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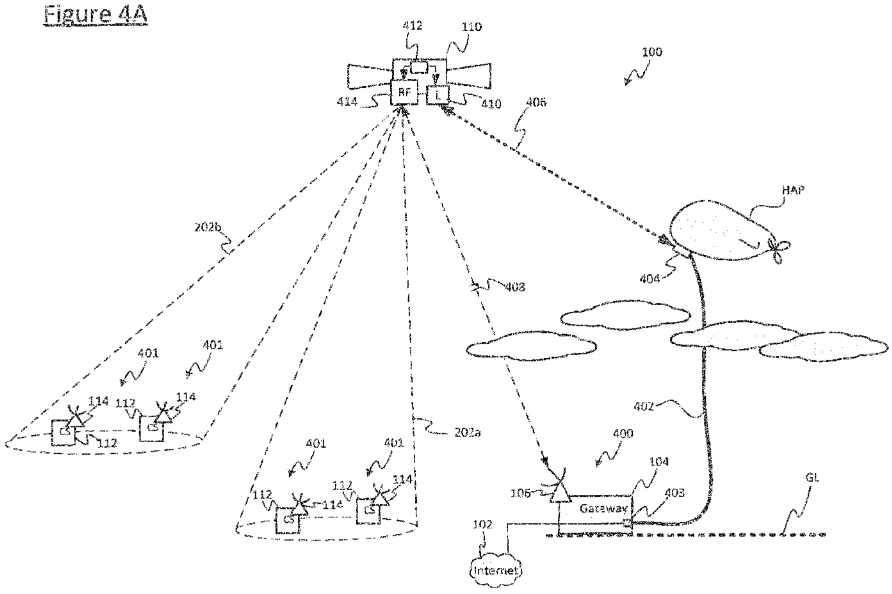
(54) Title: SATELLITE COMMUNICATION

Figure 4A



(57) Abstract: A support structure supports a wireless interface at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud. Earth and/or its atmosphere provides an upward force on the support structure to maintain said elevation. A ground station is connected to the wireless interface by a ground-to-air communication link between the ground station and the wireless interface. The wireless interface relays data bearing signals between the ground-to-air communication link and a wireless air-to satellite communication link between the wireless interface and the satellite, thereby effecting data communication between the ground station and the satellite.

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SATELLITE COMMUNICATION

Technical field

This disclosure relates to satellite communications, and in particular to communication between a ground station and a satellite.

Background

Some regions of the world such as rural, developing or isolated areas often have limited communication infrastructure where high speed broadband through traditional, ground-based (e.g. wired) means is not feasible. Providing an internet link via satellite enables such regions to obtain modern standards of internet access without the need to build a large amount of new infrastructure on the ground. Furthermore, satellite-based internet access can even be used as an alternative to ground-based links in regions that do have a developed communication infrastructure, or as backup to such infrastructure in case a ground-based link fails.

Figure 1 gives a schematic overview of a satellite communication system 100, which is suitable for providing access to a network. The network is an internet 102 i.e. a wide area internetwork such as that commonly referred to as the Internet (capital I). The system 100 comprises a gateway Earth station (gateway) 104, a satellite 110 in orbit about the Earth (labelled "E" in various figures), and one or more client systems 112 remote from the gateway 104 and located in a region on the Earth's surface to which internet access is being provided. The gateway 104 comprises a satellite hub 103 connected to the internet 102, and at least one gateway antenna 106 connected to the hub 103. Each of the client systems comprises an antenna 114, connected to a satellite modem 420. The satellite 110 is arranged to be able to communicate wirelessly with the hub 103 of the satellite gateway 104 via the gateway antenna 106, and with the modems 420 of the client systems 112 via the antennae 114, and thereby provide a satellite link 107 for transmitting internet traffic between the source or destination on the internet 102 and the client systems 112. For example the satellite link 107, hub 103 and modems 420 may operate on the Ka microwave band (26.5 to 40 GHz). The satellite link 107 comprises a forward link 107F for transmitting traffic originating with an internet source to the client systems 112, and a return link 107R for transmitting traffic originating with the client systems 112 to an internet destination.

The hub 103 serves (i.e. provides an internet access service to) the client systems 112 so that internet traffic can be transmitted and received between the client systems 112 and the internet 102 via the satellite link 107 and the hub 103. Though not shown in figure 1, the gateway may comprise multiple such hubs, each serving a respective subset of client systems.

In one model the operator of the satellite 110 and/or gateway 104 provides bandwidth to a downstream internet service provider (ISP), who in turn provides an internet access service based on that bandwidth to a plurality of end users 116. The end users 116 may be individual people (consumers) or businesses. Depending on implementation, the client systems 112 may comprise a central satellite gateway run by the ISP (the satellite gateway comprising an antenna 114 and modem 420), and a local communication infrastructure providing access onwards to the equipment of a plurality of users within the region in question. E.g. the local communication infrastructure may comprise a relatively short range wireless technology or a local wired infrastructure, connecting onwards to home or business routers or individual user devices. Alternatively or additionally, the client systems 112 may comprise individual, private user terminals each with its own satellite antenna 114 and modem 420 for connecting to the satellite 110 and local access point for connecting to one or more respective user devices. In this case the ISP does not necessarily provide any extra infrastructure, but acts as a broker for the bandwidth provided by the satellite 110. For example an individual femtocell or picocell could be located in each home or business, each connecting to a respective one or more user devices using a short range wireless technology, e.g. a local RF technology such as Wi-Fi.

Referring to Figure 2 by way of example, the satellite 110 is deployed in a geostationary orbit and arranged so that its field of view or signal covers roughly a certain geographic region 200 on the Earth's surface. Figure 2 shows South Africa as an example, but this could equally be any other country or region within any one or more countries (e.g. a state, county or province, or some other non-politically defined region).

Furthermore, referring to Figures 2 and 3, using modern techniques the satellite 110 may be configured as a spot-beam satellite for example using directional antennae or based on a beam-forming technology, so that the communications between the satellite 110 and the client equipment 112 in the covered region 200 are divided amongst a plurality of spatially distinct beams 202 ("user beams"). A beam refers to a volume of space or "lobe" in which transmission and/or reception of one or more given signals are approximately confined, typically a signal cone. Each beam 202 is directed in a different respective direction such that beams are arranged into a cluster, each beam covering a different respective (sub) area on the Earth's surface within the region 200 in question (though the areas covered by the beams 202 may be arranged to overlap somewhat to avoid gaps in coverage). This is a way of increasing capacity, as the limited frequency band of the satellite 110 (e.g. Ka band) can be re-used separately in different beams 202 – i.e. it provides a form of directional spatial division multiplexing (though adjacent beams may still use different bands or sub-bands, especially if they overlap in space). By way of example Figure 2 shows five beams 202a-202e which between them approximately cover the area of South Africa, but it will be appreciated that other numbers and/or sizes of beam are also possible.

In this arrangement, a factor which limits the overall capacity of the system 100 is communication between the satellite 110 and the gateway 104. A single gateway does not provide the same opportunity for spatial multiplexing in the way that multiple client systems distributed over a relatively wide geographic area do. Thus all user beams 202 need to be served from the gateway 104 using the limited spectrum available for transmissions between the gateway 104 and the satellite 110. In other words, the bandwidth of the leg of the satellite link 107 between the gateway 104 and the satellite 110 that becomes the factor that limits overall capacity. This is true for transmissions in both directions i.e. from the client system(s) 112 to the gateway 104 via the satellite 110, and from the gateway 104 to the client system(s) 112 via the satellite 110.

Summary

One solution to this problem is to provide multiple gateways or gateway antennas, geographically distributed over distances sufficient to provide similar spatial multiplexing for the leg of the satellite link between the gateways and the client systems. However, deploying additional gateways is not always desirable, and may not even be possible for example in environments that have limited transport infrastructure, inappropriate terrain etc.

In a first aspect of the present invention, a satellite communication system comprises:

a support structure supporting a wireless interface at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud, wherein Earth and/or its atmosphere provides an upward force on the support structure to maintain said elevation; and

a ground station connected to the wireless interface by a ground-to-air communication link between the ground station and the wireless interface;

wherein the wireless interface is configured to relay data bearing signals between the ground-to-air communication link and a wireless air-to-satellite communication link between the wireless interface and the satellite, thereby effecting data communication between the ground station and the satellite.

In conventional satellite communication systems, such as the one described above, a direct, wireless ground-to-satellite communication link is provided between a ground station, such as a gateway, and a satellite. The possible configurations of such a single ground-to-satellite link are limited, and generally only an RF (Radio Frequency) link is viable, RF meaning radio waves with frequencies between about 3kHZ and 300GHz (these are administrated by WARC), satellite communications are typically between 1GHz and 60GHz. Operating at frequencies significantly above this soon requires the use of multiple geographically separate locations, due to disruption by cloud in Earth's atmosphere. The present invention instead provides two, series communication links between the ground station and the satellite – a ground-to-air link and a separate air-to-satellite link, connected in series via the elevated wireless interface. The wireless interface performs any necessary signal conversion to effect the relaying. By elevating the wireless interface above cloud level in its local environment so that always remains substantially unobstructed by cloud, the air-to-satellite wireless link is not burdened by cloud constraints, leaving it free to operate at significantly higher frequencies, such as infra-red and/or visible frequencies.

Preferably, the support structure is an aircraft such as an aerostat (i.e. a balloon, or other aircraft that maintains its elevation primarily through buoyancy), in particular a high-altitude platform (HAP). As is known in the art, a HAP is a quasi-stationary aircraft capable of remaining in the air at high altitudes, between about 12 and 25km depending on climactic region, for hours, days or even month or years at a time, and can for instance take the form of a balloon, airship or aeroplane. It can be manned or unmanned. In this case, the upward force to counteract gravity and maintain the necessary elevation is provided by Earth's atmosphere together with the HAP's engines.

The wireless air-to-satellite link may operate in a visible and/or infrared spectrum, for example in the near-infrared spectrum. In some environments, the near UV spectrum may also be useable. Preferably, the interface is a laser-communication interface, whereby the air-to-satellite wireless link a laser link, for instance operating in a visible and/or infrared spectrum. That is, whereby data is borne by (e.g. visible and/or infrared) laser signals transmitted to and/or received from the satellite by the laser-based interface, having been modulated onto them using suitable modulation.

Cloud level means the maximum altitude reached by opaque cloud in the local environment at any time, opaque meaning opaque to any electromagnetic signals transmitted via the wireless air-to-satellite link, for example opaque to infrared and/or visible signals in embodiments. Over time, the elevation of the highest clouds present in the local environment will vary, but will do so without ever exceeding cloud level as the term is defined herein.

The ground-to-air link may be wireless, or it may be wired i.e. provided by a communication cable connecting the ground station and the support structure, which is tethered to the ground. Advantageously, using the tether to send signals minimises the amount of equipment required on the elevated support structure e.g. HAP.

In some embodiments a direct, wireless ground-to-satellite communication link, directly connecting the same ground station and the or another satellite, may operate in parallel with the ground-to-air link. That is, two communication paths between the satellite and the same ground station may be provided: the first being a conventional radio link directly to the satellite, and the second being via the elevated support structure e.g. HAP. In embodiments, the ground station may comprise a ground-level wireless interface (i.e. on Earth's surface) configured to provide such a direct wireless ground-to-satellite communication link between the ground station and the or another satellite. "Direct" wireless link in this context means that are no intermediate, signal processing entities i.e. wireless signals are sent between the satellite and the ground station through the air/vacuum without interception or (intentional) modification. This is in contrast to the combination of the ground-to-air and air-to-satellite links, which together constitute an indirect ground-to-satellite communication link due to the deliberate interception of signals by the elevated wireless interface.

The conventional wireless ground-to-satellite link, i.e. the direct communications path between the satellite and ground station (e.g. via a gateway antenna) may operate in a lower frequency spectrum than the wireless air-to-satellite link, i.e. the communications path between the elevated support structure (e.g. HAP) and the satellite. That is, higher frequencies may be used for communication between the (e.g.) HAP and the satellite. The lower frequency makes the former less susceptible to clouds, thus more suitable for (non-geographically multiplexed) direct ground-to-satellite communications. The wireless ground-to-satellite and wireless air-to-satellite links may operate in non-overlapping spectrums, so that there is no or negligible interference between them. It can be advantageous, particularly though not exclusively where the wireless ground-to-satellite interface and wireless air-to-satellite links are to the same satellite or to nearby satellites, for the ground-to-satellite wireless link to operate in a first spectrum, e.g. RF spectrum (i.e. restricted to RF) and the air-to-satellite link to operate in a second, distinct spectrum that does not overlap with the first spectrum, e.g. a visible and/or infrared spectrum (i.e.

restricted to visible and/or infrared frequencies), so that there is no or negligible interference between the two wireless links.

The wireless ground-to-satellite communication link may operate in a microwave frequency spectrum of the radio frequency spectrum and the wireless ground-to-satellite communication link may operate in said microwave frequency spectrum.

In embodiments, the satellite communication system may comprise a remote system (remote from the ground station, but still Earth-based), and the satellite may be configured to relay signals between the wireless air-to-satellite link and a remote ground-to-satellite communication link between the satellite and the remote system. Communication between the ground station and the remote system can be effected via the satellite in a number of ways. In some embodiments, the remote link may be a direct wireless (e.g. RF) link between the satellite and the remote system, whereby the satellite relays signals between the air-to-satellite link and the remote link by performing suitable signal conversion, for example by converting laser signals received on a laser-based air-to-satellite link to an RF form for transmission via the remote link, and/or *vice versa*. Multiple such remote ground-to-air communication links to multiple remote systems may be provided within one or more user beams, the satellite being configured to relay signals between the remote links and the air-to-satellite link. The remote links may be distributed between multiple user beams.

The ground station may be a gateway to a network, the network being accessible to the remote system(s) via the air-to-satellite and ground-to-air links. For example, the network may be an internet such as the Internet (capital I), whereby the gateway provides an Internet access service to the remote system(s) using the ground-to-air and air-to-satellite links so that it/they can access Internet services such as Web services, email services etc. via the ground-to-air and air-to-satellite links.

In a preferred embodiment, the ground station is configured for the most part in the manner of a conventional gateway Earth station, with a gateway antenna providing a direct ground-to-satellite communication link in the manner described above, but with the addition of the ground-to-air and air-to-satellite links to provide extra capacity, without having to provide additional, geographically distributed gateways. Signals are communicated between the gateway and the satellite in both RF and laser forms, but are only communicated between the satellite and the client system(s) in RF form, with the satellite performing appropriate signal conversion. In this manner, the gateway 104 can for instance provide an Internet access service to the client system(s), which is provided in part using the ground-to-air and air-to-satellite communication links between the gateway and the satellite. In alternative embodiments, the RF infrastructure of the gateway may be omitted so that service is provided entirely via the ground-to-air and air-to-satellite links.

As indicated, cloud level is the maximum height ever attained by opaque cloud at the geographic location of the support structure during the current season (cloud level may be subject to both geographic and seasonal variations) – within this limit, the height and amount of cloud may vary over time, on a day-to-day, hour-to-hour or minute-to-minute basis.

Note the terms "ground-to-air" communication, "air-to-satellite" communication, "air-to-satellite" communication etc. do not imply any particular direction of communication, and can mean one-way communication in either direction (signals sent from the ground to the air only, or signals set from the air to the ground only etc.) or two-way communication in both directions. Thus, any of the aforementioned communication links can be unidirectional in either of the relevant directions, or bidirectional.

In a second aspect of the present invention, a method of effecting satellite-based communication comprises:

transmitting and/or receiving, by a ground station, data bearing signals via a ground-to-air communication link between the ground station and a wireless interface, the wireless interface supported at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud, wherein Earth and/or its atmosphere provides an upward force to maintain said elevation;

relaying, by the wireless interface, data bearing signals between the ground-to-air communication link and a wireless air-to-satellite communication link between the wireless interface and the satellite.

In embodiments, the method may implement any of the system functionality disclosed herein,

Brief Description of Figures

Figure 1 is a schematic diagram of a known type system for providing internet access via satellite;

Figure 2 is a schematic diagram showing geographic coverage of a cluster of satellite beams;

Figure 3 is a schematic diagram of a part of a system for providing internet access via satellite beams;

Figure 4 is a schematic illustration showing how a satellite communication system may be configured in various embodiments of the present invention;

Figure 4A is a schematic illustration of a satellite communication system in a first embodiment;

Figure 4B is a schematic illustration of a satellite communication system in a second embodiment;

Figure 5 schematically illustrates layers of Earth's atmosphere.

Detailed Description of Embodiments

Figure 1 shows how the satellite communication system 100 may be reconfigured in various embodiments. The system 100 comprises a ground station 400 at a geographic location having a local environment, a remote system 401 at another geographic location remote from the ground station 400, and a satellite 110.

The satellite 110 is in a geostationary orbit, and is thus substantially stationary relative to the ground station 400.

A cable interface 403 of the ground station 400 is connected to one end of a long communication cable 402. The cable 402 runs from the ground station 400 in a generally vertical direction up to a high altitude platform "HAP" at an elevation above the local environment's local cloud level. The HAP comprises a wireless interface 404 and a cable interface 405 connected to the wireless interface 404. The wireless interface 404 is supported by the HAP. The other end of the long cable 402 is connected to the cable interface 405 of the HAP. As mentioned, in operation the HAP maintains an elevation Hs of typically about 12-25km above sea level SL thus the cable 402 needs to have a length at least comparable to this, though this depends on the ground level GL at the geographic location of the ground station 400. The cable may in practice need some additional slack to account for movement of the HAP relative to Earth. The cable may for instance be an electrical or optical (e.g. fibre-optic) cable, capable of carrying data bearing electrical and optical signals respectively. The cable 402 provides a wired ground-to-air communication link, which is bidirectional in this example i.e. via which data can be sent both from the HAP to the ground station 400 and from the ground station 400 to the HAP.

The HAP has a line of sight to the satellite 110 which, due to its elevation above local cloud level, remains substantially unobstructed by opaque cloud at all times. The HAP and the satellite 110 each comprise a respective wireless interface in the form of a respective laser-communication interface 404, 410. Each laser interface 404, 410 comprises a respective laser beam emitter E and laser beam receiver R. Data bearing laser beams (i.e. onto which data has been modulated) emitted by the emitter E of one of the laser interfaces 404, 410 along the line of sight are receivable by the receiver R of the other laser interface 410, 404, free from disruption by cloud. In this manner, the laser interfaces 404, 410 provide a bidirectional laser link 406 between the HAP and the satellite 110, which is an example of a wireless air-to-satellite communication link.

In practice, the HAP will not remain fully stationary relative to Earth or the satellite 110, but this can for instance be accounted for with station-keeping using engines hosted on the HAP, complemented by tracking systems on the laser telescopes on the satellite and HAP.

The ground-to-air link provided by the cable 402 and the air-to-satellite link 406 constitute an indirect ground-to-satellite link, which is indirect due to the presence and operation of the elevated wireless and cable interfaces 404, 405 on board the HAP.

A remote ground-to-satellite communication link 403 (remote from the ground station 400) is also provided for communication between the remote system and the satellite 110. The remote link 403 may for instance be a conventional direct RF link to a remote system 401 on Earth's surface (see first embodiment, below), or it may be another indirect link with equivalent constituent ground-to-air and air-to-satellite components provided in the same manner. That is, the remote system 401 may formed of another ground station and another HAP connected in the same configuration as the HAP 404 and ground station 400 (see second embodiment, below).

The problem of lasers being disrupted by clouds has arisen in the context of radio telescope technology. However, the solution offered has always been to provide multiple, geographically distributed laser interfaces at ground level so as to provide redundancy should cloud hamper or halt the operation of one or some.

Figure 4A shows how the satellite communication system may be reconfigured in a first embodiment. In the first embodiment, the ground station 400 is a gateway Earth station 104, operating as a gateway to the network 102 and having a gateway antenna 106. The cable interface 403 now included in the gateway 104 is connected to the network 102, whereby data can be communicated in both directions between the network 102 and the HAP via the cable 402.

A plurality of remote systems 401 take the form of client systems 112 of the kind described with reference to figure 1, each having a respective antenna 116 capable of emitting and receiving RF signals form the satellite 110. The satellite 110 is configured as a spot-beam satellite to provide a plurality of user beams 202a, 202b in the manner described above with reference to figures 2 and 3, each covering a respective subset of the client systems 112. That is, communication between the satellite 110 and the client systems 112 is based on the same spot-beam technology as described above with reference to figures 1-3. In other words, communication between each client system 112 is via a respective direct RF link, between that client system and the satellite 110, that is contained within the user beam covering that client system. Thus advantageously no reconfiguration of the client systems 112 is needed in this embodiment; communication between the gateway 104 and the satellite 110 still takes place via a direct RF link 408 in the known manner described above. The satellite 110 can also operate on the same radio technology as existing spot-beam satellite i.e. it can have RF communications logic 414 which is the same as existing spot-beam satellite. The only extra components needed are an on board laser interface 410 of the kind described above and signal conversion logic 412 for converting signals between laser and RF forms.

Only two user beams are shown in figure 4A, but there may be more than this, or alternatively a single user beam (e.g. wide beam) may be provided.

In the first embodiment, the ground-to-air link provided by the cable 402 and the air-to-satellite laser link 406 are “extra” links, in that they provide extra capacity for communications between the gateway 102 and the satellite 110 above and beyond that provided by the conventional, direct RF ground-to-satellite link 408. Data transmitted from the satellite 110 within any one of the user beams 202a to a client system 112 may have arrived at the satellite 110 by either of the direct link 408 or the extra indirect link i.e. via the HAP. Conversely, data received from a client system within any one of the user beams may be relayed down to the gateway 104 via either of the direct link 408 or the extra indirect link. The extra capacity in this scenario is achieved firstly because signals transmitted via the cable 402 create no or negligible disruption for the direct RF link 408 (because they are largely contained within the cable 402), and secondly because signals transmitted from the HAP are at higher, non-overlapping frequencies (which is made viable by the elevation of the HAP above cloud level).

Figure 4B illustrates a second embodiment, in which two ground station stations 404a, 404b are each connected to a respective high altitude platform HAPa, HAPb via a respective cable 402a, 402b, each having a respective wireless interface 404a, 404b, whereby respective wireless air-to-satellite links 406a, 406b are provided between each of the HAPS HAPa, HAPb and the satellite 110. Each ground station-HAP pairs is configured individually in the manner described above with reference to figure 4, so that a respective indirect ground-to-satellite link is provided between each ground station 400a, 400b and the satellite 110 and the relevant HAP HAPa, HAPb. Thus data can be communicated between the ground stations, which travels via both indirect links in turn, in both directions. One of the ground stations may be a gateway 104, and the other a client system 112 (for example).

In the context of this disclosure, "wireless link" refers to communication by electromagnetic signals. A line of sight being "substantially unobstructed" by cloud means that no or negligible opaque cloud obstructs the line of sight. Opaque means opaque to any electromagnetic signals transmitted via the wireless link, for example infrared and/or visible electromagnetic signals. As indicated, cloud level means the maximum altitude reached by opaque cloud in a local environment at a geographic location during the current season, wherein it can be guaranteed that no or negligible opaque cloud will be present in the local environment above that elevation.

Figure 5 shows some of the lowest layers of Earth's atmosphere, to illustrate suitable elevations of a HAP in accordance with this disclosure. T troposphere TS and stratosphere SS are shown. The tropopause, labelled TP, is the boundary between the troposphere TS and stratosphere SS. Most of Earth's weather is contained below the tropopause TP within in the troposphere TS, and there is generally no or negligible cloud in the stratosphere SS. The height of the tropopause TP above sea level SL varies with both season and geographic location, and is highest in equatorial regions. Overall, it can vary between about 7km-10km above sea level SL at the poles, and about 17-20km above sea level SL at the equator. Generally, cloud level as it is defined herein will correspond at least approximately to the current height of the troposphere the geographic location of the wireless interface, although this will depend on the local environment i.e. local environmental factors can mean that cloud level as it is defined herein is somewhat lower than the top of the troposphere (see below). Thus cloud level may vary with the height of the troposphere. The tropopause can be considered as three sub regions – high, middle and low (H, M, F in figure 5), defined by the physical characteristics of the cloud found at different altitudes. At some geographic locations, opaque cloud may be essentially contained within the low and middle regions i.e. so as not to exceed about 10km (order of magnitude) above sea level. This may mean that cloud level is significantly lower than the height of the troposphere at some geographic locations, at least at some points in the year. For a given local environment and geographic location, what constitutes cloud level will be determinable by way of routine meteorological practices. In any event, for all practicable geographic locations, cloud level as defined herein will not exceed the height of the tropopause at that location, whatever that height may be given the current location and season. Thus any object above the troposphere will, in practice, be above cloud level as the term is used herein. At some locations there may be some small clouds (normally only near the poles), or insubstantial cloud jets, above the tropopause. These are not expected to disrupt the wireless link, thus do not have any effect on the cloud level at the term is defined herein.

Unlike sea level SL, ground level GL varies with geographic location. Except in mountainous regions, the difference between ground and sea level in this context will be negligible. Thus, in most cases, the wireless interface will be elevated at a minimum height multiple kilometres above the ground vertically beneath it, typically at least 10km (order of magnitude). Thus, typically, the ends of cable 402 will be have a vertical separation equal to this minimum height, and will be at least this long. Whatever the height of the wireless interface, it will always be in Earth's atmosphere.

The wireless interface need not remain above cloud level at all times. In some embodiments, the height of the support structure may be varied, for example to lower the wireless interface when no or only low opaque cloud is present and raise it above cloud level only when opaque cloud reaching cloud level returns. This may, for instance, be based on meteorological monitoring of the local environment. Cloud level may exhibit long-term variations, e.g. due to climate change, as well as cyclic, seasonal variations.

Whilst in the above, a support structure takes the form of a HAP, the possibility of a very tall support structure on Earth's surface is not excluded – in this case an upward reaction force maintains the necessary elevation of the wireless interface.

Various embodiments have been described above for the purposes of illustration, and other embodiments of the invention may be apparent to the skilled person in view of the present teaching. The scope is not limited by the described embodiments but only by the claims.

Claims:

1. A satellite communication system comprising:

a support structure supporting a wireless interface at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud, wherein Earth and/or its atmosphere provides an upward force on the support structure to maintain said elevation; and

a ground station connected to the wireless interface by a ground-to-air communication link between the ground station and the wireless interface;

wherein the wireless interface is configured to relay data bearing signals between the ground-to-air communication link and a wireless air-to-satellite communication link between the wireless interface and the satellite, thereby effecting data communication between the ground station and the satellite.

2. A satellite communication according to claim 1 wherein the support structure is an aircraft.

3. A satellite communication system according to claim 2 wherein the aircraft is a balloon.

4. A satellite communication system according to claim 2 or 3 wherein the aircraft is a high-altitude platform.

5. A satellite communication system according to claim 1, 2, 3 or 4 wherein the wireless interface is a laser-communication interface, whereby the air-to-satellite wireless link is a laser link.

6. A satellite communication system according to claim 1, 2, 3, 4 or 5 wherein the wireless air-to-satellite link operates in a visible and/or infrared spectrum.

7. A satellite communication system according to any preceding claim wherein the ground-to-air link is a wired link provided by a communication cable connecting the ground station and the support structure.

8. A satellite communication system according to any preceding claim wherein the ground station comprises a ground-level wireless interface configured to provide a direct wireless ground-to-satellite communication link between the ground station and the or another satellite.

9. A satellite communication system according to claim 8 wherein the wireless ground-to-satellite link operates in a lower frequency spectrum than the wireless air-to-satellite link.

10. A satellite communication system according to claim 9 wherein the wireless ground-to-satellite link and wireless air-to-satellite links operate non-overlapping spectrums.

11. A satellite communication system according to claim 9 or 10 wherein the wireless ground-to-satellite communication link operates in a radio frequency spectrum.

12. A satellite communication system according to claim 11 wherein said radio frequency spectrum comprises a microwave frequency spectrum and the wireless ground-to-satellite communication link operates in said microwave frequency spectrum.

13. A satellite communication system according to any preceding claim, comprising a remote system, wherein the satellite is configured to relay signals between the wireless air-to-satellite link and a remote ground-to-satellite communication link between the satellite and the remote system.

14. A satellite communication system according to claim 13 wherein the remote ground-to-satellite link is a direct wireless link operating in a radio frequency spectrum.

15. A satellite communication system according to claim 12 or 13, wherein multiple such remote ground-to-air communication links to multiple remote systems

are provided within one or more user beams, the satellite being configured to relay signals between the remote links and the air-to-satellite link.

16. A satellite communication system according to claim 15 wherein the remote links are distributed between multiple user beams.

17. A satellite communication system according to any of claims 12 to 16, wherein the ground station is a gateway to a network, the network being accessible to the remote system(s) via the air-to-satellite and ground-to-air links.

18. A satellite communication system according to claim 17 wherein the network is the Internet, whereby the gateway provides an Internet access service to the remote system(s) using the ground-to-air and air-to-satellite links.

19. A method of effecting satellite-based communication comprising:

transmitting and/or receiving, by a ground station, data bearing signals via a ground-to-air communication link between the ground station and a wireless interface, the wireless interface supported at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud, wherein Earth and/or its atmosphere provides an upward force to maintain said elevation;

relaying, by the wireless interface, data bearing signals between the ground-to-air communication link and a wireless air-to-satellite communication link between the wireless interface and the satellite.

AMENDED CLAIMS
received by the International Bureau on 13 December 2016 (13.12.2016)

Claims:

1. A satellite communication system comprising:

a support structure supporting a wireless interface at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud, wherein Earth and/or its atmosphere provides an upward force on the support structure to maintain said elevation; and

a ground station connected to the wireless interface by a ground-to-air communication link between the ground station and the wireless interface;

wherein the wireless interface is configured to relay data bearing signals between the ground-to-air communication link and a wireless air-to-satellite communication link between the wireless interface and the satellite, thereby effecting data communication between the ground station and the satellite.

2. A satellite communication according to claim 1 wherein the support structure is an aircraft.

3. A satellite communication system according to claim 2 wherein the aircraft is a balloon.

4. A satellite communication system according to claim 2 or 3 wherein the aircraft is a high-altitude platform.

5. A satellite communication system according to claim 1, 2, 3 or 4 wherein the wireless interface is a laser-communication interface, whereby the air-to-satellite wireless link is a laser link.

6. A satellite communication system according to claim 1, 2, 3, 4 or 5 wherein the wireless air-to-satellite link operates in a visible and/or infrared spectrum.

7. A satellite communication system according to any preceding claim wherein the ground-to-air link is a wired link provided by a communication cable connecting the ground station and the support structure.

8. A satellite communication system according to any preceding claim wherein the ground station comprises a ground-level wireless interface configured to provide a direct wireless ground-to-satellite communication link between the ground station and the or another satellite.

9. A satellite communication system according to claim 8 wherein the wireless ground-to-satellite link operates in a lower frequency spectrum than the wireless air-to-satellite link.

10. A satellite communication system according to claim 9 wherein the wireless ground-to-satellite link and wireless air-to-satellite links operate non-overlapping spectrums.

11. A satellite communication system according to claim 9 or 10 wherein the wireless ground-to-satellite communication link operates in a radio frequency spectrum.

12. A satellite communication system according to claim 11 wherein said radio frequency spectrum comprises a microwave frequency spectrum and the wireless ground-to-satellite communication link operates in said microwave frequency spectrum.

13. A satellite communication system according to any preceding claim, comprising a remote system, wherein the satellite is configured to relay signals between the wireless air-to-satellite link and a remote ground-to-satellite communication link between the satellite and the remote system.

14. A satellite communication system according to claim 13 wherein the remote ground-to-satellite link is a direct wireless link operating in a radio frequency spectrum.

15. A satellite communication system according to claim 11 or 13, wherein multiple such remote ground-to-air communication links to multiple remote systems

are provided within one or more user beams, the satellite being configured to relay signals between the remote links and the air-to-satellite link.

16. A satellite communication system according to claim 15 wherein the remote links are distributed between multiple user beams.

17. A satellite communication system according to any of claims 13 to 16, wherein the ground station is a gateway to a network, the network being accessible to the remote system(s) via the air-to-satellite and ground-to-air links.

18. A satellite communication system according to claim 17 wherein the network is the Internet, whereby the gateway provides an Internet access service to the remote system(s) using the ground-to-air and air-to-satellite links.

19. A method of effecting satellite-based communication comprising:

transmitting and/or receiving, by a ground station, data bearing signals via a ground-to-air communication link between the ground station and a wireless interface, the wireless interface supported at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud, wherein Earth and/or its atmosphere provides an upward force to maintain said elevation;

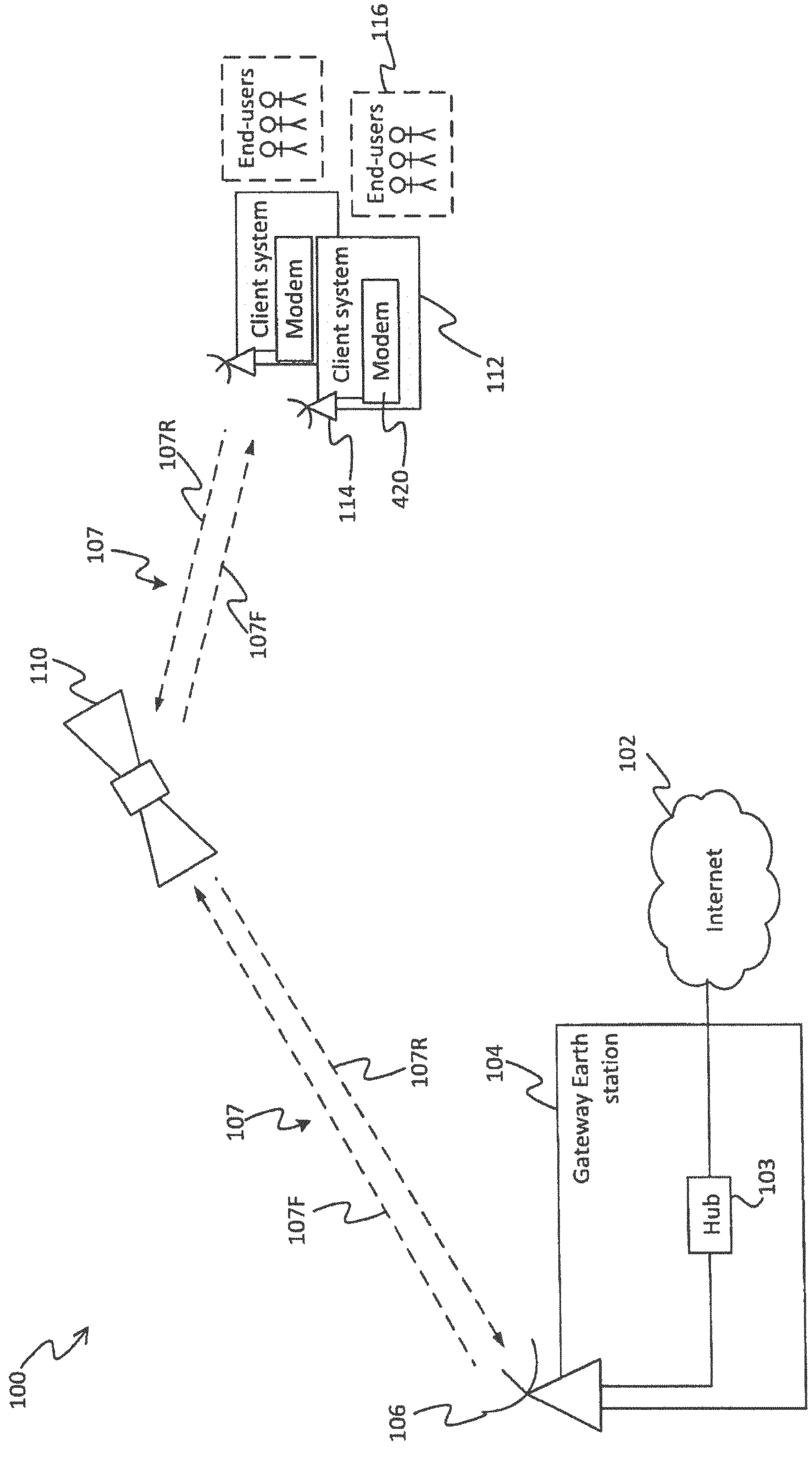
relaying, by the wireless interface, data bearing signals between the ground-to-air communication link and a wireless air-to-satellite communication link between the wireless interface and the satellite.

20. A satellite communication system comprising:

a support structure supporting a wireless interface at an elevation above cloud level, whereby the wireless interface has a line of sight to a satellite which remains substantially unobstructed by cloud, wherein Earth and/or its atmosphere provides an upward force on the support structure to maintain said elevation; and

a ground station connected to the wireless interface by a ground-to-air communication link between the ground station and the wireless interface, wherein said communication link is a wired link provided by a communication cable, and the ground station comprises a ground-level wireless interface configured to provide a direct wireless ground-to-satellite communication link between the ground station and the satellite;

wherein the wireless interface of the supporting structure is configured to relay data bearing signals between the ground-to-air communication link and a wireless air-to-satellite communication link between the wireless interface and the satellite, wherein the wireless air-to-satellite communication link operates in a visible and/or infrared spectrum, thereby effecting data communication between the ground station and the satellite, and the ground-to-satellite link operates in a lower frequency spectrum than the wireless air-to-satellite link.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106
104
Gateway Earth station
Hub
103
Internet
102
107
107F
107R
110
107
107F
107R
114
420
Client system
Modem
Client system
Modem
112
End-users
End-users
116

Figure 1

Figure 2

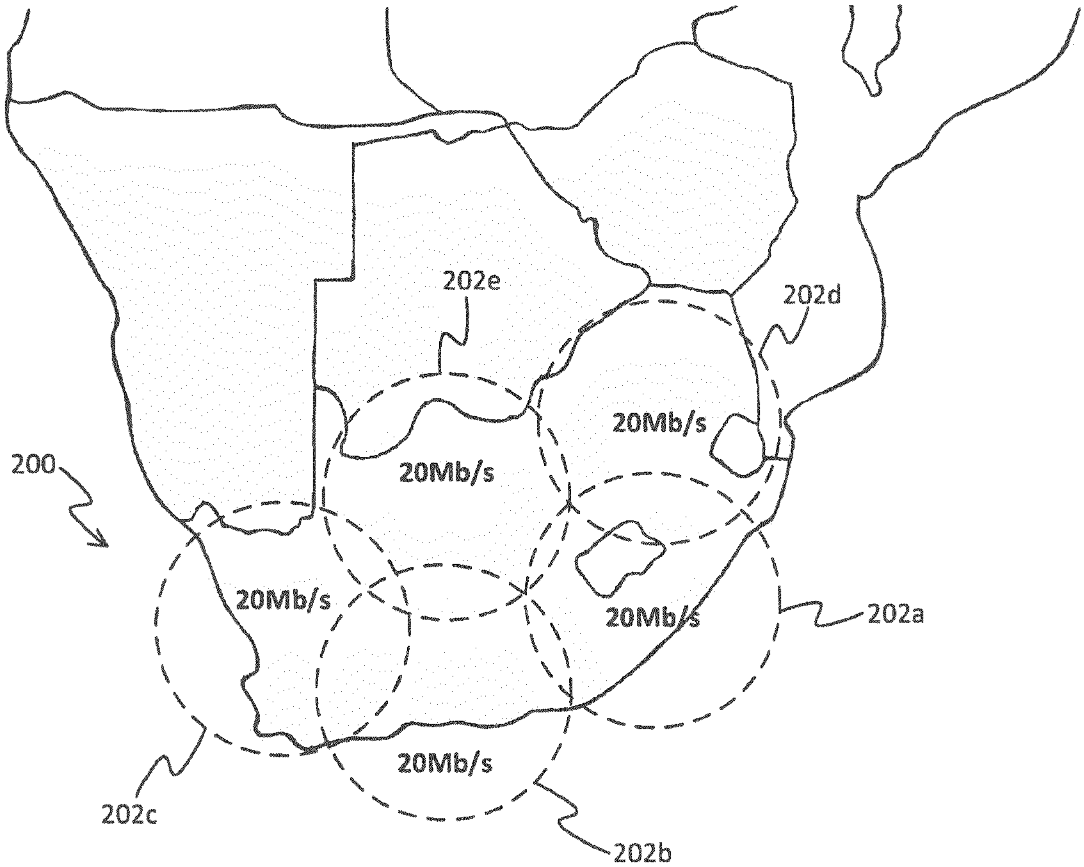
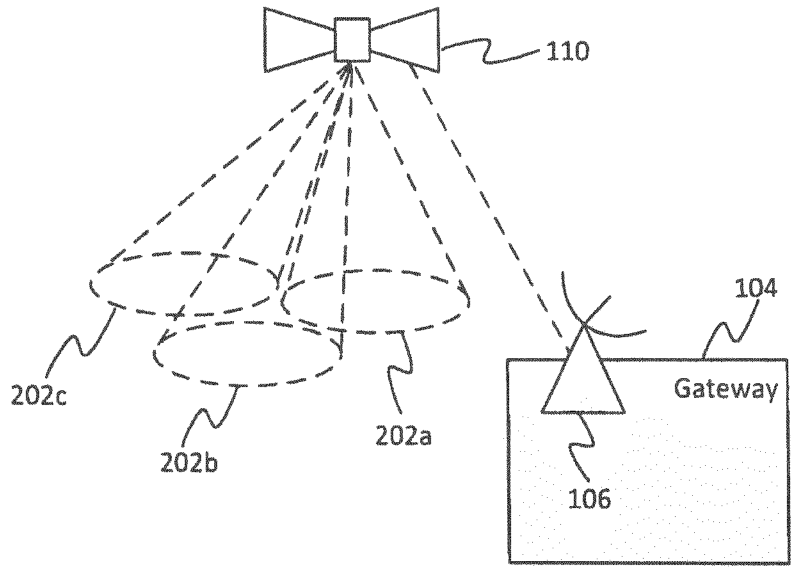
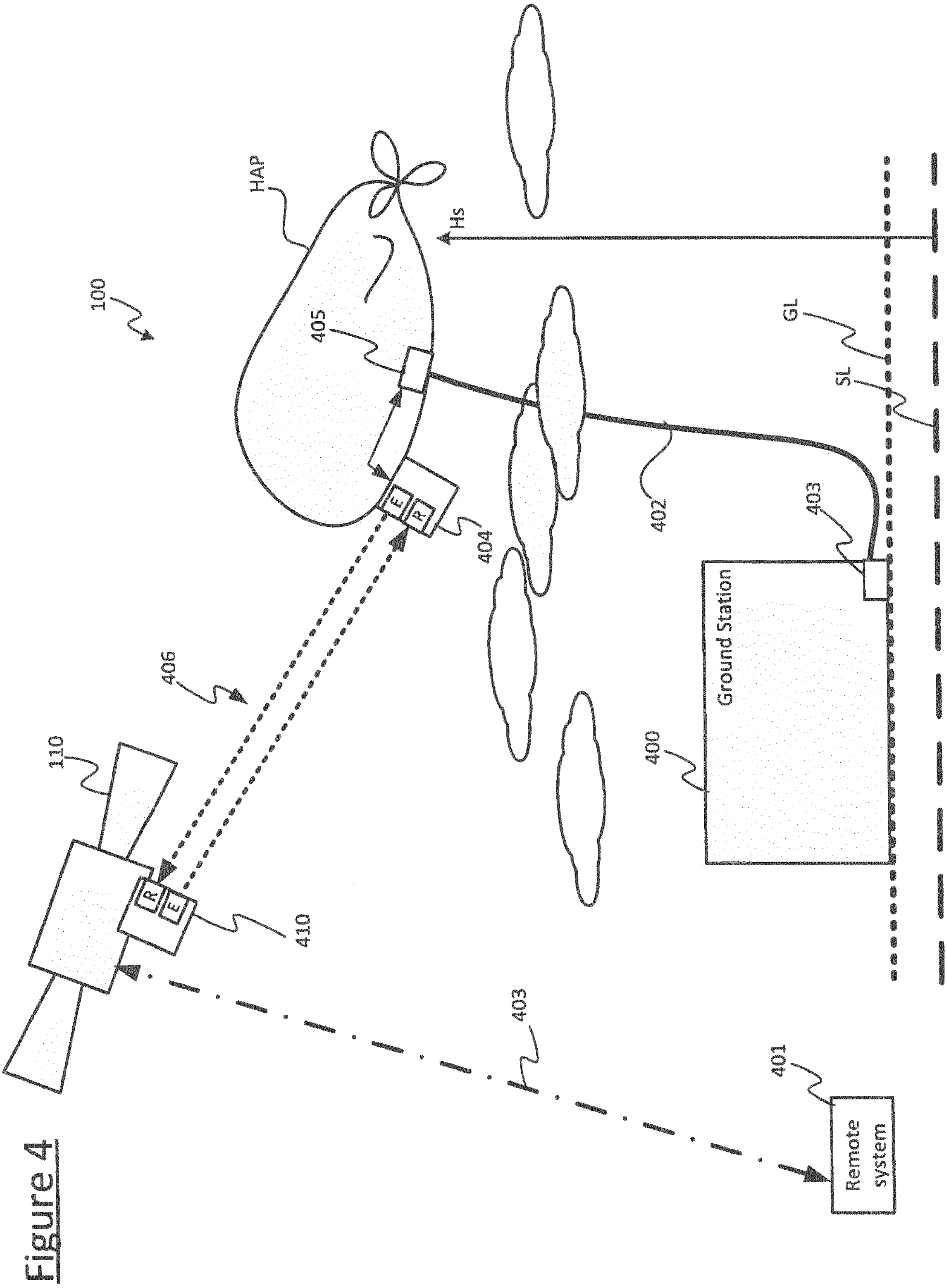


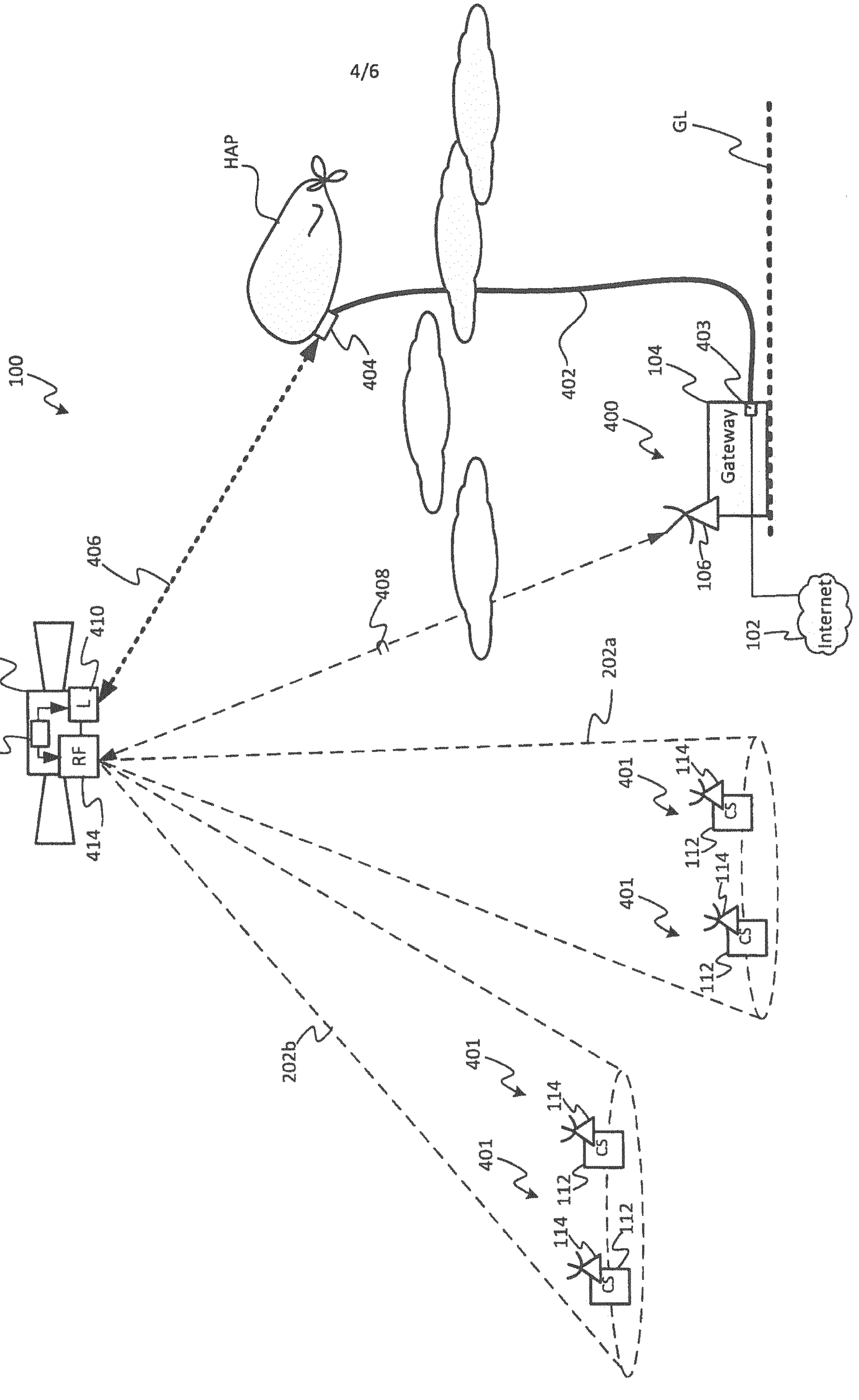
Figure 3





HAP
Hs
100
405
GL
SL
402
403
404
E
R
Ground Station
406
400
110
R
E
410
403
401
Remote system

Figure 4


100
HAP
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402
GL
104
403
Gateway
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Internet
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406
408
110
410
412
L
RF
414
202a
401
114
CS
112
202b

Figure 4A

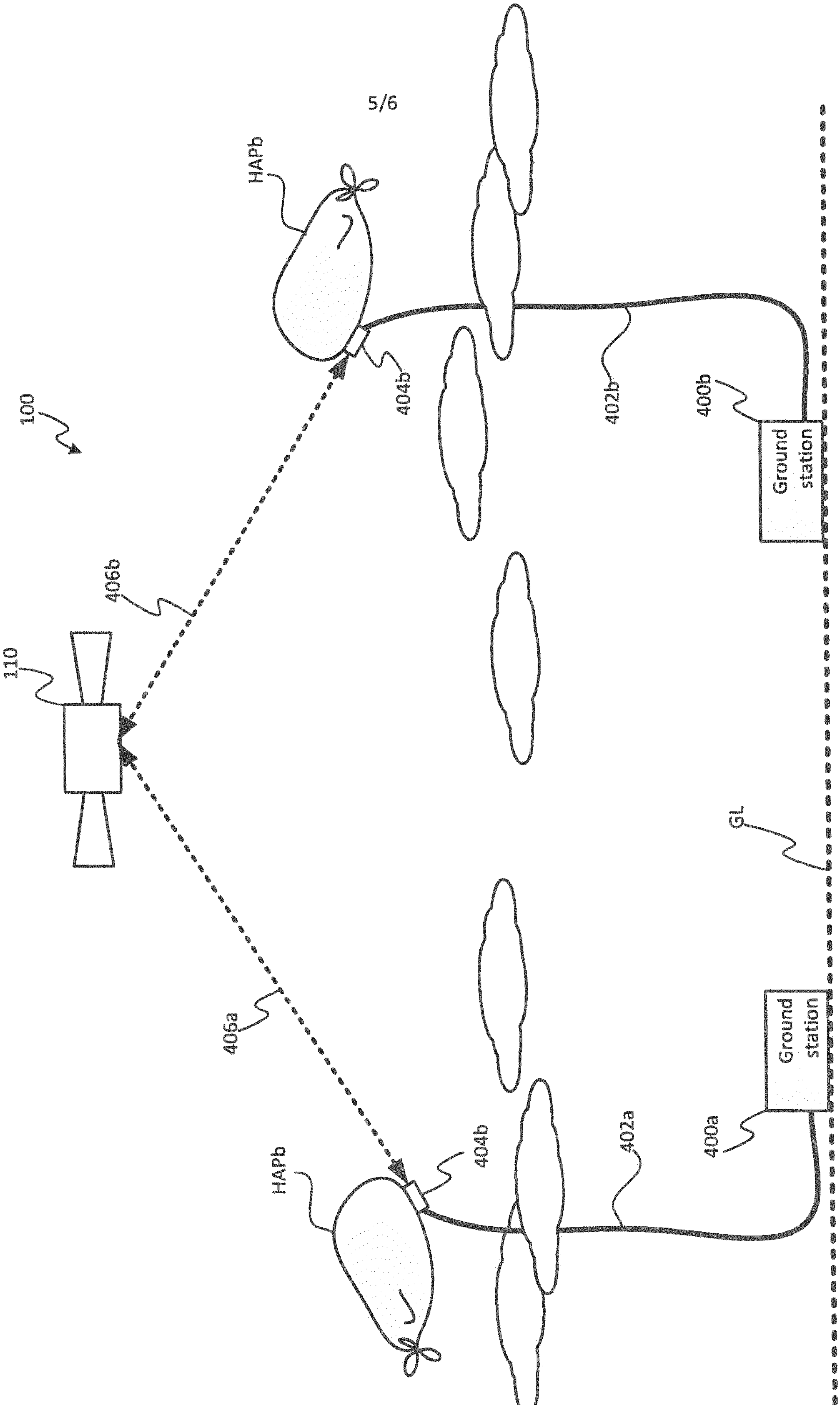
100
110
406b
406a
HAPb
404b
402b
400b
Ground station
GL
HAPb
404b
402a
400a
Ground station

Figure 4B

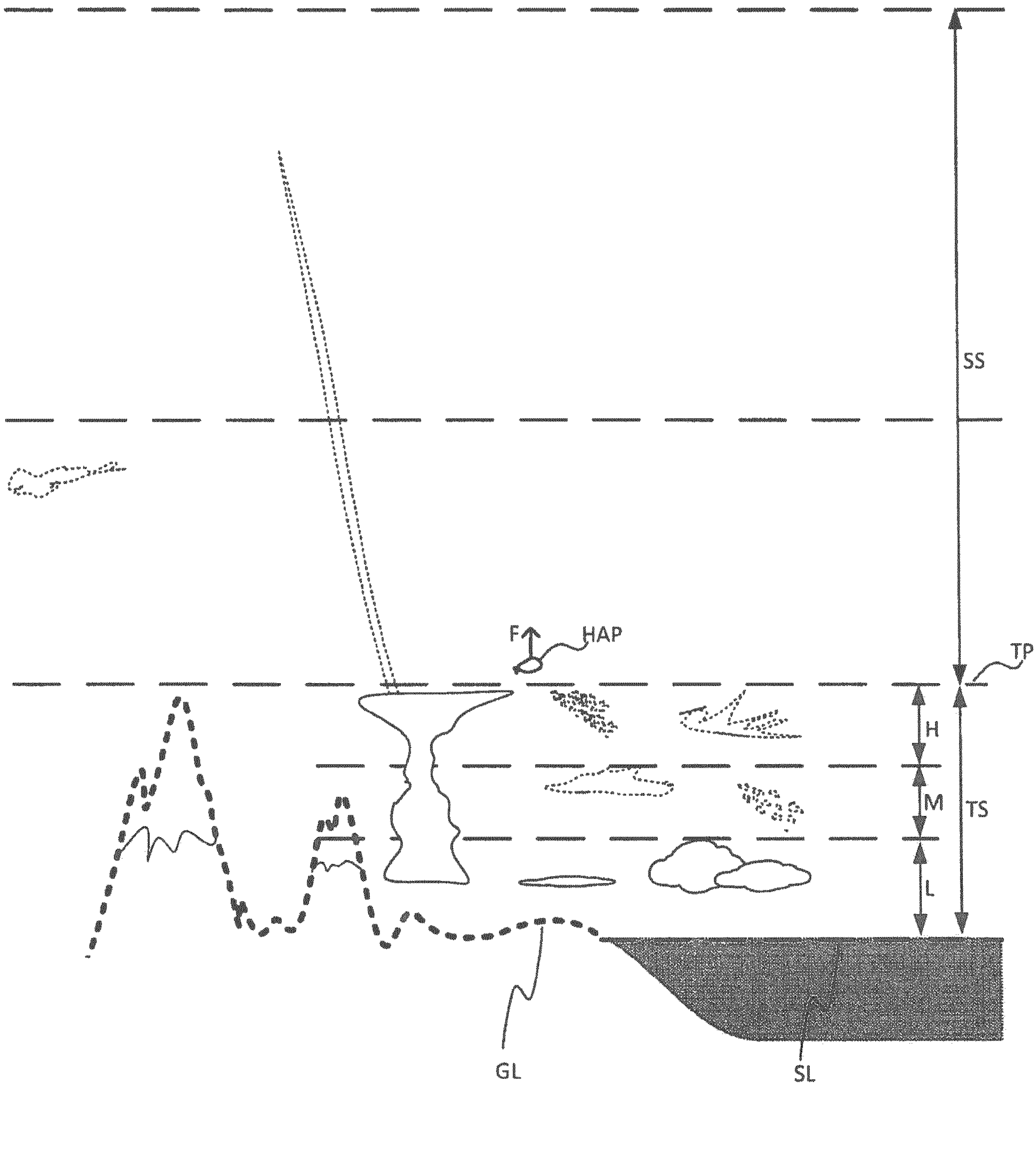

Figure 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/067798

A. CLASSIFICATION OF SUBJECT MATTER
INV. 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)
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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97/33790 A1 (WONG ALFRED Y [US]) 18 September 1997 (1997-09-18) abstract page 1, line 22 - page 2, line 7 page 3, lines 20-25 page 7, lines 12-19 page 11, line 18 - page 12, line 5 page 13, lines 9-20 page 27, lines 17-24 figures claims -----	1-19

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 October 2016	12/10/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Dejonghe, Olivier

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/067798

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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X	WO 01/78256 A1 (SKYCOM CORP [US]) 18 October 2001 (2001-10-18) abstract page 3, lines 1-18 page 3, line 32 - page 4, line 4 page 5, line 1 - page 6, line 17 page 7, lines 1-6 page 8, lines 1-15 figures claims -----	1-19
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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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Information on patent family members

International application No
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