



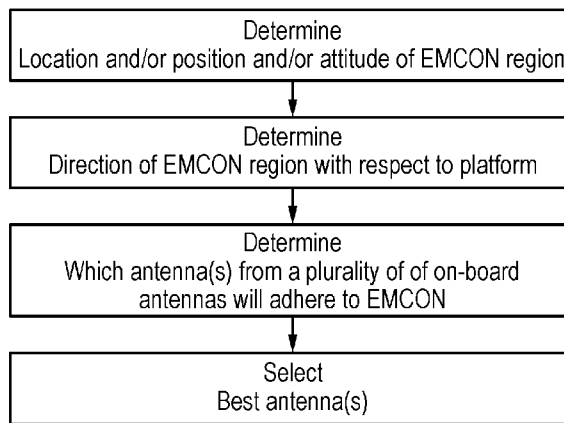
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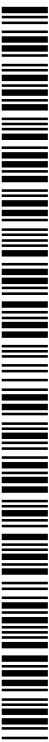
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(54) **Title:** APPARATUS AND METHOD FOR COMMUNICATIONS MANAGEMENT

Fig. 8



(57) **Abstract:** Apparatus for management of communications resources of a moving platform comprising an on-board communications system configured to effect wireless data communication between said moving platform and another node, said communications resources comprising a plurality of wireless communications links and a plurality of antennas associated therewith, the apparatus comprising an antenna analysis and selection module residing with said communications system and configured to: - receive, during a mission from one or more systems/subsystems and/or functions of said moving platform, attribute data representative of said emissions control criteria, said attribute data comprising (i) location data representative of a specified emissions control region, and/or (ii) position and/or attitude and/or velocity data representative of an adversary node defining an emissions control region; - determine, using said attribute data and based on said emissions control criteria, suitability of one or more on-board antennas and/or portions of aperture antenna for supporting said communications requirement; - for each of a plurality of antennas/portions of aperture antenna determined to be suitable for supporting said communications requirement based on said emissions control criteria, determine a quality metric, said quality metric being indicative of a respective performance criterion; and - select one or more of said suitable antennas/portion of aperture antenna having a highest performance criterion, for facilitating said communications requirement.



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## APPARATUS AND METHOD FOR COMMUNICATIONS MANAGEMENT

This invention relates generally to an apparatus and method for communications and information management and, more particularly, but not necessarily exclusively, to an apparatus and method for management of  
5 wireless communications resources between a moving platform and at least one remote recipient.

There are many applications in which it is required to apply a level of management in respect of wireless communications resources and the  
10 management of information, particularly between a moving platform and one or more remote platform(s), and maintain adequate wireless communications therebetween for safe operation of the moving platform and mission success.

For example, in the case of aerial vehicles and, more particularly, unmanned aerial vehicles (UAVs), there is an ongoing and stringent  
15 requirement to maintain an adequate communications link between the aerial vehicle and a ground station, for example, and unexpected loss or degradation of such a communications link can be catastrophic.

A UAS is composed of three main parts, the unmanned air vehicle (UAV), unmanned control station (UCS) and support systems of the UAS (for  
20 pre-mission planning). A UAS Mission System may be composed of the following functional components/subsystems: Mission Management, Communications, Vehicle Health, Navigation System, Airspace Integration, Payload and Power Management. Multiple, different dynamic in-mission planners may reside in one or more of the above-mentioned functional  
25 components/subsystems. In a typical UAV, a dynamic route planner generates a new route, in real time, when there is a change in the operational environment, e.g. severe weather, threat, or a change of circumstances, e.g. an emergency, or a dynamic manoeuvre plan is generated to avoid an airborne obstacle. The aim is thus to maintain safety and the survivability of the aircraft  
30 by determining a feasible route and/or manoeuvre in real time, while avoiding pop-up, static and dynamic obstacles, for example.

However, the operational environment of moving platforms, at least in some applications, can be particularly challenging from a communications perspective. The antennas are normally securely mounted to an aircraft and are not movable relative to the aircraft. An antenna on the aircraft used for transmitting messages will not always be optimally oriented with respect to the recipient as the aircraft manoeuvres. The signal is lost or adversely affected by aircraft orientation, which cause the antenna on the aircraft to be pointed in an unfavourable direction or the path between the transmitting antenna on the aircraft and recipient to be blocked by the aircraft structure (e.g. wing). Thus, a particular on-board antenna may not always be optimally oriented to establish or maintain an adequate communications with an antenna on another node, as the aircraft manoeuvres.

An on-board antenna for transmitting messages may be oriented in an unfavourable direction relative to an imposed emissions control (EMCON) region or with respect to an adversary. Also, the energy radiated in that direction may exceed an acceptable threshold for emissions control, increasing the vulnerability of the node and possibly betraying its existence. Traditionally a platform is required to operate in silence, in order to avoid being overheard. If the communications system was able to adapt and respond accordingly, for example by using an alternate antenna, it may still be possible to maintain communications whilst adhering to EMCON. It would therefore be desirable to provide an intelligent communications management system for a moving platform that is able to adapt and respond dynamically to an uncertain dynamic battlefield environment, such as threats, by managing their communications resources accordingly.

In accordance with an aspect of the present invention, there is provided apparatus for management of communications resources of a moving platform comprising an on-board communications system configured to effect wireless data communication between said moving platform and another node, said communications resources comprising a plurality of wireless communications links and a plurality of antennas associated therewith, the apparatus comprising an antenna analysis and selection module residing with said communications system and configured to:

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- receive, during a mission from one or more systems/subsystems and/or functions of said moving platform, attribute data representative of said emissions control criteria, said attribute data comprising (i) location data representative of a specified emissions control region, and/or (ii) position and/or attitude and/or velocity data representative of an adversary node defining an emissions control region;

- determine, using said attribute data and based on said emissions control criteria, suitability of one or more on-board antennas and/or portions of aperture antenna for supporting said communications requirement;

10 - for each of a plurality of antennas/portions of aperture antenna determined to be suitable for supporting said communications requirement based on said emissions control criteria, determine a quality metric, said quality metric being indicative of a respective performance criterion; and

- select one or more of said suitable antennas/portion of aperture antenna having a highest performance criterion, for facilitating said communications requirement.

The above-mentioned attribute data may, optionally, also include platform movement data. In this case, the platform movement data may comprise (i) instantaneous knowledge of a movement of said moving platform, and/or (ii) future known movement of said moving platform and/or (iii) future predicted movement of said moving platform and/or other platforms in the operational environment.

In an exemplary embodiment, the apparatus may be configured to obtain (i) data representative of a location of a fixed other node with respect to said moving platform, or (ii) data representative of position and/or attitude and/or velocity of a mobile other node with respect to said moving platform; and to:

- determine a direction of said moving platform relative to said fixed/mobile node;

- determine modified antenna pointing data in respect of each said antenna/portion of aperture antenna at said other node and/or said moving platform; and

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- calculate a quality metric for each said antenna/portion of aperture antenna.

Optionally, the apparatus may be configured to determine an antenna pointing metric for each said antenna/portion of aperture antenna, calculate a signal power value for each said antenna/portion of aperture antenna, and determine a signal power metric based on said signal power value and a signal power threshold for each said antenna/portion of aperture antenna, wherein said quality metric is based on said signal power metric.

The above-mentioned modified antenna pointing data may be determined based on data representative of antenna location, antenna pointing, and platform attitude and/or position for said moving platform.

The pointing metric may be indicative of whether said antenna/portion of aperture antenna is pointing in the direction of an emissions control region, based on said modified antenna pointing data, direction/orientation of said moving platform relative to said other node, transmitting antenna gain pattern in respect of said moving platform and receiver antenna gain pattern in respect of said other node.

In an exemplary embodiment, the apparatus may be configured to calculate said quality metric based on calculations of orientation between said moving platform and said other node.

The quality metric may include antenna availability and/or preference and/or compatibility.

In an exemplary embodiment, a signal power value in respect of a communications link for an antenna/portion of aperture antenna may be based on a relative distance between said moving platform and said emissions control region, loss factors, transmitting antenna gain and/or receiving antenna gain. In the case, the relative distance may be a function of time and velocity of said moving platform and/or adversary node.

In accordance with another aspect of the present invention, there is provided a management system for a moving platform comprising a plurality of systems/subsystems and/or functions, a plurality of communications resources

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comprising a plurality of wireless communications links and a plurality of antennas associated therewith, and a communications system configured to effect wireless data communication between said moving platform and another node via said communications resources, wherein said communications system  
5 includes apparatus substantially as described above.

In accordance with yet another aspect of the present invention, there is provided a method of management of communications resources of a moving platform comprising an on-board communications system configured to effect wireless data communication between said moving platform and another node,  
10 said communications resources comprising a plurality of wireless communications links and a plurality of antennas associated therewith, the method comprising using an antenna analysis and selection module residing with said communications system to:

- receive, during a mission from one or more systems/subsystems  
15 and/or functions of said moving platform, attribute data representative of said emissions control criteria, said attribute data comprising (i) location data representative of a specified emissions control region, and/or (ii) position and/or attitude and/or velocity data representative of an adversary node defining an emissions control region;

20 - determine, using said attribute data and based on said emissions control criteria, suitability of one or more on-board antennas and/or portions of aperture antenna for supporting said communications requirement;

- for each of a plurality of antennas/portions of aperture antenna determined to be suitable for supporting said communications requirement  
25 based on said emissions control criteria, determine a quality metric, said quality metric being indicative of a respective performance criterion; and

- select one or more of said suitable antennas/portion of aperture antenna having a highest performance criterion, for facilitating said communications requirement.

30

These and other aspects of the present invention will be apparent from the following specific description, in which embodiments of the present invention are described, by way of examples only, and with reference to the accompanying drawings, in which:

5           Figure 1 is a schematic block diagram illustrating a moving platform management system, including apparatus according to an exemplary embodiment of the present invention;

          Figure 2 is a schematic block diagram illustrating some principal features of the moving platform management system of Figure 1 in more detail;

10           Figure 3 is a schematic block diagram illustrating an exemplary implementation of antenna selection incorporating apparatus according to an exemplary embodiment of the present invention;

          Figure 4 is a schematic block diagram illustrating an exemplary implementation of antenna selection incorporating apparatus according to an  
15           exemplary embodiment of the present invention;

          Figure 5 is a schematic block diagram illustrating an exemplary implementation of antenna selection incorporating apparatus according to an  
          exemplary embodiment of the present invention;

          Figure 6 is a schematic block diagram of an antenna analysis and  
20           selection module according to an exemplary embodiment of the present invention;

          Figure 7 is a flow chart illustrating the principal steps in an antenna selection method according to an exemplary embodiment of the present invention;

25           Figure 8 is a flow chart illustrating the principal steps of an exemplary implementation of antenna “goodness” function for use in a method according to an exemplary embodiment of the present invention;

          Figure 9 is a flow chart illustrating the principal steps in a method for determining an antenna metric for use in apparatus according to an exemplary  
30           embodiment of the present invention; and



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Figures 10, 11 and 12 illustrate schematically some specific circumstances in which exemplary embodiments of the present invention may be employed.

Antenna selection, in accordance with exemplary embodiments of the present invention, considers node motion to determine the best antenna for optimal communications prevailing situational and/or environmental constraints and without violating prevailing emissions control criteria. It will be apparent to a person skilled in the art that antennas are normally securely mounted to an aircraft, or other moving platform, and are not moveable relative thereto. An antenna on a platform used for transmitting messages will not always be optimally oriented with respect to the recipient as the platform manoeuvres. The signal may be lost or adversely affected by platform orientation during, for example in the case of an aircraft, banking manoeuvres or a change in heading, which cause the aircraft antenna to be pointed in an unfavourable direction or the path between the antenna and recipient to be blocked by the aircraft structure (e.g. wing). Using antenna selection, in accordance with exemplary embodiments of the present invention, an alternate antenna may be selected that could otherwise result in a loss of communications. In addition, antenna selection in accordance with exemplary embodiments of the present invention also considers emissions control (EMCON) criteria to determine the best antenna for optimal communications without violating EMCON. During restricted emissions control, it may be desirable to maintain contact with a fixed or mobile node while operating, without betraying its existence. An antenna on the platform used for transmitting messages may be pointed in an unfavourable direction with respect to an imposed EMCON region or with respect to an adversary. Furthermore, the energy radiated in that direction may exceed an acceptable threshold for emissions control, thus increasing the vulnerability of the node and exposing its existence. With antenna selection according to exemplary embodiments of the present invention, an alternate antenna is selected to maintain communications whilst adhering to emissions control.

Exemplary embodiments of the present invention provide an intelligent communications management system configured to maintain adequate connectivity throughout a mission, dynamically responding to unplanned events,

e.g. any unexpected degradation or loss of a wireless data link in real (or near real) time, as well as emission control strategies and policies.

Traditionally, all aspects of communications, such as multiple, different communications links/radios, reside within the communications system (of an aircraft for example). Each of the communications links/radios is an independent system and usually dedicated to transmitting specific messages. If, for example, an unexpected event occurs, such as a link failure or degradation, change in mission priorities and new operational constraints, the system is unable to adapt and respond accordingly to maintain adequate communications. The communications system is usually a dedicated system without much interaction, if not at all, with other platform systems and avionics applications on the platform. Furthermore, in some cases, a higher-level planner is required, which resides outside the communications system, to meet the changing demands of the platform and new operational constraints.

In contrast, in aspects of the present invention, it is recognised that all functions/systems on a platform (e.g. mission management, communications health management) work in concert to achieve objectives and to maintain integrity of the platform. For example, health monitoring can be used to ensure that communications failure will not lead to catastrophe. Thus, and as will be described in more detail later, the communications system is concerned with low-level decision making, i.e. day-to-day running and decisions. In one exemplary embodiment, the communications management system manages a plurality of communications resources, namely its on-board antennas in aspects of the present invention, for an air vehicle. Based on a list or look-up table of available and/or preferred antennas, it determines the best antenna to use from a plurality of antennas in order to maintain connectivity. However, in aspects of the present invention, if it is unable to resolve a communications issue, for example, all available links to it have failed or severely degraded links, then higher-level planning is invoked via apparatus according to exemplary embodiments of the present invention. In this case, the communications interface may be configured to request that the dynamic planning and management system generate a modified plan to maintain adequate communications. For example, in aspects of the present invention, the higher-

level planner selects to use a sensor system's (e.g. RADAR) antenna. In another example, the higher-level planner selects to use an antenna and manoeuvre the platform to optimise communications. In other exemplary embodiments, higher-level planning is invoked in response to receiving  
5 information from other parts of the platform, if an adversary is detected for example, in order to generate a communications plan accordingly.

In one exemplary embodiment, apparatus according to the invention may operate in the communications management system, to perform antenna selection and transmit data representative of the selected antenna(s) directly to  
10 an antenna controller, for example, to establish communications. In other exemplary embodiments, however, apparatus according to the invention may operate outside of the communications system within a dynamic planning and management system, to perform antenna selection and transmit data representative of the selected antenna(s) directly to the communications  
15 system/radio to establish communications. In yet other exemplary embodiments, both the aforementioned implementations may co-exist within a single platform.

Thus, in one embodiment, it is envisaged that the aircraft's future flight trajectory and/or route and/or manoeuvre is provided to the dynamic planning  
20 and management system to assess the impact of the trajectory and/or route and/or manoeuvre plan on the communications plan and select antennas for use therein, to maintain adequate communications. In another embodiment, it is envisaged that the communications system, coupled with apparatus according to an exemplary embodiment of the present invention, uses instant  
25 knowledge regarding the aircraft's current manoeuvre (e.g. heading or banking), or indeed current knowledge of any other situational/environmental condition affecting a current communications link, to select one or more appropriate antennas in order to maintain adequate communications.

In another exemplary embodiment, an antenna selection module may  
30 reside within higher-planning, for example: to plan the use of a sensor system's antenna for communications, which can only be done at a higher-level; to generate a communications plan based on received future platform manoeuvre;

and to generate a communications plan as part of platform protection when operating under EMCON.

However, it will be appreciated, that the present invention is in no way intended to be limited as to the location within the overall platform system of the antenna selection module provided by exemplary embodiments of the present invention. For example, an antenna selection module could be provided as part of a higher-level planning element and/or within a message routing function.

It will be appreciated by a person skilled in the art that the proposed antenna analysis and/or antenna selection may be employed equally effectively:

- 10 - during an initial planning phase, i.e. pre-mission planning, wherein the antenna analysis function may be used during the route and/or communications planning phase;
- during mission execution, when dynamic communications planning (higher-level planning) is performed, in relation to imposed EMCON and/or platform movement, whereby platform movement can be based on: (i) a priori known future platform manoeuvre and/or route and/or trajectory based on data representative thereof (e.g. attitude) received from the dynamic planner or human planner, and (ii) predicted future platform manoeuvre and/or trajectory and/or route; or
- 15
- 20 - during mission execution, when the communications management system (lower-level planning) is required to be performed in real (or near real) time, without warning, as a result of a platform movement, based on data representative of a platform movement, for example instantaneous manoeuvre data (e.g. current attitude), received from
- 25 one or more platform systems.

The operational environment can comprise a plurality of nodes, in the air and on the ground (e.g. airborne platform, mobile and/or fixed control station). These nodes interact with each other over line-of-sight (LOS) or via relay(s), cooperatively working together sharing information, responsibilities and tasks, and exchanging command and control data. In general, a node has multiple data links/radios to enable it to interact with other nodes via different networks, as required.

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In the following description of the drawings, a communications management apparatus according to an exemplary embodiment of the invention will be described in relation to a UAV. However, it is to be understood that the present invention is not necessarily intended to be limited in this regard and, indeed, finds application in many other types of moving platform management systems in which it is required to manage communications in an intelligent manner and, for the avoidance of doubt, this would include road and sea-going vehicles, as well as manned aerial vehicles.

Referring to Figure 1 of the drawings, an intelligent management module 10, including an intelligent communications management interface according to an exemplary embodiment of an aspect of the present invention, is illustrated schematically at the centre of a typical UAV system. The UAV comprises several functional components/sub-systems, including communications, navigation system, prognostics and health, etc. Thus, in the schematic diagram of Figure 1, the intelligent communications management module 10 is depicted as being communicably coupled to other parts 12 of the vehicle. It can be seen from the diagram that two-way data communication is provided between the other parts 12 of the vehicle and the intelligent management module 10. The other parts 12 of the vehicle may comprise a plurality of functional components, possibly including, but not necessarily limited to, a prognostics and health functional component, a navigation system, a control authority, e.g. pilot or on-board authority with executive decision functionality, a utilities management functional component, defensive aids functional component, data transfer and recording functional component, and an HMI (Human Machine Interface) functional component. Any and all of these functional components are configured to provide data, such as navigation data and detected threat, to the intelligent communications management module 10 for use in its decision making.

The intelligent management module 10 is also configured to receive data from a plurality of avionics applications. Such avionics applications may, for example, comprise civil and/or military applications, such as tactical datalink applications 14, sensor applications 16 (e.g. video, images, etc), mission management applications 18 (for example, command and control data), and

platform management applications 20 (e.g. health of node). It will be appreciated that this is not a comprehensive list of typical or possible applications from which the intelligent communications management system may receive data and others will be apparent to a person skilled in the art, depending upon the specific application within which the present invention is to be employed.

The intelligent management module 10 is configured to manage multiple communications links (generally depicted in Figure 1 as 'network' 21), which may include (but are not limited to) tactical data links, satellite links, free space optical links and other data links, as will be apparent to a person skilled in the art, and it may have different antenna types (depicted generally at 22) to manage including, but not limited to, omni-directional and directional antennas, shared aperture antennas, fixed or beam-steerable antennas. The antennas may be shared between communications links/radios, or with sensor systems. In the example illustrated in Figure 1, the communications from the platform antennas 22 are directed at an end user 23, for example, the remote pilot of a UAV located at a ground station. However, communications are not intended to be limited in this regard, and the type and receiver of communications managed by exemplary embodiments of the present invention may vary greatly, depending on application, system configuration and requirements.

Thus, the Intelligent Communications Management System has access to a wealth of information, such as mission environment and internal state of the node, and uses this information in its decision making. The environment represents the systems knowledge about the outside world, including network and link performance, other nodes in the network environment, dynamic threats, terrain, obstacles and weather data. The internal state is a representation of the internals of the system. It collects internal data from contributing sub-systems, such as real-time node attitude and position, current operational mode and applications' communications requirements, and it retains communications/information exchange plans, policies and information about installed resources (e.g. communications links, antennas).

A database (not shown) provides the intelligent communications management module 10 with knowledge about its mission environment and

internal state, and stores data policies and plans. The environmental data represents the system's knowledge about the outside world, including network and link performance, other nodes in the network environment, dynamic threats, terrain, obstacles and weather data. The internal state is a representation of the internal sub-systems of the system. The database collects internal data from contributing sub-systems, such as real-time node attitude and position, current operational mode and the communications requirements of individual applications, and it retains communications/information exchange plans, policies and information about installed resources (e.g. communication systems, antennas, etc). For example, an antenna performance model (i.e. antenna gain patterns) would be stored for each node to be used by the intelligent management module 10 in respect of, for example, antenna selection. In this example, the antenna gain patterns are mapped with respect to the body reference frame of the node, i.e. location of the antenna on the node.

It will be appreciated that the term "database" used above, is used simply to define one or more repositories for the required data. In one exemplary embodiment, the database may be a single repository, common to the moving platform, and accessed by the intelligent management module 10 (or at least dedicated thereto) in which all of the aforementioned data is stored for use thereby. In other exemplary embodiments, such a single repository may be used to store only a sub-set of the data, such as policies and installed antenna performance, to be accessed as required, with data that changes dynamically during a flight or mission, such as node position and operational mode, being sent directly from a relevant part of the overall platform management system to the intelligent communications management module.

Also illustrated in Figure 1, are data inputs representative of constraints 24, platform demands, and policy 28. These factors and the manner in which data representative thereof can be obtained will be known to a person skilled in the art. The policy 28, for example, may be designed by the network designer. A copy of this policy may reside within the intelligent management module 10, or accessible thereby. The policy contains a set of rules that, for example, define how links and antennas can be used, what action to take in the event of a hardware fault and/or loss of signal, and how avionics applications can be

served to support the mission. Such rules may be expressed as condition-action pairs (i.e. IF condition THEN action) and/or in look-up tables.

Thus, the Intelligent Communications Management System can be divided into two distinct parts with inputs and outputs to each other and other parts of the aircraft or ground-based system, as shown in Figure 2. In another  
5 implementation, the different functions may reside in one box; this implementation may be appropriate for manned systems, such as a manned air vehicle.

EMCON or 'emission control' policies and strategies are used to prevent  
10 detection, identification and location of a moving platform, and/or minimise interference among the node systems of the moving platform. Whilst EMCON conditions (and, therefore policies and strategies for implementing them) vary, according to the application as well as particular circumstances, the underlying principles of EMCON will be well known to a person skilled in the art. Setting  
15 EMCON requires four basic steps: criteria, objectives, notification and authority. The criteria specify the overarching planning, procedure and responsibility for EMCON policy or strategy. The objectives, as will be apparent, define the desired result of the EMCON policy or strategy and may include, for example, minimising detection by third party sensors, allowing effective command and  
20 control (C2) communications between nodes, supporting operational deception (OPDEC), supporting operations security (OPSEC), minimising interference among nodes, and degrading effectiveness of third party C2 communications. It is these objectives that may be used by a communications planning module according to an exemplary embodiment of the present invention (in addition to  
25 node position/orientation and antenna type) to determine the suitability of an antenna for a particular information exchange when EMCON restrictions prevail, and/or the communication mode (e.g. output power) that can be used for a selected antenna to support that information exchange.

For completeness, the notification criterion specifies the parties to be  
30 notified of the EMCON policy or strategy, and the manner in which the criteria will be notified and monitored. Finally, authority defines the party or parties authorised to impose an EMCON condition in any particular case.



Referring now to Figure 2 of the drawings, the intelligent management module 10 comprises a dynamic planning and management module 11 and a communications management system 42. The communications management system 42 is concerned with low-level decision making. When it is unable to resolve certain communications issues, then higher-level planning is invoked, i.e. it is configured to generate a plan request to the Dynamic Planning and Management unit (i.e. higher-level planning) in order to maintain adequate communications. In this case, a plan is generated for resolving communication issues, taking into account, not only prevailing situational and/or environmental conditions (including platform position/orientation, etc.) but also prevailing EMCON policy or strategy with respect to those conditions. A plan in this context may, for example, consist of data representative of a selected antenna together with power control data configured to control the power emissions from the selected antenna, to maintain communications without violating emission control criteria. In an alternative exemplary embodiment, the plan may consist of data representative of a selected antenna together with a node manoeuvre, in order to maintain communications. In yet another alternative exemplary embodiment, the plan involves the use of a sensor system's (e.g. RADAR) antenna or aperture antenna. In some cases, authorisation from the vehicle's decision maker will be required, especially if it involves changes to the platform behaviour (e.g. node manoeuvre) or the use of another system's resources (e.g. sensor system's antenna).

In the example shown, the dynamic planning and management module 11 comprises a dynamic planner 40 and a manager 41, that provides an interface between the dynamic planner 40 and the communications management system 42, as will be described in more detail below.

In exemplary embodiments of the present invention, at least parts 12 of the rest of the aircraft are communicably coupled to the communications management system 42 and the intelligent communications management system 10 works cooperatively with the rest of the node functional components/sub-systems to achieve the mission goal: to provide information for situational awareness and safety purposes, and to receive information used in its decision making.

The intelligent communications management system 10 receives a large quantity of information from different parts of the platform, which it can use in its decision-making processes, as described in more detail below. It is consequently mission-, motion-, and network-aware and understands what resources it has to manage, as well as their performance capability. Mission-awareness provides information on what the platform is trying to achieve. There can be various operational modes, that might include normal operation, reconnaissance, under attack, attack, taxiing, landing, etc. This is common to the entire platform and is of particular concern to the communications module 42. The communications module 42 monitors and evaluates current network performance, so it is network-aware. Network awareness information may also be shared with the dynamic planning and management 11 for planning purposes. Motion-awareness enables communications module 42 to intelligently route information along the best path to ensure connectivity to a fixed and/or mobile node is maintained, for example, in response to an unexpected and possibly a sharp manoeuvre. The dynamic planning and management 11 is also motion-aware, in that it may receive a priori future route and/or manoeuvre plan in order to assess its impact on communications and to select suitable communications link(s), including antennas. The dynamic planning and management 11 is aware of other platform demands, such as emission demands. It is thus, mission-, network-, motion- and platform-aware, enabling the intelligent communications management system 10 to dynamically adapt and respond to unexpected events, e.g. change in mission priorities, mission environment and network conditions.

Referring back to Figure 2 of the drawings, dynamic planners are also widely known and used in many different applications. A dynamic planner is typically provided in respect of, for example, a UAV for planning its route/path, from a start point (typically, but not always) to a defined end point (and optionally including any defined waypoints therebetween), as well as planning its manoeuvre and/or trajectory. Known dynamic planners (path, manoeuvre and trajectory) tend to base their calculation on several factors, such as terrain, threat, weather, and platform constraints. For example, a manoeuvre may be calculated to avoid an airborne obstacle or a path calculated to avoid detection

of the UAV. Other types of dynamic planners for route planning in many different applications will be known to a person skilled in the art and the present invention is not necessarily intended to be limited in this regard. However, in prior art systems, the need to perform dynamic communications management in respect of a platform movement and/or as part of platform protection to avoid detection (in the case of EMCON), has not been considered.

In this exemplary embodiment of the present invention, the management function 41 of the dynamic planning and management module 11 may be configured to interface with the dynamic planner 40, the communications management system 42 (for example, via a communications executive, as will be described in more detail below) and other parts of the node system 12. In this case, the management function 41 may be responsible for generating plan requests and providing attributes to the dynamic planner 40, evaluating new plans, selecting the best plan, requesting authorisation from the platform/pilot to execute the new plan (e.g. use a sensor system for communication purposes, manoeuvre a node), in order to optimise communications.

In the following method, according to an exemplary embodiment of the present invention, for the selection of antennas in an aircraft (or other moving platform) communications system is described in more detail. It will be appreciated that antenna selection methods according to various exemplary embodiments of the present invention, can exist in their own right, be part of a planning element, or be part of another system, such as message routing, and the present invention is not necessarily intended to be in any way limited in this regard.

Referring to Figure 3 of the drawings, a node/platform has a communications link with two antennas 501, 502 that can be used to support a wireless data link 503 for information exchange with another node. For example, one antenna 501 may have a different gain pattern to the other antenna 502 (e.g. omni-directional and directional antennas), or both antennas 501, 502 may have the same gain pattern but be mounted at different locations on the node. In this case, an antenna selection method according to an exemplary embodiment of the invention (depicted at 504) evaluates each of the antennas 501, 502 and selects the antenna determined to offer the best

performance (including emissions control constraints). The selection is passed onto an antenna controller (not shown) for execution. For example, the antenna controller interfaces between an antenna selection unit 504 and an antenna switch 505 (e.g. low level controls). Upon receiving the selected antenna choice from the antenna selection unit 504, it sends lower-level control commands to execute the selection to either one or other of the antennas 501, 502. The antenna controller is aware of the success or failure of the action carried out to implement the selection and, in the event of a failure, the controller is configured to report the failure to the antenna selection unit 504 for alternate or remedial action.

Referring to Figure 4 of the drawings, the antennas 601, 602, 603 may be shared between various communications links 604, 605, or with sensor systems. The antenna selection method (depicted at 606) according to an exemplary embodiment of the present invention evaluates each of the antennas 601, 602, 603 and then selects the antenna determined to offer the best performance (includes adherence to emissions control) for a given communications link 604, 605. Once again, data representative of the selected antenna is sent from the antenna selection unit 606, via an antenna controller 607 to an antenna switch 608, for example, to couple a specified link to the selected antenna.

One or more communications links may also share an aperture antenna with other systems (such as RADAR, ESM and Navigation), wherein the shared antenna (also known as a shared aperture antenna) is composed of multiple portions. Referring to Figure 5 of the drawings, the multiple portions of an aperture antenna 701, 702, 703 may be shared between various communications links 704, 705, and/or with other systems 708 (e.g. sensor). The antenna selection method (depicted at 706) according to an exemplary embodiment of the present invention evaluates each of the portions of the aperture antenna 701, 702, 703 and then selects the portion of the antenna determined to offer the best performance (includes adherence to emissions control) for a given communications link 704, 705. Once again, data representative of the selected antenna is sent from the antenna selection unit 606, via an antenna controller 707 for implementation, in order to couple a

specified link to the selected antenna. Furthermore, for a selected portion of an aperture antenna pertaining to a sensor (e.g. RADAR), this may require authorisation from the platform decision maker regarding the use of this antenna before use.

5 Evaluation of the antennas, and selection of the 'best' antenna, may be performed on the basis of the current position, attitude and/or velocity of the node(s) and it may include predicted future values thereof. In other exemplary embodiments, evaluation of the antennas, and subsequent selection, may be based on *a priori* known values, such as manoeuvre, trajectory, position and  
10 attitude of node(s) (based on a manoeuvre and/or trajectory plan calculated by the dynamic planner, or otherwise). This method, once again, evaluates the antennas based on node position, node attitude and the (known) antenna gain characteristics of the various antennas on the node to dynamically select which of the various antennas to use to communicate with the recipient node or with a  
15 source node. The antenna with the best performance is selected for the communications link and the selection is passed to the antenna controller for execution.

Referring to Figure 6, the antenna selection module comprises an antenna analysis function and antenna selection function. An antenna analysis  
20 function determines the suitability of one or more antennas, or shared aperture antennas, to be used for either transmission or reception of messages; and an antenna selection function then selects the 'best' antenna(s) to route a message. The antenna analysis is based on a plurality of factors, such as antenna availability, antenna compatibility, antenna preferences, antenna  
25 pointing, location and performance, estimated and/or measured network performance, platform movement, EMCON, operational mode, policy and communications requirements for platform application. Antenna Availability represents whether an antenna is available for communications e.g. in good working order or not. Antenna Preference represents the preference of using  
30 an antenna for communications. For example, the preference for using a communications antenna is assigned a 10-value, while the preference for using a RADAR antenna is assigned a 5-value. Antenna Compatibility determines whether the antenna can support the waveform needed to transmit or receive a

signal (e.g. cannot use a 5GHz antenna to transmit or receive a signal operating at 1GHz). The antenna availability, antenna compatibility and antenna preference can be determined using a look-up table.

Referring to Figure 7 of the drawings, a flow chart is provided, which illustrates a method of one embodiment of antenna selection, namely the selection of a transmitting antenna (or portion of an aperture antenna). To select a receiving antenna, a similar method, as that illustrated in Figure 7, can be followed. In the illustrated method, node movement at the source and/or destination is considered (it is noted here that the recipient node may be a fixed or mobile node. For example, the recipient node could be a fixed ground station, or it could be a mobile, airborne or ground node, or even a satellite). The method begins by determining, at step 801, the position and/or attitude of the recipient node. In one exemplary embodiment, the position and attitude of other nodes can be obtained via in-mission updates, with which a person skilled in the art will be familiar. For example, the node broadcasts its own position and heading. In another exemplary embodiment, the position of a fixed node is determined by accessing the database. In another exemplary embodiment, the position of the mobile node is predicted based on past trajectory and heading data, for example (shared via broadcasts). In yet another exemplary embodiment, location and attitude can be inferred from previously received messages from a node.

At step 802, the method proceeds with the determination of the direction of the recipient node with respect to the source node. In an exemplary embodiment, this method step comprises calculating a vector based on the position of the two nodes, wherein the source node could, in accordance with one exemplary embodiment, could be provided by satellite data for example.

At step 804, the method proceeds with determining the antenna pointing loss with respect to the transmitting node and then proceeds with determining the antenna pointing loss with respect to the receiver. The antenna pointing loss, for either a transmitter or receiver antenna, is a function of antenna position, antenna gain (at source or recipient) and node attitude.

The antenna position can be described as the physical location of the antenna (e.g. in terms of attitude) on a node and the antenna pointing. The antenna position attributes are accessed via a database. It will be apparent to a person skilled in the art, a “new” antenna position (i.e. “new” mount and “new” pointing) is determined as a function of “stored” antenna position, node attitude and node position (e.g. longitude, latitude, altitude). The “new” antenna pointing is then used to determine the antenna pointing loss (i.e. the loss due to node manoeuvre) from the antenna gain pattern.

At step 805, the method determines the suitability (i.e. the “goodness”) of the antenna to support the required communications link, i.e. by estimating the quality of the communications link if a particular antenna is used. The estimate considers the effect of node manoeuvre on the quality of the link, in terms of antenna pointing loss(es) (from the previous step) and considers other loss factors, such as free-space propagation loss and atmospheric loss.

Referring to Figure 8 of the drawings, a flow chart is provided to illustrate an implementation of an antenna “goodness” function that may be used, and the following exemplary method describes how the suitability of the antenna for communications may be determined.

The method starts with estimating the SNR of the communication links for a given antenna. The SNR is estimated in order to determine the impact of node manoeuvre on the signal quality. The SNR estimation includes the antenna pointing losses, free-space propagation loss, and the gains for transmitting and receiving antennas. Additional losses can also be considered e.g. atmospheric loss. The calculation can, for example, be based on the Friis Transmission formula, but other appropriate equations will be apparent to a person skilled in the art.

The method proceeds with calculating a signal quality metric for a given antenna. The metric can be based on the estimated SNR against a pre-defined threshold. The metric may have a value between 0 and 1.

The method proceeds with calculating the Antenna Metric. In one embodiment, the antenna metric may have a value between 0 and 10, for

example. This metric can also be based on the estimated signal quality and Antenna Availability and/or Antenna Compatibility and/or Antenna Preference.

In another embodiment, the link quality for a given antenna may also be determined, in terms of throughput and latency. In which case, link quality can be based on the estimated SNR. For example, throughput can be calculated by using Shannon's theorem,  $C = W \log_2 (1 + \text{SNR})$ . The Antenna Metric can then be based on the estimated link quality and Antenna Availability.

Referring back to Figure 7, at the next step 808, the best antenna from amongst a plurality of on-board antennas is selected either to transmit information to the recipient node or to receive information from a source node. The method may also be configured to select more than one "best" antenna to transmit the same message, for example for network redundancy implementations. The selection is based on the antenna with the highest metric.

Thus, the above-described method has, for simplicity, been provided to illustrate generally the concept of antenna selection based on node manoeuvre attributes, when no EMCON conditions are imposed. In exemplary embodiments of the present invention, the method is expanded to provide a method of antenna selection in moving platform (e.g. aircraft) communications systems, when the communications system has been informed that the respective node is required to operate under EMCON conditions.

Referring to Figure 8 of the drawings, the illustrated flow chart demonstrates the process of antenna analysis and selection whilst considering emissions control for a given antenna. The aim is determine whether the use of a transmitting antenna will expose the platform i.e. violate emissions control. Thus, the antenna analysis function receives data representative of the location or position and attitude of the EMCON region (e.g. from another platform system); then for each antenna, it determines whether the antenna is pointing in the direction of the EMCON region (based on its understanding of where it's antenna is physically located on the node and pointing, and node position and location); if so, it determines whether a hypothetical transmission will violate EMCON; based on the analysis it determines the "goodness" of the antenna to



adhere to EMCON, and finally selects the best antenna or antennas to use from a plurality of on-board antennas.

A method according to an exemplary embodiment of the present invention begins with determining the location of the emissions control region, wherein a fixed adversary resides. This information can be obtained via  
5 dynamic in-mission updates, or by accessing a database. The emissions control region can be defined in terms of longitude, latitude, and altitude. In another embodiment, the method determines the position of the emissions control region for a known mobile adversary, as well as other attributes, such as  
10 attitude of the adversary.

The method proceeds with determining the direction of the EMCON region with respect to the node. In one embodiment, the position of the node is provided by satellite data. The position of the EMCON region is determined in the previous step.

15 The method proceeds with determining whether an antenna will adhere to emissions control or not, with respect to the defined EMCON region. An Antenna Metric is calculated to determine how good or bad the antenna is. The metric considers the (new) antenna pointing, antenna radiation pattern (in terms of mainlobe, sidelobes and beamwidth), the location of the EMCON region and  
20 the signal quality, in terms of SNR, in the direction of the EMCON region. Signal quality varies with distance between two points, decreasing in value as the distance increases. At a particular distance between the two points, the signal is low enough that it becomes undetectable. Hence, a given antenna could be pointing towards the EMCON region (fixed or mobile adversary), but its  
25 emission at certain distance from the node is below a SNR threshold. In which case, there is no EMCON violation. Hence this step determines whether an antenna will adhere to emissions control. The antenna pointing vector (i.e. in what direction is the antenna pointing) is determined by considering the antenna position, node attitude and node position.

30 An exemplary method that can be used to calculate the antenna metric is illustrated schematically in Figure 9 of the drawings, and will be described later.

Thus, referring back to Figure 8, the method proceeds with selecting the best antenna or antennas from among a plurality of on-board antennas for use while operating under emissions control. Note: the selection does not mean that the antenna will be suitable to route a message in an expedient fashion to the destination, for example in terms of throughput or latency. The path from the node to the recipient will need to be assessed in terms of link and network performance, and the application's communications requirements in order to deliver a message.

Referring to Figure 9 of the drawings, there is provided a flow chart which is illustrative of the principal steps that may be performed in the implementation of an exemplary antenna "goodness" function, as described above.

The illustrated method describes how the suitability of an antenna for communications is determined while operating under EMCON or avoiding to be heard by an adversary.

The first step starts by determining whether the antenna is pointing in the direction of the EMCON region (fixed or mobile adversary). This is based on the antenna pointing vector, antenna radiation pattern and the location of the EMCON region or adversary with respect to the node. A binary 1 or 0 may be used to represent whether the antenna is pointing in the direction of the EMCON region or adversary node, or not.

The next step estimates a signal quality, such as the SNR, at a given distance from the node in the direction of the EMCON region. For example, the distance can be defined as the distance from the node to the start of the EMCON region, or the distance from the node to a pre-defined distance before the EMCON region (e.g. 1 Nautical Mile before EMCON region begins). The Friis Transmission equation may, for example, be used to estimate the SNR, but other appropriate equations will be apparent to a person skilled in the art.

The method proceeds by determining a SNR Metric based on the estimated SNR to determine if the SNR will violate EMCON or not. The SNR Metric can be a value in the range of 0 and 1. In one embodiment, a look-up table can then be used to map the SNR metric directly to two QoS states of high SNR and low SNR.

The final step calculates an Antenna Metric. The Antenna Metric can be based on the SNR Metric.

In one embodiment, the antenna selection approach uses a priori knowledge regarding the aircraft's future flight trajectory and/or route to select appropriate antenna. For example, in one embodiment, the antenna selection approach is coupled to the aircraft's route planner or mission management system, which plans the flight path for the aircraft. The trajectory and/or route plan is received by the Antenna Selection unit a priori; antenna selection chooses the best antenna or best antennas for the aircraft over some future interval of time.

In some exemplary embodiments of the present invention, the antenna selection approach may use *a priori* knowledge regarding the aircraft's future flight manoeuvre (e.g. heading) to select appropriate antenna. For example, in one embodiment, the antenna selection approach is coupled to aircraft's dynamic manoeuvre planner, which plans the heading the aircraft will take. A manoeuvre plan is received *a priori*; antenna selection chooses the best antenna for the aircraft over some future interval of time. One example of a manoeuvre plan is a sense and avoid plan for avoiding obstacles.

In another exemplary embodiment, the antenna selection method may use instant knowledge regarding the aircraft's current manoeuvre (e.g. heading, banking) to select appropriate antenna. In one embodiment, the antenna selection approach is coupled to the vehicle control system or other system to receive current attributes, such as position and attitude that the aircraft is undertaking.

In yet another exemplary implementation, the antenna selection method uses current knowledge and future calculations to determine the best antenna to use. The future calculation can be based on predicted or *a priori* knowledge of future node movement (e.g. trajectory, manoeuvre and route) and attitude. As an example, based on the current attributes an antenna is good enough to use, but in the future it will no longer be suitable. For example, at some time in the future (e.g. over the next 2 minutes travel time) the antenna will no longer adhere to emissions control, because the distance between the "good" node

and (fixed or mobile) adversary node is decreasing as a function of time. In another example, in the future (e.g. over the next 3 minutes travel time) the antenna will not be optimally orientated with respect to another. As a result, the antenna is given a low metric (i.e. not suitable). As such, the antenna metric  
5 comprises of a current metric and one or more future metrics, based on predicted or a priori known attributes, such as trajectory and attitude.

In some exemplary embodiments of the present invention, for a shared aperture antenna, the abovementioned can be used to evaluate portions of the aperture antenna and select the portion of aperture antenna determined to offer  
10 the best performance (includes adherence to emissions control) for a given communications link.

In some exemplary embodiments, the antenna selection result may be accompanied by an additional plan element for enabling the antenna selection to be performed adequately, whilst adhering to prevailing EMCON conditions.  
15 Thus, in one exemplary embodiment, antenna selection combined with a node manoeuvre may be required to maintain adequate communications without violating emissions control. In other exemplary embodiments, antenna selection is combined with power control to maintain adequate communications without violating emissions control.

20 Examples of embodiments of the present invention, when in use, will now be described with reference to Figures 10, 11 and 12 of the drawings. Thus, referring to Figure 10 of the drawings, an aircraft 130 can be seen using its left-hand antenna for transmission to a recipient node 132 along its flight path. As the aircraft 130 manoeuvres, the left-side antenna is no longer pointing in the  
25 direction of the recipient 132. Instead, the antenna selection method described above, having determined that there are no prevailing EMCON restrictions operating, causes the antenna at the front of the aircraft 130, which has line-of-sight with the recipient 132, to be selected and used to maintain the link with the recipient 132. The recipient 132 may be a fixed or mobile node.

30 Referring to Figure 11 of the drawings, an aircraft 230 having a directional transmission antenna pattern 232 to its right-hand side and an additional omni-directional transmission pattern 234 is illustrated schematically.

On its planned flight path, it communicates with another node using the omnidirectional antenna. On course, dynamic emissions control is imposed in-flight in respect of the top-left quadrant 236. It will be appreciated that the omnidirectional antenna is now pointing in the direction of a prohibited region and the energy radiation from the antenna is significant to violate the emissions control. Thus, the apparatus of the present invention is triggered to cause the directional transmission antenna mounted on the right-hand side of the aircraft 230 to be used instead so as to maintain a link with the recipient node 238, whilst adhering to emissions control. If the recipient node 238 had been located to the bottom right hand quadrant, then antenna selection and a node manoeuvre plan (as mentioned above) would be required to establish the required link whilst adhering to EMCON; a node manoeuvre plan changes the orientation of the aircraft 230 so as to place the directional antenna at a position and orientation that would enable it to establish the required link with the recipient node 238.

Referring to Figure 12 of the drawings, an aircraft 130 can be seen using its left-hand antenna for reception from a transmitting node 132 along its flight path. As the aircraft 130 manoeuvres, the left-side antenna is no longer pointing in the direction of the source/transmitting node 132. Instead, the antenna selection method described above, causes the antenna at the back/on the tail of the aircraft 130, which has line-of-sight with the transmitting node 132, to be selected in order to maintain communications. The transmitting node 132 may be a fixed or a mobile node.

It will be apparent to a person skilled in the art, from the foregoing description, that modifications and variations can be made to the described embodiments without departing from the scope of the invention as defined by the appended claims.

## CLAIMS

1. Apparatus for management of communications resources of a moving platform comprising an on-board communications system configured to effect wireless data communication between said moving platform and another node, said communications resources comprising a plurality of wireless communications links and a plurality of antennas associated therewith, the apparatus comprising an antenna analysis and selection module residing with said communications system and configured to:
  - receive, during a mission from one or more systems/subsystems and/or functions of said moving platform, attribute data representative of said emissions control criteria, said attribute data comprising (i) location data representative of a specified emissions control region, and/or (ii) position and/or attitude and/or velocity data representative of an adversary node defining an emissions control region;
  - determine, using said attribute data and based on said emissions control criteria, suitability of one or more on-board antennas and/or portions of aperture antenna for supporting said communications requirement;
  - for each of a plurality of antennas/portions of aperture antenna determined to be suitable for supporting said communications requirement based on said emissions control criteria, determine a quality metric, said quality metric being indicative of a respective performance criterion; and
  - select one or more of said suitable antennas/portion of aperture antenna having a highest performance criterion, for facilitating said communications requirement.
2. Apparatus according to claim 1, wherein said attribute data includes platform movement data.
3. Apparatus according to claim 2, wherein said platform movement data comprises (i) instantaneous knowledge of a movement of said moving platform, and/or (ii) future known movement of said moving platform

and/or (iii) future predicted movement of said moving platform and/or other platforms in the operational environment.

4. Apparatus according to any of the preceding claims, configured to obtain  
5 (i) data representative of a location of a fixed other node with respect to said moving platform, or (ii) data representative of position and/or attitude and/or velocity of a mobile other node with respect to said moving platform; and to:
  - determine a direction of said moving platform relative to said fixed/mobile node;
  - 10 - determine modified antenna pointing data in respect of each said antenna/portion of aperture antenna at said other node and/or said moving platform; and
  - calculate a quality metric for each said antenna/portion of aperture antenna.
- 15 5. Apparatus according to claim 4, configured to determine an antenna pointing metric for each said antenna/portion of aperture antenna, calculate a signal power value for each said antenna/portion of aperture antenna, and determine a signal power metric based on said signal power value and a signal power threshold for each said antenna/portion  
20 of aperture antenna, wherein said quality metric is based on said signal power metric.
6. Apparatus according to claim 4 or claim 5, wherein said modified antenna pointing data is determined based on data representative of antenna location, antenna pointing, and platform attitude and/or position  
25 for said moving platform.
7. Apparatus according to claim 5, wherein said pointing metric is indicative of whether said antenna/portion of aperture antenna is pointing in the direction of an emissions control region, based on said modified antenna pointing data, direction/orientation of said moving platform relative to said  
30 other node, transmitting antenna gain pattern in respect of said moving platform and receiver antenna gain pattern in respect of said other node.

8. Apparatus according to any of the preceding claims, configured to calculate said quality metric based on calculations of orientation between said moving platform and said other node.
9. Apparatus according to any of the preceding claims, wherein said quality  
5 metric includes antenna availability and/or preference and/or compatibility.
10. Apparatus according to claim 7, wherein a signal power value in respect of a communications link for an antenna/portion of aperture antenna is based on a relative distance between said moving platform and said  
10 emissions control region, loss factors, transmitting antenna gain and/or receiving antenna gain.
11. Apparatus according to claim 12, wherein said relative distance is a function of time and velocity of said moving platform and/or adversary node.
- 15 12. A management system for a moving platform comprising a plurality of systems/subsystems and/or functions, a plurality of communications resources comprising a plurality of wireless communications links and a plurality of antennas associated therewith, and a communications system configured to effect wireless data communication between said moving  
20 platform and another node via said communications resources, wherein said communications system includes apparatus according to any of the preceding claims.
- 25 13. A method of management of communications resources of a moving platform comprising an on-board communications system configured to effect wireless data communication between said moving platform and another node, said communications resources comprising a plurality of wireless communications links and a plurality of antennas associated therewith, the method comprising using an antenna analysis and selection module residing with said communications system to:
- 30 - receive, during a mission from one or more systems/subsystems and/or functions of said moving platform, attribute data representative of said emissions control criteria, said attribute data comprising (i)

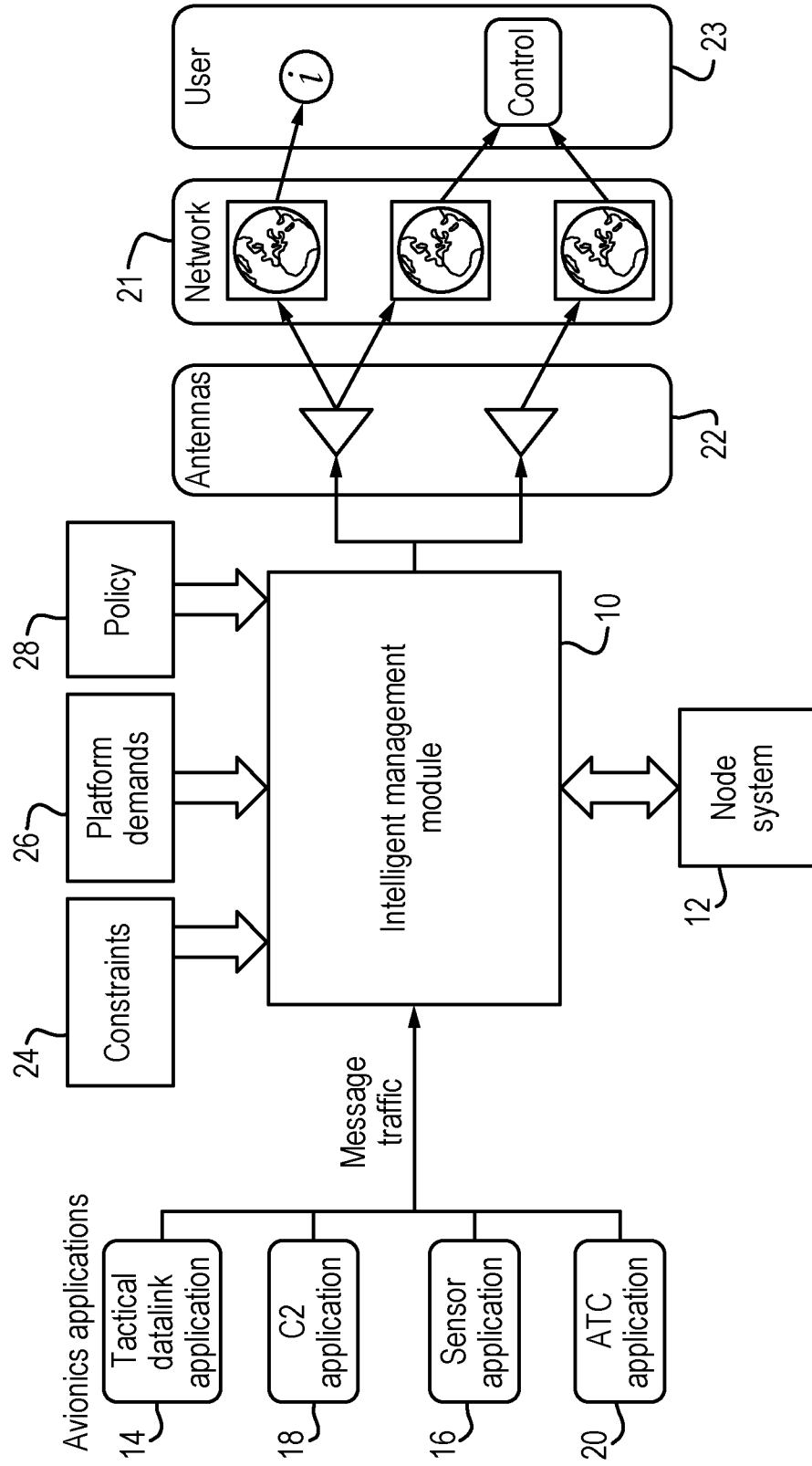


- 31 -

location data representative of a specified emissions control region, and/or (ii) position and/or attitude and/or velocity data representative of an adversary node defining an emissions control region;

- 5 - determine, using said attribute data and based on said emissions control criteria, suitability of one or more on-board antennas and/or portions of aperture antenna for supporting said communications requirement;
- 10 - for each of a plurality of antennas/portions of aperture antenna determined to be suitable for supporting said communications requirement based on said emissions control criteria, determine a quality metric, said quality metric being indicative of a respective performance criterion; and
- 15 - select one or more of said suitable antennas/portion of aperture antenna having a highest performance criterion, for facilitating said communications requirement.

Fig. 1



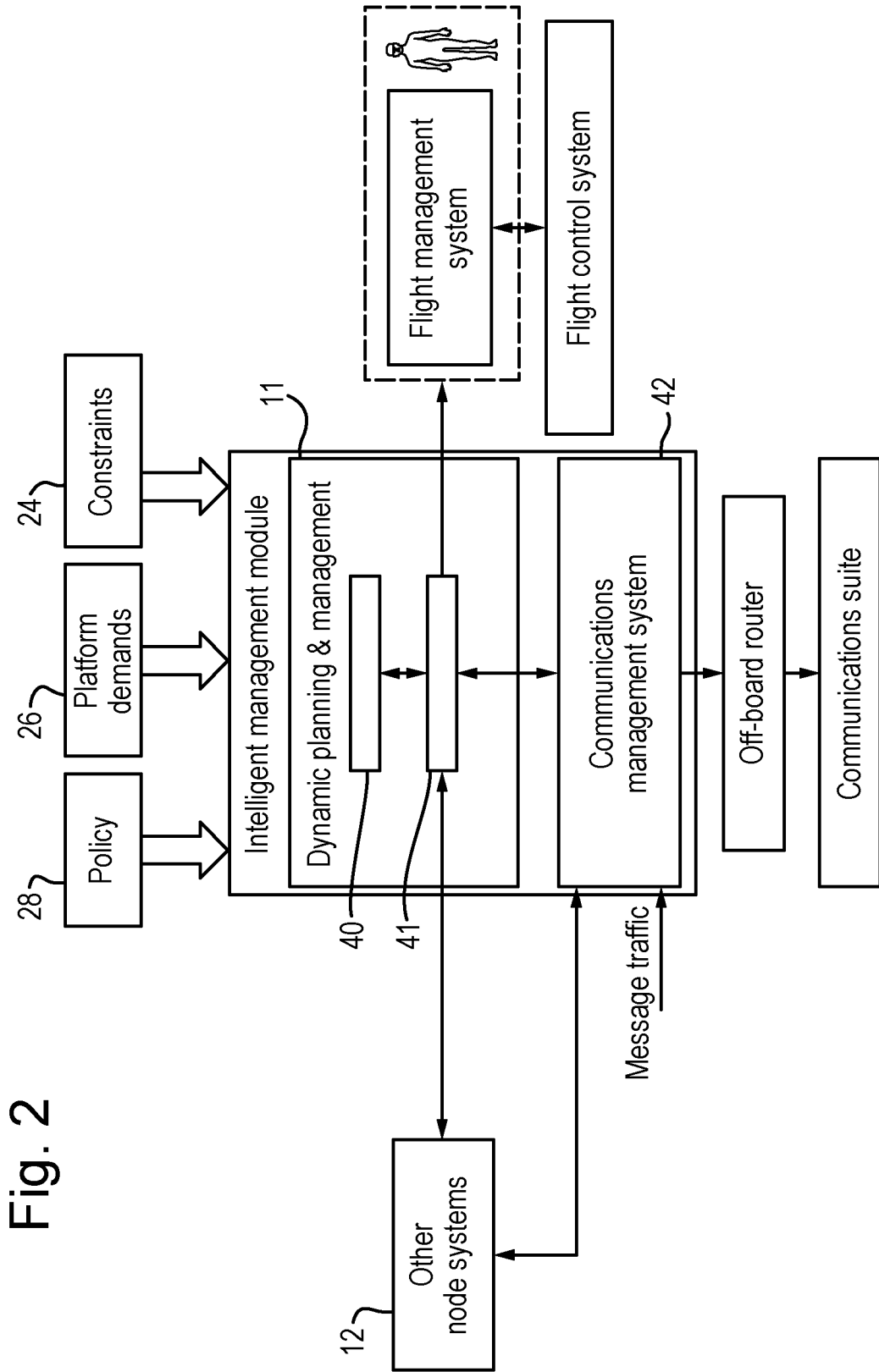


Fig. 2

Fig. 3

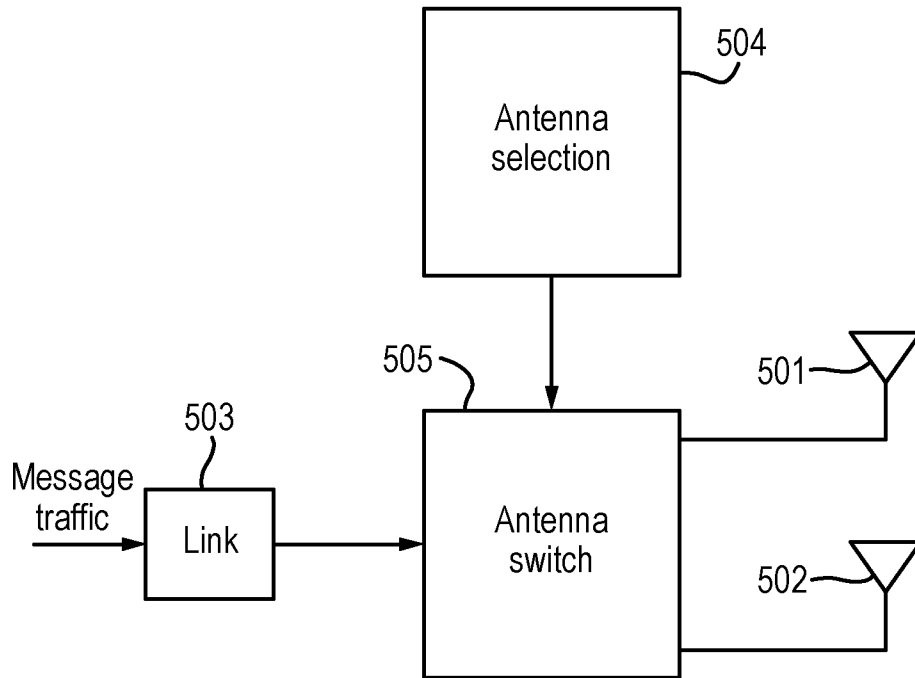


Fig. 4

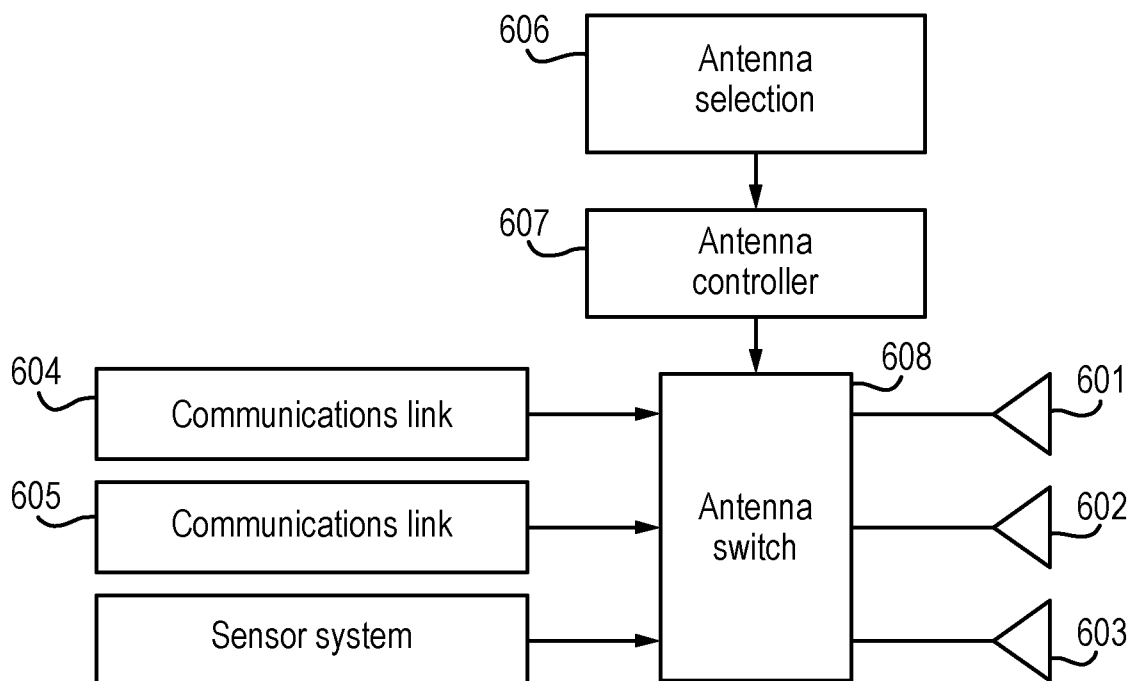


Fig. 5

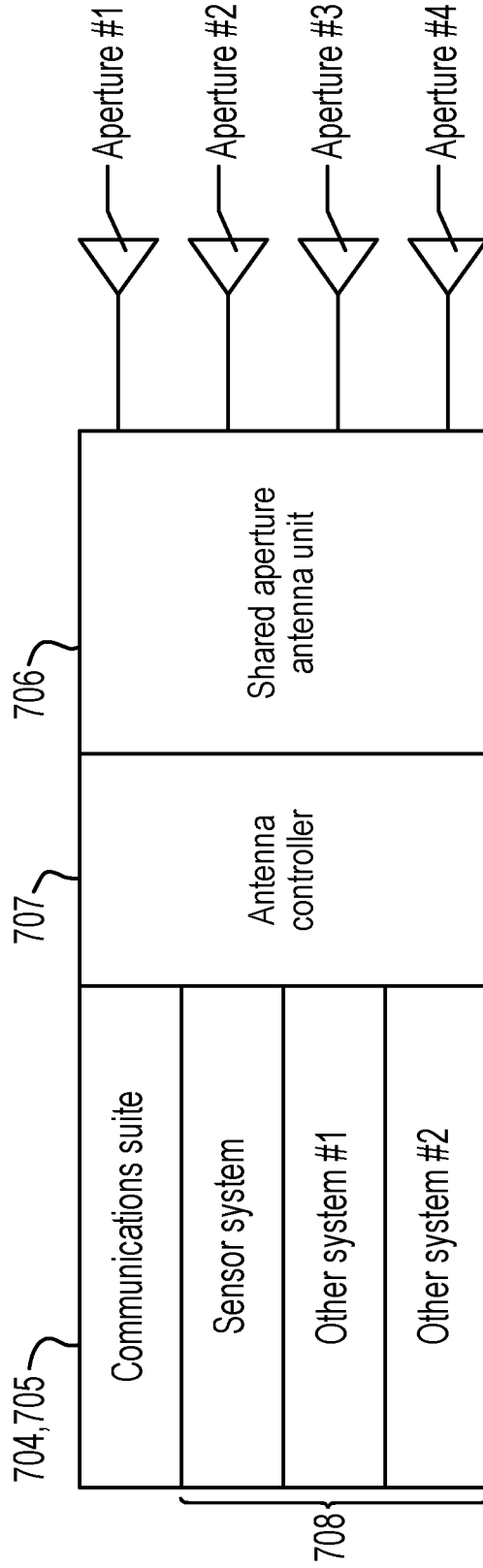


Fig. 6

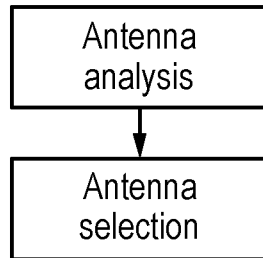
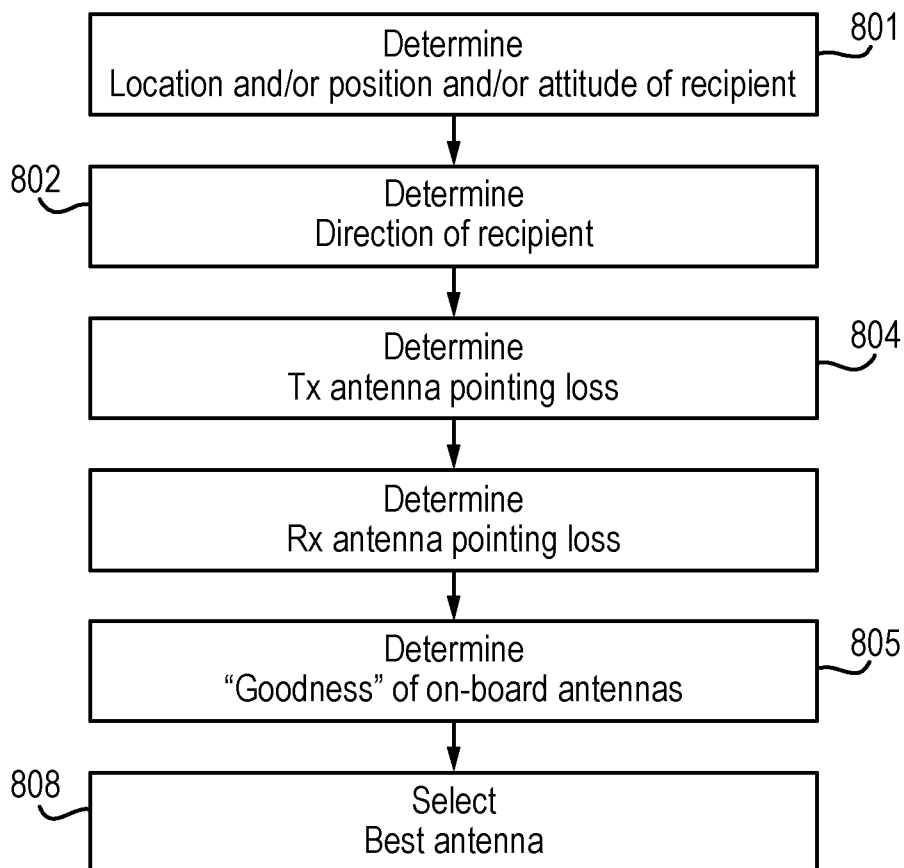
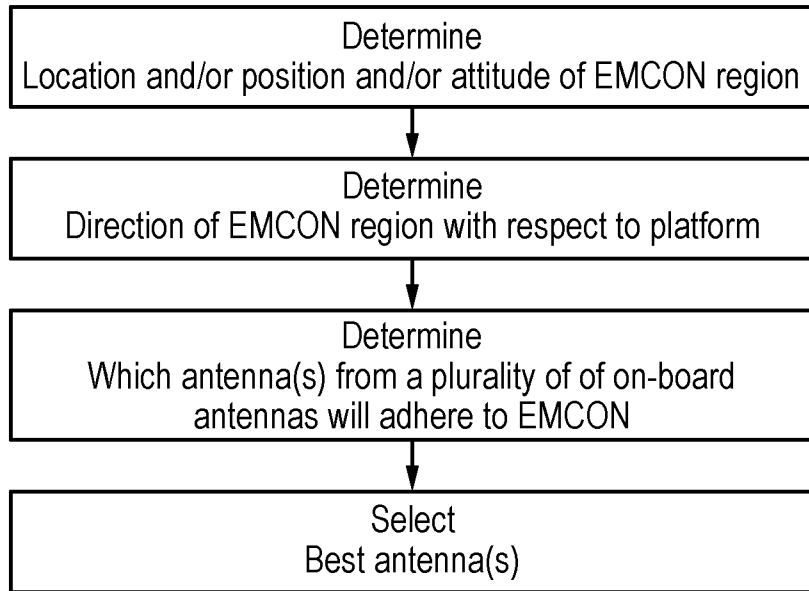


Fig. 7



6/8

### Fig. 8



### Fig. 9

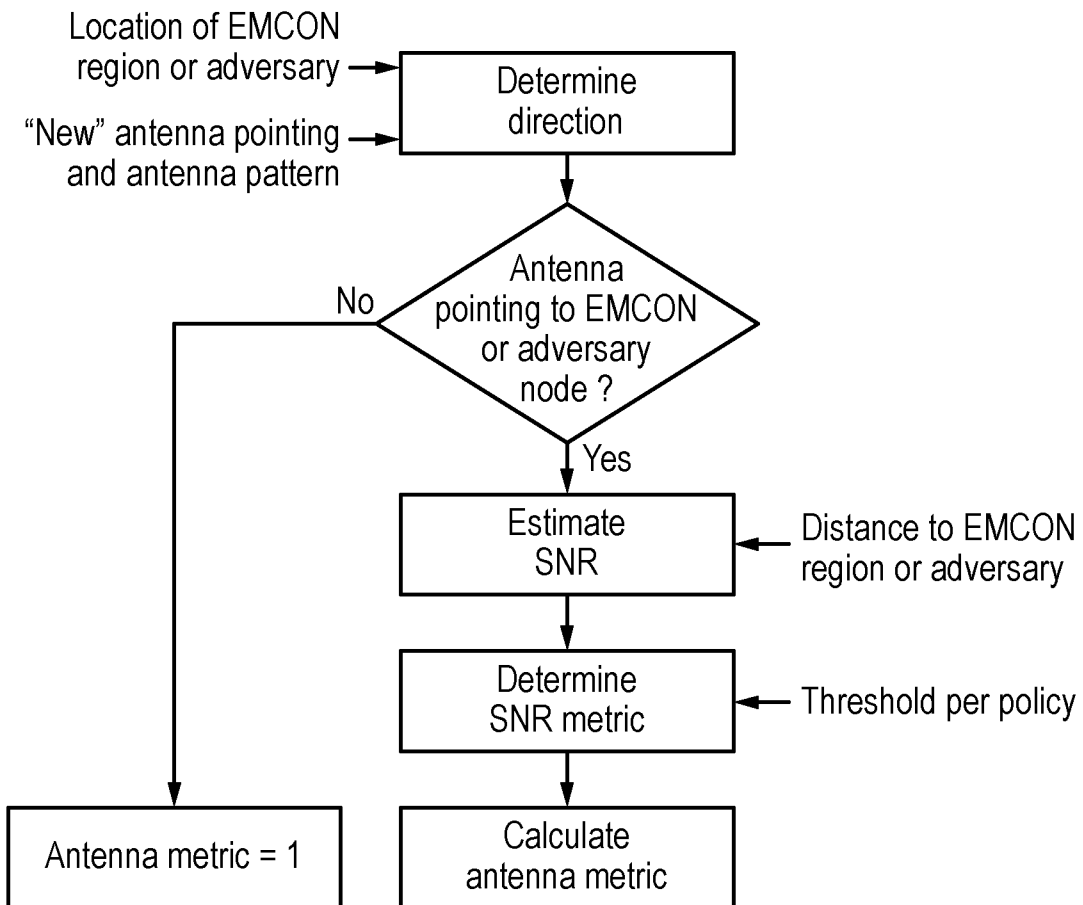


Fig. 10

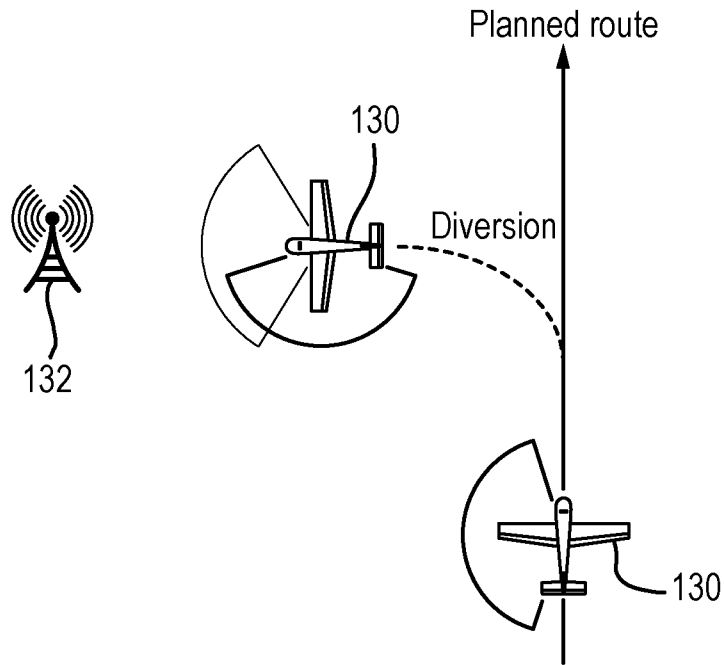


Fig. 11

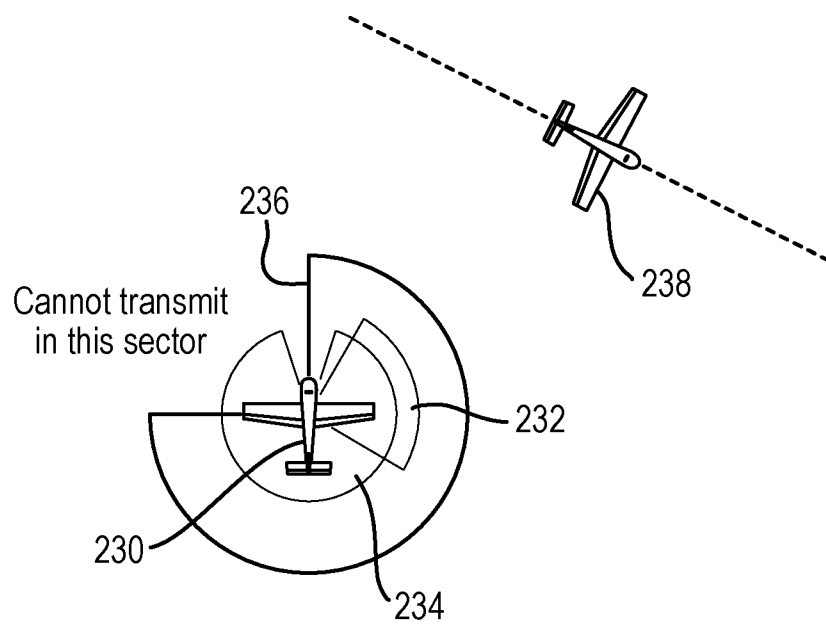
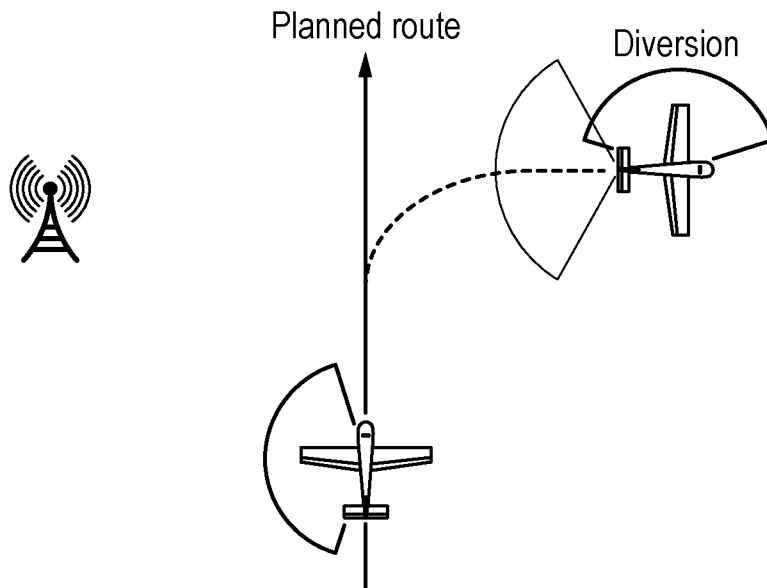




Fig. 12



INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2016/052484

A. CLASSIFICATION OF SUBJECT MATTER  
INV. H04L12/24 H04B7/185  
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)  
H04L 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.
X	US 2012/268319 A1 (MITCHELL JAMES P [US]) 25 October 2012 (2012-10-25) abstract; figure 13 paragraphs [0053] - [0059] -----	1-13
X	EP 2 869 479 A1 (MITSUBISHI HEAVY IND LTD [JP]) 6 May 2015 (2015-05-06) abstract; figures 2-9 paragraphs [0030] - [0075] -----	1-13
X	US 2015/102953 A1 (STAYTON GREGORY T [US]) 16 April 2015 (2015-04-16) paragraphs [0014] - [0027]; figures 1,2 ----- -/--	1,13

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	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search  18 October 2016	Date of mailing of the international search report  26/10/2016
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Esbri, Oriol
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## INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2016/052484

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>CHEN-MOU CHENG ET AL: "Transmit Antenna Selection Based on Link-layer Channel Probing",            WORLD OF WIRELESS, MOBILE AND MULTIMEDIA NETWORKS, 2007. WOWMOM 2007. IEEE INTERNATIONAL SYMPOSIUM ON A, IEEE, PI, 1 June 2007 (2007-06-01), pages 1-6, XP031149144,            DOI: 10.1109/WOWMOM.2007.4351703            ISBN: 978-1-4244-0992-1            abstract            Sections 3, 6 and 7</p> <p style="text-align: center;">-----</p>	1,13
A	<p>WO 2007/110607 A1 (BAE SYSTEMS PLC [GB]; DAY PETER STEPHEN [GB]; BLADON PETER [GB])            4 October 2007 (2007-10-04)            abstract; figure 4            pages 2-7            pages 15-20</p> <p style="text-align: center;">-----</p>	1,13

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Information on patent family members

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