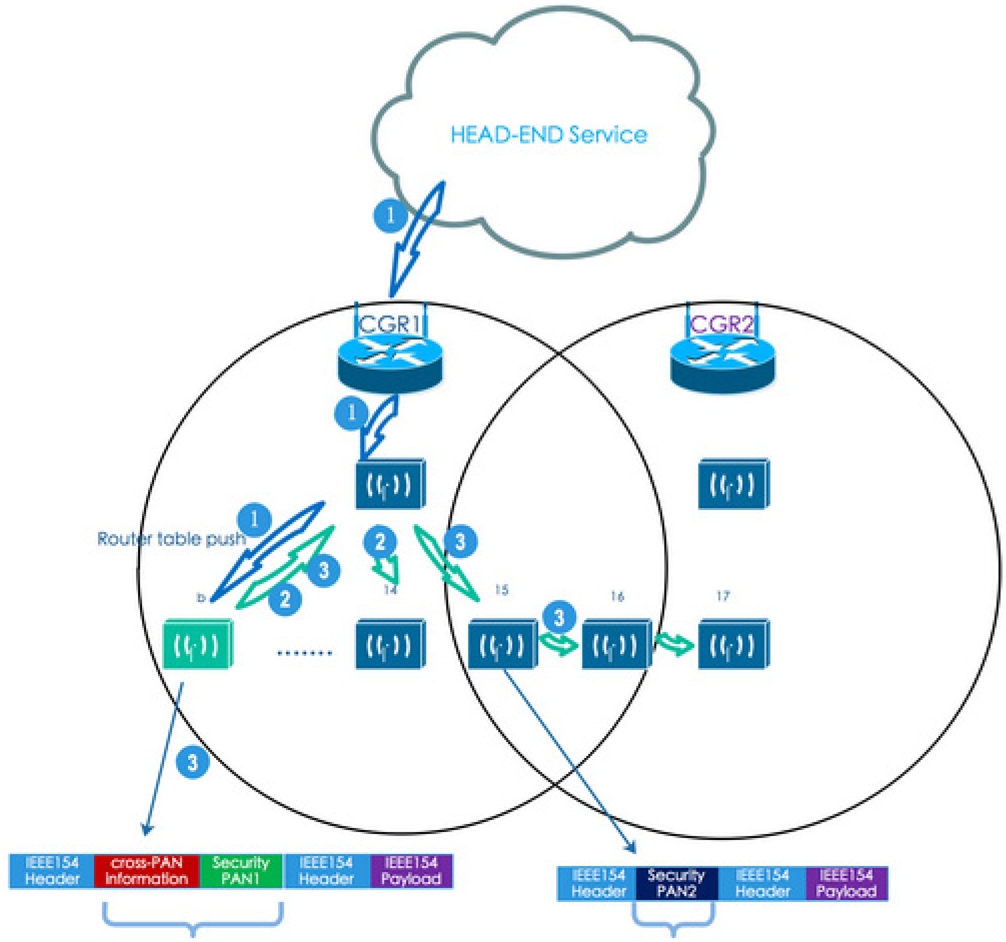

Figure 7

In summary, techniques are described herein for broadcast and unicast mechanisms to perform cross PAN communication in a CG-Mesh. Neighboring PAN information (e.g., security, PAN, etc.) is stored in a cross-PAN node. A lighting group ID allocation may be used for the broadcast mechanism, and route table creation may be used for the unicast mechanism. This allows a system to meet any lighting timing requirements.