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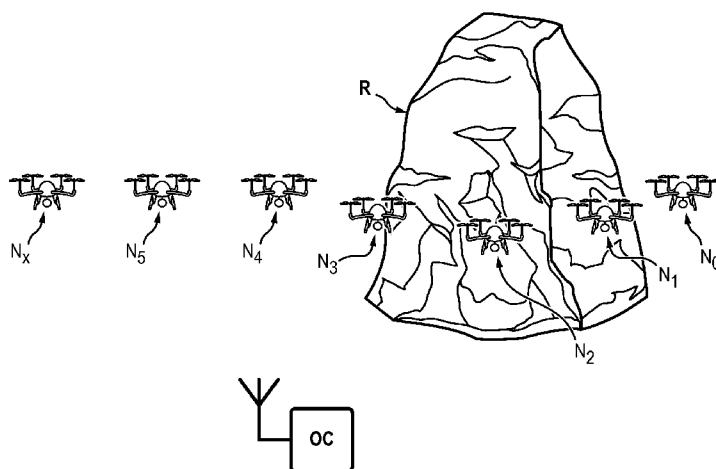
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## (54) Title: METHOD FOR MANAGING A SQUAD OF MOBILE ROBOTIC VEHICLES

FIG. 1



(57) Abstract: The invention concerns a method for managing a squad of mobile robotic vehicles, such as drones, each mobile robotic vehicle being configured to communicate and exchange information with other mobile robotic vehicles so that they constitute a network of mobile robotic vehicles and configured to communicate and exchange information with an operating center, said method comprising the following steps of: launching (S1) a first mobile robotic vehicle (NO) which is the leader of the squad, the leader being configured to stay at a distance from an operating center (OC) for exchanging information with the operating center (OC) by ensuring that a quality of link ( $Q_{NO, OC}$ ) of power exchanged between said first mobile robotic vehicle (NO) and said operating center (OC) is greater or equal to X dBm, the method comprising, if the quality of link ( $Q_{NO - OC}$ ) becomes lower than X dBm, launching (S4, S7) consecutively at least one mobile robotic vehicle (N1, N2, ..., Nx) so that: each mobile robotic vehicle is configured to stay at distance from his closest neighbor(s) for exchanging information with his closest neighbor(s) by ensuring that a quality of link of power exchanged between said each mobile robotic vehicle and said closest neighbor(s) is greater or equal to X dBm; the last launched mobile robotic vehicle (Nx) is configured to stay at a distance from the operating center for exchanging information with the operating center by ensuring that a quality of link of power exchanged between said last mobile robotic vehicle and said operating center is greater or equal to X dBm.

bor(s) by ensuring that a quality of link of power exchanged between said each mobile robotic vehicle and said closest neighbor(s) is greater or equal to X dBm; the last launched mobile robotic vehicle (Nx) is configured to stay at a distance from the operating center for exchanging information with the operating center by ensuring that a quality of link of power exchanged between said last mobile robotic vehicle and said operating center is greater or equal to X dBm.

## Method for managing a squad of mobile robotic vehicles

### Technical field and background of the invention

The invention concerns a method for managing a squad of mobile robotic vehicles, such as  
5 drones, each mobile robotic vehicle being configured to communicate and exchange  
information with other mobile robotic vehicles.

More particularly, the invention concerns the positioning of a group of mobile robotic  
vehicles, such as drones, operating together in order to optimize a given mission that they  
are supposed to accomplish.

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### Summary of the invention

An aim of the invention is to manage efficiently a squad of mobile robotic vehicles for a  
mission.

To this end, the invention concerns a method for managing a squad of mobile  
15 robotic vehicles, such as drones each mobile robotic vehicle being configured to  
communicate and exchange information with other mobile robotic vehicles so that they  
constitute a network of mobile robotic vehicles and configured to communicate and  
exchange information with an operating center, said method comprising the following steps  
of:

20 launching a first mobile robotic vehicle which is the leader of the squad, the leader  
being configured to stay at a distance from an operating center for exchanging information  
with the operating center by ensuring that a quality of link of power exchanged between  
said first mobile robotic vehicle and said operating center is greater or equal to X dBm, the  
method comprising, if the quality of link becomes lower than X dBm,

25 launching consecutively at least one mobile robotic vehicle so that:

each mobile robotic vehicle is configured to stay at distance from his closest  
neighbor(s) for exchanging information with his closest neighbor(s) by ensuring that  
a quality of link of power exchanged between said each mobile robotic vehicle and  
said closest neighbor(s) is greater or equal to X dBm;

30 the last launched mobile robotic vehicle is configured to stay at a distance  
from the operating center for exchanging information with the operating center by  
ensuring that a quality of link of power exchanged between said last mobile robotic  
vehicle and said operating center is greater or equal to X dBm.

The method of the invention may have one of the following features:

At least three mobile robotic vehicle have been launched, and for a given mobile robotic vehicle its two neighbors are configured to stay at distance from the given mobile robotic vehicle so that said two neighbors calculate a quality of link of power exchanged between said two neighbors greater or equal to Y dBm.

5 For each launched mobile robotic vehicle, a step of calculating quality links between the closest neighbors and the quality link between the last launched mobile robotic vehicle and the operating center.

The step of calculating comprises the application of a smoothing algorithm to the quality link calculated.

10 Each mobile robotic vehicle is configured to implement a step of broadcasting periodically a hello message to its neighboring, in which they communicate the received power from their neighbors, in order to detect communications link linking each neighbor.

The method comprises a step of initializing the squad in order to define a topology of the squad.

15 Each mobile robotic vehicle is configured to implement a step of broadcasting periodically a topology message in order to be aware of a current network topology.

The method comprises a step of defining a number of multiple paths from the leader of the squad, the steps of launching the mobile robotic vehicle after the step of launching the first mobile robotic vehicle being implemented in parallel for each path having the same leader, the last launched mobile robotic vehicle of each path exchanging information with  
20 the operating center with a quality of link greater or equal to X dBm.

The step of defining a number of multiple paths is implemented by a Manhattan model.

25 With the invention, it is possible to optimize the drones's synchronization and positioning according to the application and the mission that they are accomplishing, as far as possible for a given number of mobile robotic vehicles.

Indeed, relaying information between drones is strongly related to the bandwidth required by the application's traffic. When it concerns video streaming, for example, the bit rate and the quality of the video should be satisfied. In that case, drones should provide the  
30 correct radio propagation to relay the video while respecting the required quality along a path of communication as long as possible.

Thus the invention provides a method for managing a squad of mobile robotic vehicles allowing to relay information with the required quality of link, even if the leader goes more and more away the fixed operation center in order to accomplish his mission.

35

#### Brief description of the drawings

Other features and advantages of the invention will appear in the following description.

Embodiments of the invention will be described with reference to the drawings, in which

- Figure 1 illustrates a squad of drones according to a first embodiment;
- 5    - Figure 2 illustrates the main steps of a method according to the invention;
- Figure 3 illustrates sub steps of the method according to the invention;
- Figure 4 illustrates the positioning between several drones of a squad;
- Figure 5 illustrates a squad of drones according to a second embodiment;
- Figure 6 illustrates sub step of the method according to the invention.

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#### Detailed description

**Figure 1** illustrates a squad of seven mobile robotic vehicles, from N0 to Nx ( $x=6$  on Figure 1). The number of the mobile robotic vehicles does not have to be considered as a limiting.

The mobile robotic vehicles can be a drone or ground robot.

15

The mobile robotic vehicles are configured to communicate and exchange information between them and with an operating center. To this end the mobile robotic vehicles are equipped with radio interfaces such as Wi-Fi interfaces or any other technology able to provide Device to Device feature.

20    The operating center OC is localized at remote distance from the squad and the squad is constituted from the operating center according to a method described here below.

Assuming an area to be observed in a hostile region or behind an obstacle R (see Figure 1) from the operating center OC. A single drone could not make the observation alone in real time because of the loss of connection with the operating center OC. Therefore, according to the method, several drones can be launched in order to create a path to  
25    communicate, where the video will be relayed across the squad.

The following method is implemented according to several assumptions:

- a sufficient number of drones is available;
- one of the available drone is selected to be the leader of the squad;
- drones are launched one after the other to form the squad;
- 30    - drones are maintained at a given altitude with known methods (not described here);
- each drone can take into account external constraints such as the weather, or interferences when launched (to stay at a distance from another drone or at a given altitude, etc.)

In relation with **Figure 2**, the method comprises a step S0 of initializing a squad in order to define a topology of the squad and to permit each drone to discover its neighbor.

This step of initializing S0 consists to define the leader of the squad, i.e. the first drone to be launched and the order of launch of the other drones.

5        This step S0 of initializing comprises a sub step of powering-on S01 each drone of the squad, each drone broadcasting S02 a topology message in order to be aware of an initial network topology (see **Figure 3**). To this end, each drone maintains a topology table stored in a memory located in the drone.

10        Once the initial network topology is determined, the method comprises a step of launching S1 a first drone N0 which is the leader of the squad.

      The leader exchanges information with the operating center OC with a quality of link  $Q_{N0,OC}$  greater or equal to X dBm. In the example of Figure 1, this level of quality link permits to transmit a video observed by the leader N0. The quality link is defined as a received power exchanged between a drone with another drone or with the operating center. For  
15        instance a quality of link using Wi-Fi of around - 45 dBm is required for video applications and - 80 dBm for text messages. In a general manner the quality link depends on the technologies used for the traffic transfer.

      In particular, the leader N0 is configured to stay at a distance from the operating center OC for exchanging information with it with a quality of link  $Q_{N0,OC}$  greater or equal to  
20        X dBm. One can note that the leader can be managed from the operating center OC or the leader can be configured to be autonomous.

      This quality of link is continually calculated S2 and monitored S3 for maintaining a correct quality of link.

25        In case, the quality of link  $Q_{N0-OC}$  becomes lower than X dBm (due to distance attenuation or interferences), the method comprises a step of launching S4 a second drone N1.

      This second drone N1 is configured to stay at a distance from the leader N0 for exchanging information with the leader N0.

30        Also, this second drone N1 must exchange information with the operating center OC at level greater or equal to X dBm for maintaining the link.

      Again, this quality of link is continually calculated S5 and monitored S6. If the quality of link  $Q_{N1-OC}$  becomes lower than X dBm, the method comprises a step of launching S7 a third drone.

35        Therefore, the method is based, after the launch of the leader N0, on the launching consecutively of at least one drone N1, N2, N3 ..., Nx so that:

- each drone is configured to stay at distance from his closest neighbor(s) for exchanging information with his closest neighbor(s) with a quality of link  $Q_{Nn, Nn-1}$  greater or equal to X dBm;
- the last launched drone  $N_x$  is configured to stay at a distance from the operating center OC for exchanging information with it with a quality of link greater or equal to X dBm.

In order to optimize the positioning between drones when at least three mobile robotic vehicles have been launched, for a given mobile robotic vehicle  $N_i$ , its two neighbors  $N_{i-1}$ ,  $N_{i+1}$  are configured to stay at distance from the given mobile robotic vehicle  $N_i$  so that said two neighbors  $N_{i-1}$ ,  $N_{i+1}$  calculates the quality of link  $Q_{N_{i-1}, N_{i+1}}$  greater or equal to Y dBm (see **Figure 4**). Thus the information exchanged from mobile robotic vehicle  $N_{i-1}$  to mobile robotic vehicle  $N_{i+1}$  is relayed by mobile robotic vehicle  $N_i$ . In addition, this optimization offers to drones the possibility to maximize the distance between them while respecting the traffic constraints and hence to reduce the number of used drones for the considered mission.

The number of drones launched depends on a mission to be made: reaching a given area or the coverage of a given area or watching behind obstacles.

As a complement, when drones have been launched, they periodically broadcast S8 a hello message network neighboring discovered message to its neighboring. Generally speaking, a hello message is a WS-Discovery message used to announce the presence of a device or service on the network. Within the scope of the invention, hello messages are used in order to detect the radio links connecting each neighbor. To this end, the radio interfaces of each drone send hello messages where they communicate the received power from their neighbors. A drone is considered as a neighboring drone if and only if the received power is above a considered threshold.

The period is set by default to 2 seconds but can be set to another value according to the drones's velocity.

Each hello message comprises the average value of the received signal and if the value is above a given threshold, the drone is considered as a neighbor otherwise not. One can note that a symmetric link is considered after the exchange of three hellos messages.

Each drone comprises a neighboring table stored in memory located in the drone. As known, this neighboring table has two entries: the MAC address and the received powers of the neighbor.

In a similar way, each drone updates its topology table by flooding S9 periodically a topology message (the same of the initializing step S0). The period is set by default to 5

seconds. Each drone floods its neighboring table to all drones of the squad. This step uses an optimized flooding to minimize the number of topology messages. When receiving a topology message, every drone checks the entries in its topology table and updates information. Therefore, after this step each drone is aware of the network topology.

5           As complementary again, when a calculation of a quality link is implemented, this step of calculating comprises the application of a smoothing algorithm to the quality link calculated. The use of such algorithm permits to avoid oscillation on the decision that the vehicle takes according to the signal power measurement. In fact, radio signals introduce many variations while the mean is constant. Decisions should be taken on the mean and not  
10       on the raw values.

          According to another embodiment (see **Figure 5**), if the application requires resilience for multiple paths to forward the traffic, the above described method comprises a step S00 of defining a number of multiple paths K (for instance according to a Manhattan model) (see **Figure 6**).

15           Then after the leader of the squad N0 is launched the above described method is implemented for each path. In particular, the steps of launching (S4, S4', S4'', S7, S7', S7'') the mobile robotic vehicle N1, N1', N1'', N2, N2', N2'' ..., Nx, Nx', Nx'' after the step of launching the first mobile robotic vehicle being implemented in parallel for each path having the same leader, the last launched mobile robotic vehicle Nx, Nx', Nx'' of each path  
20       exchanging information with the operating center OC with a quality of link greater or equal to X dBm (figures 5 and 6 illustrate three paths for instance).

**CLAIMS**

1. A method for managing a squad of mobile robotic vehicles, such as drones, each mobile  
5 robotic vehicle being configured to communicate and exchange information with other  
mobile robotic vehicles so that they constitute a network of mobile robotic vehicles and  
configured to communicate and exchange information with an operating center, said method  
comprising the following steps of:

launching (S1) a first mobile robotic vehicle (N0) which is the leader of the squad,  
10 the leader being configured to stay at a distance from an operating center (OC) for  
exchanging information with the operating center (OC) by ensuring that a quality of link  
( $Q_{N0,OC}$ ) of power exchanged between said first mobile robotic vehicle (N0) and said  
operating center (OC) is greater or equal to X dBm, the method comprising, if the quality of  
link ( $Q_{N0-OC}$ ) becomes lower than X dBm,

15 launching (S4, S7) consecutively at least one mobile robotic vehicle (N1, N2, ..., Nx)  
so that:

each mobile robotic vehicle is configured to stay at distance from his closest  
neighbor(s) for exchanging information with his closest neighbor(s) by ensuring that  
a quality of link of power exchanged between said each mobile robotic vehicle and  
20 said closest neighbor(s) is greater or equal to X dBm;

the last launched mobile robotic vehicle (Nx) is configured to stay at a  
distance from the operating center for exchanging information with the operating  
center by ensuring that a quality of link of power exchanged between said last  
mobile robotic vehicle and said operating center is greater or equal to X dBm.

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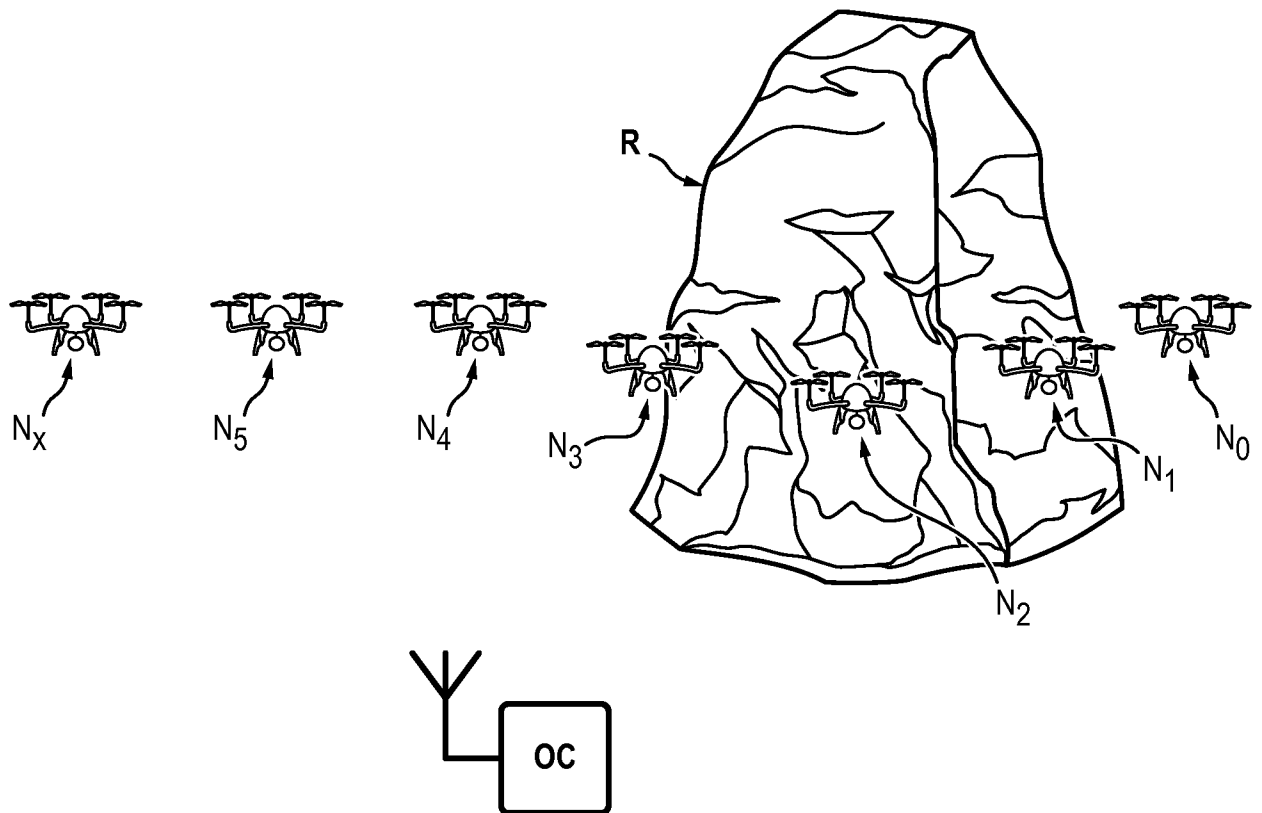
2. The method according to claim 1, wherein at least three mobile robotic vehicle have been  
launched, method wherein for a given mobile robotic vehicle (Ni) its two neighbors (Ni-1,  
Ni+1) are configured to stay at distance from the given mobile robotic vehicle (Ni) so that  
said two neighbors (Ni-1, Ni+1) calculate a quality of link  $Q_{Ni-1, Ni+1}$  of power exchanged  
30 between said two neighbors greater or equal to Y dBm.

3. The method according to any one of claims 1 to 2, comprising, for each launched mobile  
robotic vehicle, a step of calculating (S2, S5) quality links  $Q_{Ni, Ni-1}, Q_{Ni, Ni+1}$  between the closest  
neighbors and the quality link between the last launched mobile robotic vehicle (Nx) and the  
35 operating center (OC).

4. The method according to claim 3, wherein the step of calculating (S2, S5) comprises the application of a smoothing algorithm to the quality link calculated.
5. The method according to any one of claims 1 to 4, wherein each mobile robotic vehicle is configured to implement a step (S8) of broadcasting periodically a hello message to its neighboring, in which they communicate the received power from their neighbors, in order to detect communications link linking each neighbor.
6. The method according to any one of claims 1 to 5, comprising a step (S0) of initializing the squad in order to define a topology of the squad.
7. The method according to claim 6, wherein each mobile robotic vehicle is configured to implement a step (S02) of broadcasting periodically a topology message in order to be aware of a current network topology.
8. The method according to any one of claims 1 to 7, comprising a step (S00) of defining a number of multiple paths from the leader of the squad, the steps of launching (S4, S4', S4'',...S7, S7', S7'') the mobile robotic vehicle (N1, N1', N1'', N2, N2', N2'', ..., Nx, Nx', Nx'') after the step of launching the first mobile robotic vehicle (N0) being implemented in parallel for each path having the same leader, the last launched mobile robotic vehicle (Nx, Nx', Nx'') of each path exchanging information with the operating center (OC) with a quality of link greater or equal to X dBm.
9. The method according to claim 8, wherein the step of defining a number of multiple paths is implemented by a Manhattan model.

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FIG. 1



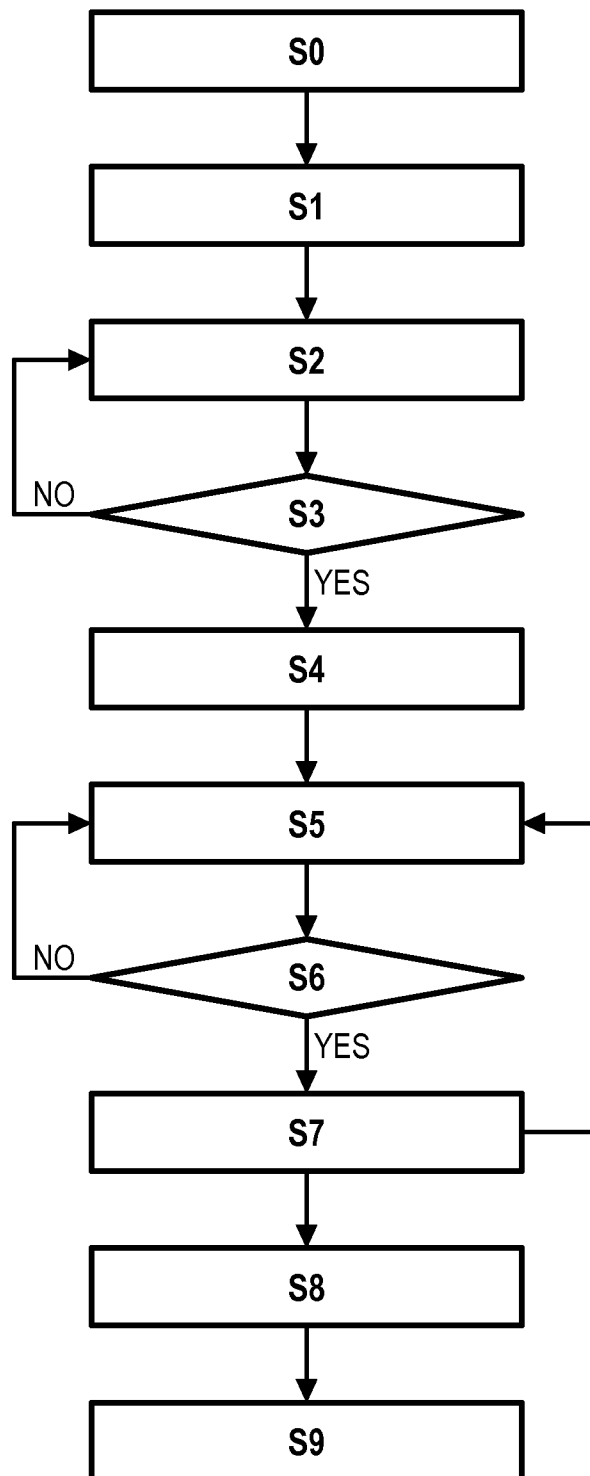
**2/4****FIG. 2**

FIG. 3

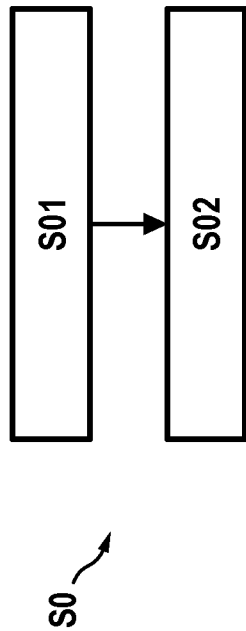
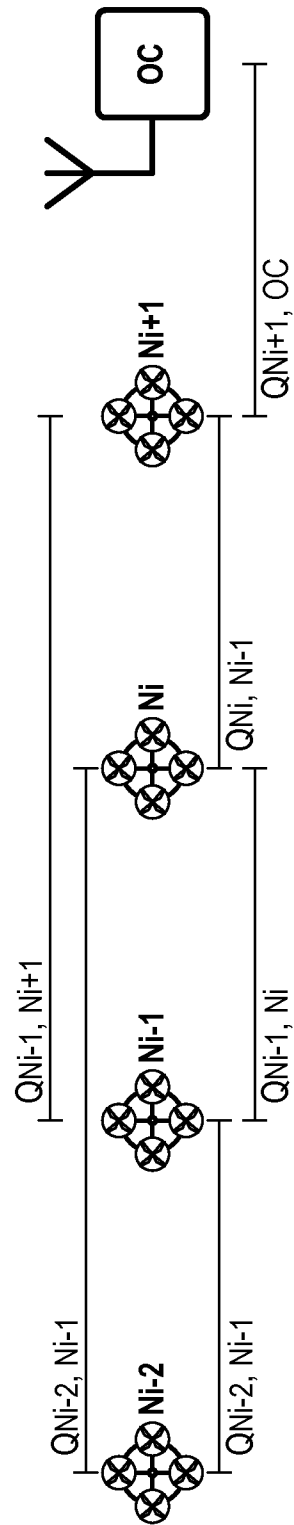


FIG. 4



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FIG. 5

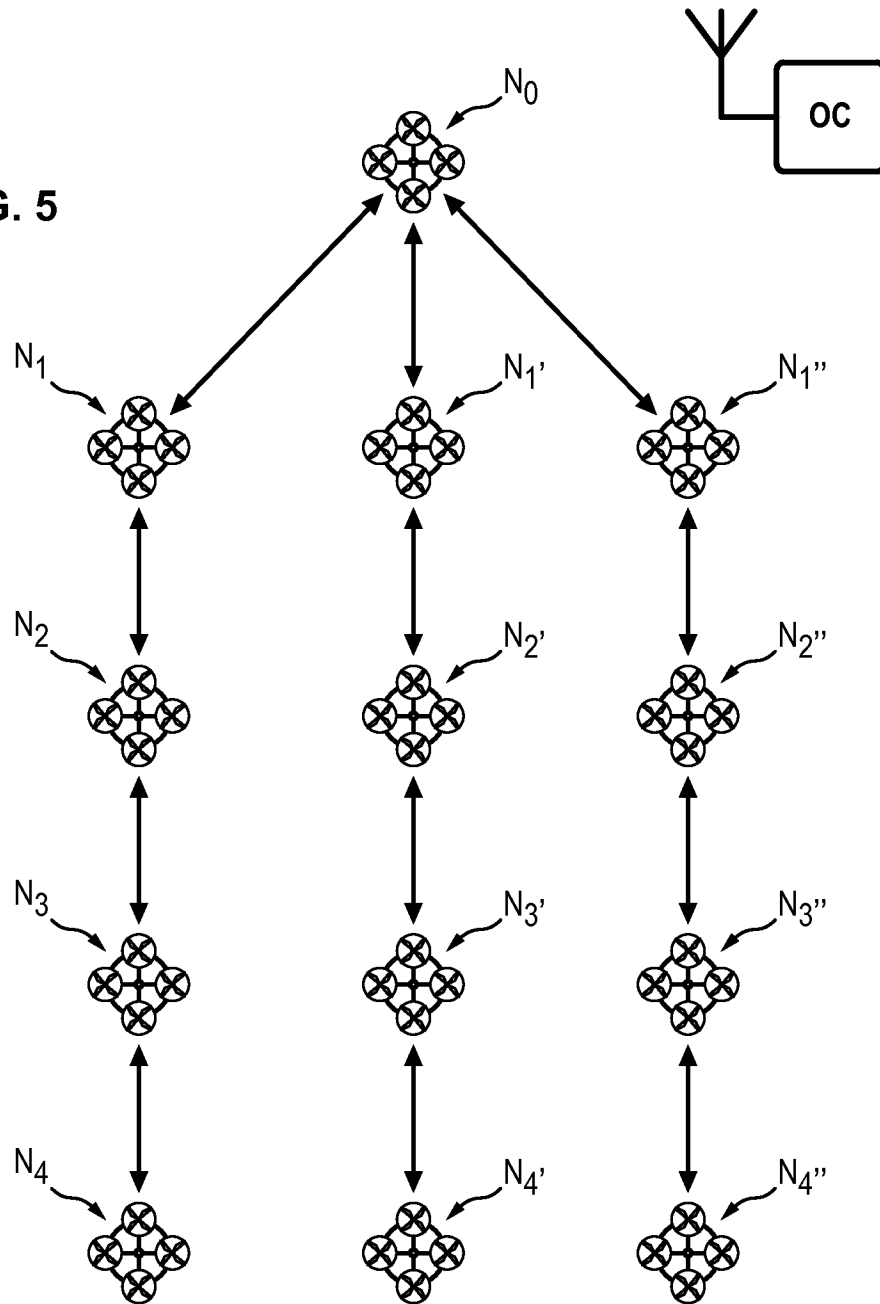
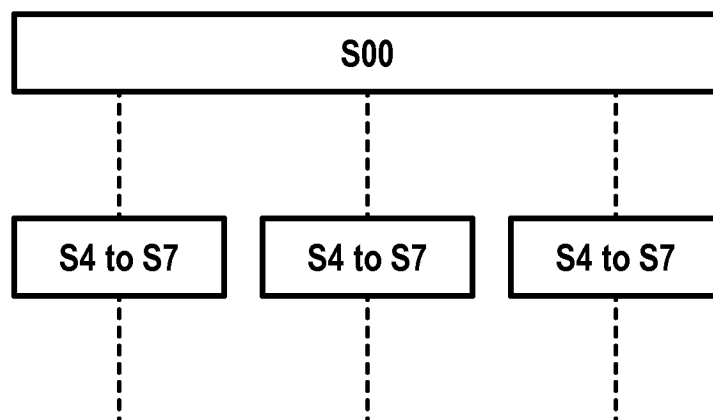


FIG. 6



## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2016/081605

## A. CLASSIFICATION OF SUBJECT MATTER

INV. G05D1/10 H04L12/26 H04L12/751  
ADD. H04L12/24

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)

G05D H04L

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. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
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| Y         | US 2013/123981 A1 (LEE CHANG EUN [KR] ET AL) 16 May 2013 (2013-05-16)<br>abstract<br>paragraph [0009]<br>paragraph [0040] - paragraph [0043];<br>figure 2<br>paragraph [0045] - paragraph [0046];<br>figure 3<br>-----<br>-/- | 1-9                   |



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See patent family annex.

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Date of the actual completion of the international search

21 February 2017

Date of mailing of the international search report

01/03/2017

Name and mailing address of the ISA/

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Bernard, Eddy

## INTERNATIONAL SEARCH REPORT

International application No  
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| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                                                                   |                       |
|------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                | Relevant to claim No. |
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/081605

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date                                                                       |
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