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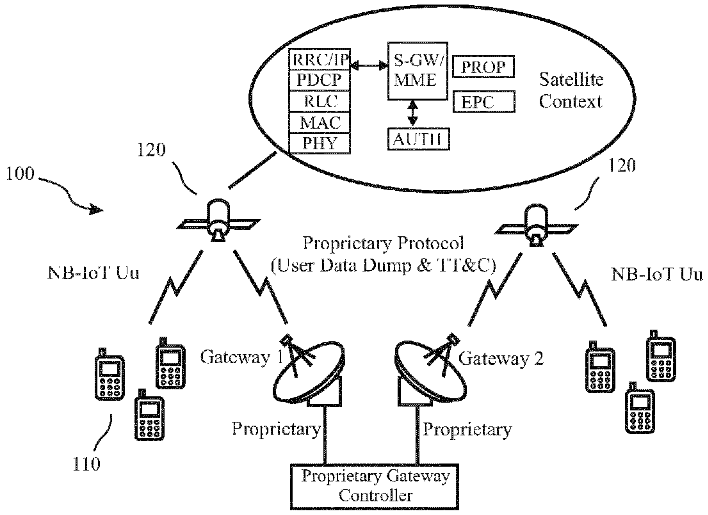

Fig. 1

(57) Abstract: The invention provides a non-terrestrial cellular data communication network comprising at least one base station for connecting at least one terminal device to said network, wherein the base station is hosted on a satellite payload. The proposes system allows for the deployment of IoT based systems in remote areas where no fixed network infrastructure is available, while using the limited available resources both on board the satellite and the terminal devices with care.

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SATELLITE INTERNET-OF-THINGS SYSTEM

Technical field

The present invention lies in the field of cellular wireless communication systems. In particular, the invention relates to cellular wireless communication systems comprising non-terrestrial network infrastructure, such as a cellular base station hosted on a satellite payload.

Background of the invention

Cellular wireless communication networks are nowadays widely available in developed and mainly urban environments. A ground-based network allows a user equipment, such as a telephone, smartphone or personal computer, to establish a data communication link with a data network such as the public Internet via a base station that manages the geographical network cell in which they evolve.

Several cellular network standards have been deployed based on GSM technology, UMTS/3G, LTE/4G and 5G networking technology. Crucially, when no cellular network infrastructure is available in a given geographic area, no wireless data communication is available for any users or device in that area. In remote areas, the construction if network infrastructure is often difficult and overly costly given a low population or device density.

The Internet of Things is a paradigm in which devices such as objects or sensors are able to enter into communication with a remote network backend, such as a data center or data processing server. The transmission of data from an IoT device is often not delay critical. However, a reliable communication link to the network backend needs to be established, at least intermittently. IoT devices may for example be deployed on maritime vessels, or in remote areas. However, in such areas, cellular network access is often not provided by the traditional fixed networking infrastructure. Such devices are usually battery-powered, so that the available transmit power is limited at any point in time.

Technical problem to be solved

It is an objective to present method and device, which overcome at least some of the disadvantages of the prior art.

Summary of the invention

In accordance with a first aspect according to the invention, a non-terrestrial cellular data communication network is provided. It comprises at least one base station for connecting at least one terminal device to said network. The network is remarkable in that in that said base station is hosted on a satellite payload.

Preferably, the network may be 3GPP Narrowband Internet-of-Things compliant cellular network, and said base station may comprise an eNodeB function of said cellular network.

Preferably, the network may comprise a plurality of satellite based base stations.

Said plurality of satellite base stations may preferably be inter-connected using satellite-to-satellite communication channels.

Said satellite may preferably evolve on a low earth orbit, LEO, middle earth orbit, MEO or geostationary orbit, GEO.

The terminal device may preferably be a user equipment (internet-of-things device, smartphone, or equivalent) or a ground-based gateway node serving a plurality of user equipments.

In accordance with another aspect in accordance with the invention, a method of communication between a terminal device and a non-terrestrial cellular data communication network comprising at least one satellite hosting a base station, characterized in that the terminal device is attached to said network by a communication channel between said terminal device and said base station.

Preferably the terminal device may comprise a data processing unit as well as data transmission and data reception means. Preferably, said data processing unit is a data processing unit of said terminal device. The data processing unit may preferably comprise a central processing unit, CPU, operatively coupled to a memory element comprising any of a solid-state drive, SSD, hard disk drive, HDD, random access memory, RAM, or any other known data storage element. The data reception and data transmission means may preferably comprise a cellular networking interface, comprising a receive antenna and a transmit antenna, as well as any required subsystems thereof, for operatively connecting said terminal device to the non-terrestrial cellular data communication network. Alternatively, the terminal device may have remote access, by means of a data communication channel, to said data processing means. The data processing unit may be provided by set of distributed computing devices configured for providing the described functionality.

Preferably, the communication system may comprise a 4G Narrowband Internet-of-Things communication system.

By using the methods in according with aspects of the invention, it becomes possible to use an satellite hosted base station, such as for example an eNodeB type communication node, as an access point for a piece of user equipment having low available power. This enables for example to connect Internet of Things, IoT, devices to a global network, without requiring the construction of fixed cellular networking infrastructure. Once the base station is within the device's line of sight, the device may synchronize to the base station, thereby improving the efficiency of the communication between the user equipment and the base station. By avoiding retransmissions due to loss of synchronization between the user equipment and the base station, this approach is able to save power on both the user equipment device and on the airborne/spaceborne base station, which as limited resources as well.

Brief description of the drawings

Several embodiments of the present invention are illustrated by way of figures, which do not limit the scope of the invention, wherein:

- figure 1 illustrates a store and forward architecture for a non-terrestrial cellular communication network;
- figure 2 illustrates a real-time non-terrestrial cellular communication network with inter-satellite link;
- figure 3 illustrates a femtocell architecture for a non-terrestrial cellular communication network.

Detailed description of the invention

This section describes aspects of the invention in further detail based on preferred embodiments and on the figures. The figures do not limit the scope of the invention. Unless otherwise stated, similar concepts are referenced by similar numerals across embodiments. For example, references 100, 200 and 300 each refer to a non-terrestrial cellular data communication network, in accordance with a first, second and third embodiment of the invention.

The 3GPP NB-IoT system is a terrestrial standard. The corresponding standards document is publically available at https://www.etsi.org/deliver/etsi_ts/136100_136199/136104/13.04.00_60/ts_136104v130400p.pdf, and is hereby incorporated by reference in its entirety. In the development any terrestrial standard, it is always assumed that the radio and core networks are never short of resources in terms of both processor capacity and power requirements. However, in satellite systems, in addition to power constraints and processor capacity limitation, the channel model, pathloss and other functional conditions for operations are different in space.

Therefore, the present invention offers solution to the problem by proposing a set of functional and architectural modifications to the system that will enable the successful and efficient operation of cellular wireless communication protocols over non-terrestrial networks.

The invention will be described with reference to an NB-IoT compliant cellular data network, without being limited thereto. The wording 'base station' refers to an access point, to which user device connect either directly or through a local gateway/proxy in order to gain access to the cellular network, its core services, and to other devices connected to the cellular network.

A satellite NB-IoT system comprises at least one satellite, but preferably a global constellation of satellites that may be Low Earth Orbit, LEO, or Medium Earth Orbit, MEO, or Geostationary Orbit, GEO, each by way of non-limiting example hosting an Satellite-based Narrow-Band IoT, S-NB-IoT, payload. Thereby, each satellite is capable of running a complete EnodeB + EPC network solution. The system further includes other allied subsystems, earth station gateways (GW), Satellite NB-IoT radio access network (SNRAN) data centers, satellite mobile network operators (SMNO), and S-NB-IoT mobile or fixed user equipment(s) (UE).

It is proposed that each satellite that is part of the non-terrestrial cellular network infrastructure flies a S-NB-IoT payload (along with other necessary sub-systems such as the Telemetry, Tracking & Control subsystem, power subsystem, thermal control subsystem, Attitude determination and Control subsystem, on-board computer, etc.) that is a complete network in a box solution based on software defined radio architecture, SDR.

Each of these S-NB-IoT payloads is essentially a Base Transceiver System (EnodeB), possibly with additional Evolved Packet Core (EPC) functionality (MME, S-GW, AUTH, etc.,) depending on the architecture. The payload can run all the layers (PHY, MAC, RLC, PDCP, RRC/IP) of the 3GPP NB-IoT protocol stack with and without modifications for both satellite and other use cases.

In cellular the Long Term Evolution, LTE, standard, an eNB is really a controller of a group of cells. A typical cell site will have a single eNB controlling 3 sectors (or cells) with a single S1 link back to the EPC. This is a convenient level of abstraction as It allows a single centralised processing system coupled with many remote radio heads, RRH, to implement the sectors (or cells). If all the scheduling is performed in one location, then this enables spontaneous interference mitigation schemes without having to exchange information with distant nodes (and the inherent delays involved in backhauling these messages).

It is proposed that the satellite NB-IoT extends this principle in that a single eNB satellite controls many cells and these are implemented as 'softly' as possible to allow flexibility and scalability. In 3GPP, the maximum number of cells that an eNB can control is 256, due to the cell id being an 8-bit quantity. It is assumed that this will be sufficient for the satellite NB-IoT application.

One important difference between satellite and cellular NB-IoT is the assumption that the satellite will have spot beams in the uplink and downlink to divide the radio and processing overhead spatially and provide methods of frequency reuse.

The known standard of NB-IoT uses a Frequency Division Duplexing, FDD, mechanism to establish radio communication between the base station (eNodeB) and the User Element (UE). The eNodeB operates in Full Duplex-FDD while the UE operates in half duplex-FDD.

In accordance with aspects of the invention, it is also proposed that the S-NB-IoT payload or base station shall employ a Time Division Duplexing, TDD, scheme which may or may not be based on the frame structure of 3GPP LTE – TDD standard.

A Half Duplex-FDD scheme of operation of the S-NB-IoT payload or base station is proposed based on the TDD frame structure of the S-NB-IoT in order to accommodate the scarcity in spectrum in the associated bandwidths of operation and reduce the complexity of design of the RF front end of the payload to be accommodate the limited power budget available in satellite implementation.

The system architecture may be implemented in one of the three ways as shown in Figure 1, Figure 2 and Figure 3.

Figure 1 illustrates is the Store-and-forward architecture. It shows a non-terrestrial cellular data network 100 comprising a terminal device 110 and a satellite-based base station 120. If the link with the Gateway is not permanent and S1 is not always available, then some of the Evolve Patent Core, EPC, roles must be incorporated into each satellite to compensate for the lack of connectivity with the gateway. Here, elements such as the S-GW and authentication centre must be localized in the satellite and updated via some OAM procedure. Similarly, any user data must be queued in the satellite and exchanged with the Gateway when the ground link is available. This is the store and forward architecture.

Each satellite in the network effectively acts as an eNB and EPC and the system are scalable by adding new satellites, just like a terrestrial network would add a new base station. Scalability is also achievable by increasing the available bandwidth for operation.

The link with the Gateway is proprietary (this could by way of example be the TT&C Link) and must provide the following functionality: the link must be bi-directional. The link may be an off-the-shelf solution such as a point to point microwave link. The transport layer can be based on any reliable transport technology, such as IP. A simple protocol to transfer stored user datagrams between the satellite and the underlying core network connection (presumed to be IP). An OAM protocol for maintenance of the software entities in the satellite context. One example of this is the add/modify/delete subscriber records in the HSS so that authentication and admission of users can be performed even when the link with core network is unavailable.

In this case, the X2 interface cannot be supported directly as it is concerned with real-time operations between satellites, which clearly is not possible when the link is not permanent. If it is discovered that some non-real time X2 operations would be beneficial in the proprietary link architecture (maybe exchanging load reports) then the messages can be added to the link, as it simply depends on IP transport.

Figure 2 illustrates an alternative architecture with a permanent S1 interface. It shows a non-terrestrial cellular data network 200 comprising a terminal device 210 and a satellite-based base station 220. If S1 is always available and reliable, then the SGW and the EPC are located on the ground and may be shared between all satellites. This is the preferred architecture for higher scalability as each satellite acts just as an eNodeB and there is a central EPC. The link with the Gateway is standardised and may be implemented in terms of any off the shelf point to point link over IP. However, this requires high complexity as inter-satellite links and greater ground station coverage to guarantee continuous visibility are required.

X2 is an optional 3GPP interface that allows eNBs to communicate directly with each other in near real-time. It used in LTE to enable features such as data forwarding during handover, interference coordination and load balancing and is included here for completeness. If S1 is a permanent interface, then X2 will be available too as is can use the same transport layer. In cellular NB-IoT X2 is also used to transfer RRC Contexts between eNBs in the user plane optimisation scheme.

Figure 3 illustrates an alternative femto-cell architecture. It shows a non-terrestrial cellular data network 300 comprising a terminal device 310, and a satellite-based base station 320. In this non-limiting example, the terminal device 310 is a gateway station, to which user equipment devices may connect. It has been proposed that instead of using NB-IoT directly as the link between satellite and UEs, then a network of ground-based NB-IoT femtocells are deployed and they are backhauled via satellite instead.

Femtocells may be deployed within buildings for in-building coverage. Femtocells can act as concentrators for groups of S-NB-IoT terminals, instead of trying to connect each S-NB-IOT terminal directly to a satellite constellation. The shorter radio links between terminals and femtocells will enable better coverage (or deployment in more hostile radio environments). Femtocells feature extensive radio resource management algorithms for ad-hoc deployments.

If the frequency available for satellite backhaul is still used, then the femtocell antenna will still need to be in Line of Sight, LOS, with the satellite, which implies the need for feeders and custom installation. The femtocell could operate on frequencies more suitable for in-building coverage. If licensed bands are used, then clearly an operating license will be required, and this will vary between territories.

To backhaul the S1 interface from the femtocells to the satellite a new real-time, high availability radio access scheme will need to be developed for this link. Presumably satellite NB-IoT cannot be used to backhaul cellular NB-IoT because of the extensive power saving schemes used and the inability to support real-time services. LTE relay over satellite could be an option but is subject to similar technical restrictions in the physical layer.

Femtocells need a permanent power supply, as the power amplifier will need to be permanently operating to generate the downlink control channels for UE synchronisation. A custom S-NB-IoT femtocell must be developed.

The proposed technology can be implemented in both licensed and unlicensed frequency bands. In order to accommodate non-IP data delivery for a store and forward architecture SCEF (Service Capability Exposure Function) components shall be a part of the EPC of the S-NB-IoT system. This connection between the SCEF and the application servers is, on a terrestrial LTE/NB-IoT network, a permanent connection.

It is proposed that the SCEF functions be modified to accommodate for, but not limited to the functions of, buffering of non-IP user data in SCEF from multiple users, mimicking the connection between SCEF and Application Servers on the ground station in the absence of an intersatellite link. In the presence of an available link the link between the SCEF and the application servers may be made permanent and implemented as recommended by the 3GPP NB-IoT standard.

It should be noted that features described for a specific embodiment described herein may be combined with the features of other embodiments unless the contrary is explicitly mentioned. Based on the description and figures that has been provided, a person with ordinary skills in the art will be enabled to develop a computer program for implementing the described methods without undue burden.

It should be understood that the detailed description of specific preferred embodiments is given by way of illustration only, since various changes and modifications within the scope of the invention will be apparent to the person skilled in the art. The scope of protection is defined by the following set of claims.

Claims

1. A non-terrestrial cellular data communication network (100, 200, 300), comprising at least one base station (120, 220, 320) for connecting at least one terminal device (110, 210, 310) to said network, characterized in that said base station is hosted on a satellite payload.

2. The network according to claim 1, wherein the network is a 3GPP Narrowband Internet-of-Things compliant cellular network, and wherein said base station comprises an eNodeB function of said cellular network.

3. The network according to any of claims 1 or 2, wherein the network comprises a plurality of satellite based base stations (120, 220, 320).

4. The network according to claim 3, wherein at least part of said plurality of satellite base stations are inter-connected using satellite-to-satellite communication channels.

5. The network according to any of claims 1 to 4, wherein said satellite evolves on a LEO, MEO or GEO orbit.

6. The network according to any of claims 1 to 5, wherein said terminal device (110, 210, 310) is a user equipment or a ground-based gateway node serving a plurality of user equipments.

7. A method of communication between a terminal device (110) and a non-terrestrial cellular data communication network (100) comprising at least one satellite hosting a base station (120), characterized in that the terminal device is attached to said network (100) by a communication channel between said terminal device (110) and said base station (120).

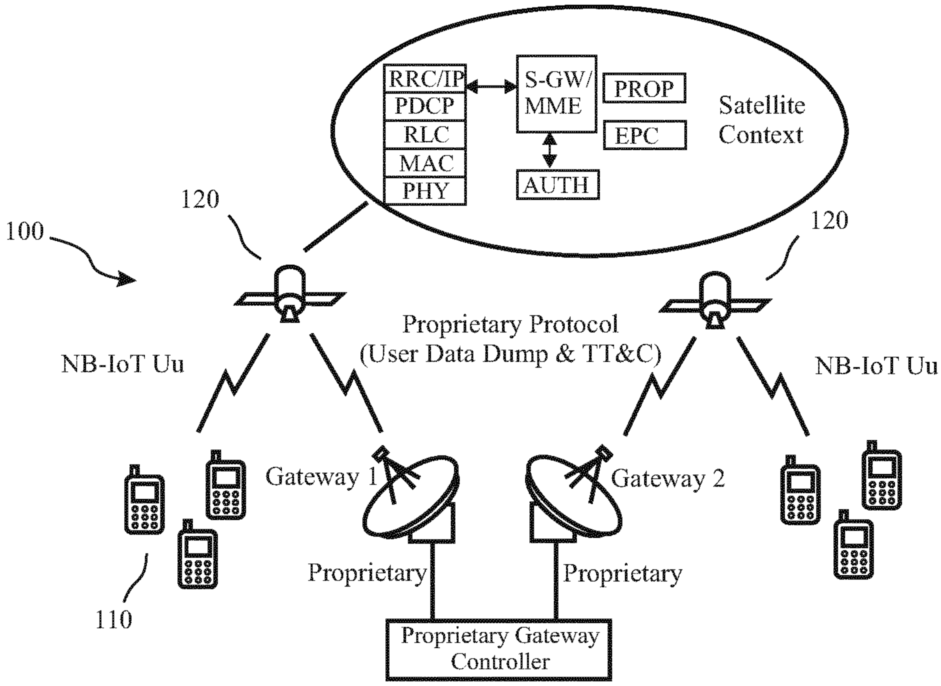
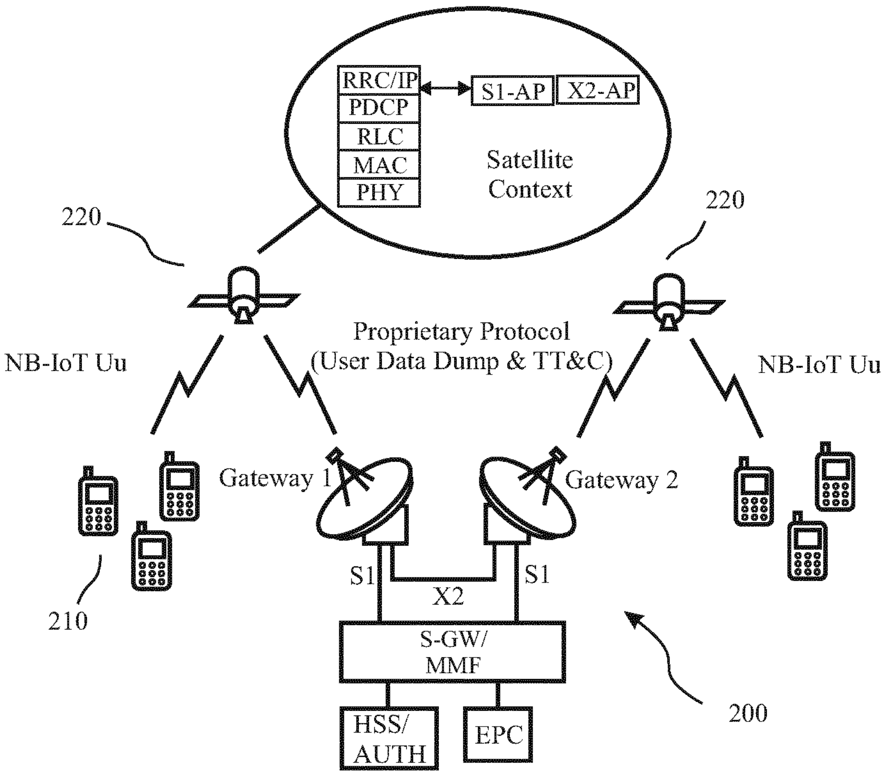

RRC/IP
PDCP
RLC
MAC
PHY
S-GW/
MME
PROP
EPC
AUTH
Satellite
Context
100
120
120
Proprietary Protocol
(User Data Dump & TT&C)
NB-IoT Uu
NB-IoT Uu
Gateway 1
Gateway 2
Proprietary
Proprietary
110
Proprietary Gateway
Controller

Fig. 1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PDCP
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MAC
PHY
S1-AP
X2-AP
Satellite
Context
220
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Proprietary Protocol
(User Data Dump & TT&C)
NB-IoT Uu
NB-IoT Uu
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Gateway 2
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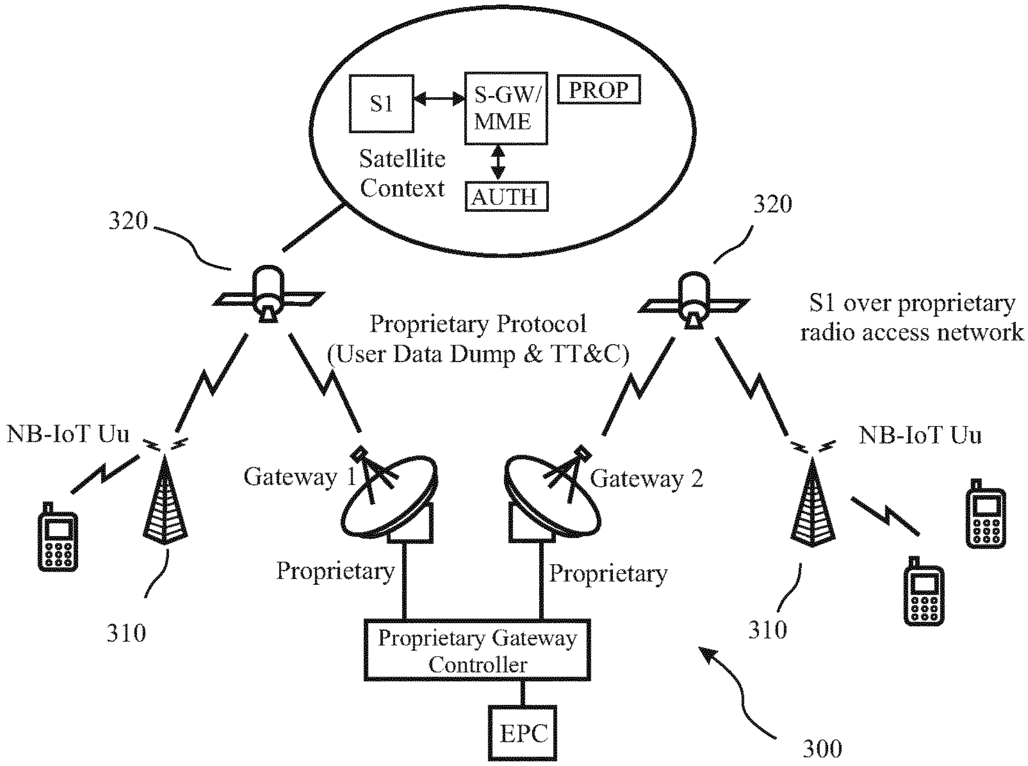
S1
X2
210
S-GW/
MMF
HSS/
AUTH
EPC
200

Fig. 2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S-GW/
MME
PROP
Satellite
Context
AUTH
320
320
S1 over proprietary
radio access network
Proprietary Protocol
(User Data Dump & TT&C)
NB-IoT Uu
NB-IoT Uu
Gateway 1
Gateway 2
Proprietary
Proprietary
310
310
Proprietary Gateway
Controller
EPC
300

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/077808

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/185 H04W52/02
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 H04W

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 A	FR 3 064 856 A1 (THALES SA [FR]) 5 October 2018 (2018-10-05) figure 1 page 1, line 22 - line 29 page 5, line 25 - line 27 page 20, line 10 - line 20 page 20, line 25 - line 31 page 22, line 1 - line 3 page 22, line 33 - page 23, line 2 page 23, line 5 - line 6 -----	1-3,5-7 4
X A	EP 3 048 745 A1 (AIRBUS DEFENCE & SPACE LTD [GB]) 27 July 2016 (2016-07-27) figure 1 paragraph [0031] paragraph [0037] paragraph [0039] -----	1,3-7 2

☐ 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

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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 December 2019	13/12/2019

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/077808

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