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(54) Title: AIRBORNE RADIO SYSTEM THAT USES NEAREST SAE-GW FOR ANCHORING NEW CONNECTIONS ALONG THE FLIGHT PAGHT AND TUNNELS EXISTING CONNECTIONS

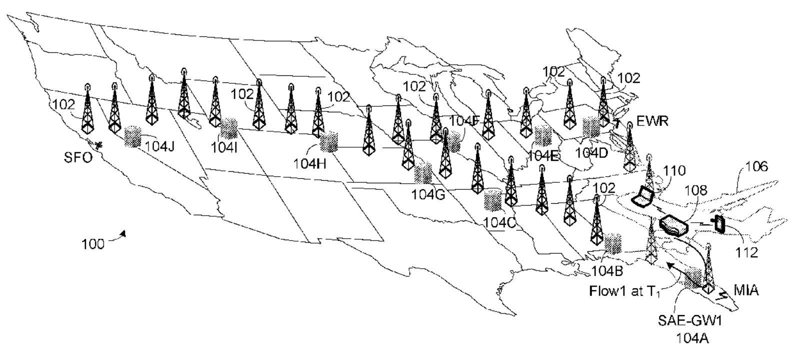

Fig. 1

(57) Abstract: An ABR-UE (airborne radio-user equipment) and Wi-Fi AP (access point) on an airplane that obtains an IP address from the closest system architecture evolution gateway (SAE-GW) for each new connection. Existing connections remain with the original SAE-GW, but as the plane travels, new connections are made with the closest SAE-GW at the time of the new connection. This reduces backhaul.

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PATENT APPLICATION

TITLE: **Airborne Radio System That uses Nearest SAE-GW for Anchoring New Connections along the Flight Path and Tunnels Existing Connections**

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Serial No. 62/315,877 entitled "Airborne Radio System That uses Nearest SAE-GW for Anchoring New Connections along the Flight Path and Tunnels Existing Connections," filed March 31, 2016, which is hereby incorporated by reference as if reproduced in its entirety.

[0002] This application is related to U.S. Patent Application Serial No. __/________ entitled "Accessing Multiple Access Point Names by Airborne Radio System for Optimal Routing to Gateways along a Flight Path," which is filed concurrently herewith and is hereby incorporated by reference as if reproduced in its entireties.

BACKGROUND

[0003] For data connectivity from moving aircraft two types of solutions exist, one that relies on satellite connection and another that uses an Air to Ground (ATG) network. The satellite-based solution is slow and has long latency, which makes it unsuitable for interactive or streaming services. The Air to Ground systems do not have satellite-like propagation delay and should be able to perform much better. The ATG network has a set of base stations spread across the terrestrial coverage, e.g. in case of United States the base stations will be from coast to coast along the flight paths. This is shown in Fig. 1 for two exemplary flight paths between Miami (MIA) and San Francisco (SFO) and Newark (EWR) and San Francisco. The ATG systems typically leverage 3G or 4G technologies, where an airborne radio (ABR) acts like a regular mobile handset or modem (user equipment or UE) for connecting to base stations and then base stations are connected to the terrestrial mobile network for connectivity to Internet or other networks. The ABR then acts as a modem connected to a Wi-Fi access point which then accepts connections from the laptops, tablets and cell phones on the aircraft.

[0004] The traditional mobile network was designed for mobility across neighborhood, cities and regions for walkable and drivable use cases. Typically the core network has a mobility anchor (packet data network gateway/gateway GPRS support node or P-GW/GGSN) in the region that connects to the Internet. The path from the UE is to radio towers (eNodeB or eNB). The eNB then connects to S-GW (serving gateway) and then the S-GW connects to the P-GW/GGSN (mobility anchor), which is a gateway to an external network such as the Internet. In the context of an ATG network, the ABR-UE on the aircraft connects to radio towers in its vicinity. A group of the eNBs are then served by a nearby S-GW. The S-GW can connect to any P-GW depending on access point name (APN) based P-GW selection. Typically, for service like Internet access the nearest P-GW with Internet connectivity is selected.

[0005] When a UE first attaches to mobile network (say upon power up) it requests connectivity to the external network (e.g. Internet) as identified by an APN (Access Point Name). The APN decides which P-GW/GGSN becomes anchor for the connecting UE. Typically, the name resolution of the APN will point to a nearby P-GW/GGSN that serves that APN. When a UE re-attaches to the mobile network (say due to powering down and then by powering up) or upon accessing new service as identified by a different APN (Access Point Name), it gets to establish a new session/context with P-GW. Depending on location or service sought, it may get connected to a different P-GW.

[0006] Once a UE establishes a session/context with the anchor (P-GW/GGSN), the IP address of the UE is assigned by the P-GW/GGSN and all its data is always routed through the anchor for the duration of connectivity, e.g. if a person attaches to network in city A and drives for a few hours to city B, his/her data flow will remained anchored through the P-GW/GGSN that it got connected to in city A. If the user was simply accessing the Internet, it would be more efficient to route the data through a P-GW/GGSN located closer to City B. However, due to the smaller distances involved, the additional delay due to such anchoring is not that big of an issue.

[0007] This situation completely changes in ATG systems, where the ABR-UE is typically connected to a Wi-Fi access point (AP) onboard and hundreds of users connect to the AP over the wireless local area network (WLAN), which then does network address translation (NAT) and sends all data through the ABR-UE to the ground. Considering a coast-to-coast flight involves 5000km of distance, the ABR-UE will be connected to a base station near the departing airport and a nearby P-GW/GGSN. Then for the duration of the flight it will remain anchored to that P-GW near the originating airport. Given that coast-to-coast propagation delays are significant, ATG solutions also suffer from long delays and perform poorly for interactive services. The ATG service will have multiple regional datacenters with P-GWs. As an illustration, say a person watches 30 min. of video on a laptop soon after takeoff from SFO. Then the person takes a nap for 2 hours, then does skype chatting using the laptop for the next fifteen minutes and then in the last one hour of flight he/she takes aerial video of the NY area using the smartphone to be emailed to a colleague in Maine. The way the ABR-UE to P-GW connection is setup, it is clear to see that the user experience will be progressively worse. Moreover, the same P-GW will be utilized for all of the flights taking off from nearby airports, making P-GWs near busy airports unnecessarily loaded, especially if many people in the flight use the service. Backhauling a lot of data across the continent is not only inefficient but expensive as well.

SUMMARY OF THE DISCLOSURE

[0008] In embodiments according to the present invention, an ABR-UE and Wi-Fi AP obtains an IP address from the closest SAE-GW for each new connection. Existing connections remain with the original SAE-GW, but as the plane travels, new connections are made with the closest SAE-GW at the time of the new connection. This reduces backhaul.

BRIEF DESCRIPTION OF THE FIGURES

[0009] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an implementation of apparatus and methods consistent with the present invention and, together with the detailed description, serve to explain advantages and principles consistent with the invention.

[0010] Figures 1-3 are block diagrams of an ATG network according to the present invention at different times.

[0011] Figure 4A is a flowchart of ABR-UE and Wi-Fi AP operation according to the present invention.

[0012] Figure 4B is a flowchart of SAE-GW operation according to the present invention.

[0013] Figure 5 is a block diagram of an S-GW or P-GW.

[0014] Figure 6 is a block diagram of a combined ABR-UE and Wi-Fi access point according to the present invention.

[0015] Figure 7 is a block diagram of a separate ABR-UE and a separate Wi-Fi access point according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] Fig. 1 is a representation of an ATG network 100. Various base stations 102, indicated by the radio towers, are positioned along the flight paths between MIA and SFO and EWR and SFO. Connected to every few base stations 102 is a combined S-GW and P-GW, referred to as a system architecture evolution gateway (SAE-GW) 104A-J, and is shown next to that group of base stations 102 for purposes of illustration. An airplane 106 is illustrated having an ABR-UE and Wi-Fi access point 108, which are connected to a laptop 110 and a tablet 112 by Wi-Fi.

[0017] This is a network based solution to problem described above. The data path from the ABR-UE 108 goes to an enB 102, where a GTP tunnel is established between the eNB 102 and an SAE-GW 104. This description uses SAE-GWs to describe the preferred embodiment but it is straightforward to see that the operations can be applied to separately implemented S-GWs and P-GWs.

[0018] In a deployment model according to this invention, each SAE-GW 104A-J acts as anchor for certain flows and can GTP tunnel others to another anchor. These SAE-GWs 104A-J typically have DPI (Deep Packet Inspection) capability and the preferred embodiment uses that. This is best illustrated with the help of an example. When the aircraft 106 takes off at time T_1, the ABR-UE 108 establishes a connection with the nearest SAE-GW1 104A. The SAE-GW1 104A assigns the ABR-UE 108 an IP address and establishes the datapath. In addition, the preferred embodiment uses the

NAT capability at the SAE-GW1 104A before routing the user packets to external data network. Thus, when a passenger establishes a Wi-Fi connection, the Wi-Fi access point/router 108 assigns an IP address to the passenger's device and then NATs it to an ABR-UE IP address. The user flow then reaches the SAE-GW1 104A. The SAE-GW1 104A then does DPI on the packet to check if it is establishment of a new flow (e.g. TCP SYN packet, or first occurrence of 4tuple in the NAT table). If it is a new flow, the SAE-GW1 104A NATs the flow using an IP address that is reverse routable to this SAE-GW1 104A. As long as the aircraft 106 remains closest to this SAE-GW1 104A, this logic works and all flows are routed in and out of the nearest SAE-GW1 104A. This is shown in Figure 1.

[0019] When the aircraft 106 moves and becomes closer to another SAE-GW2 104C, as in Fig. 2 at time T_2, in normal 3GPP routing the SAE-GW2 104C acts as an S-GW and tunnel the packets back to original SAE-GW1 104A acting as the P-GW which assigned the ABR-UE IP address in the first place. Embodiments according to the present invention modify that logic. For existing flows, the SAE-GW2 104C continues to tunnel the existing flows to the original SAE-GW1 104A. These flows will end over time. Regardless, when a new flow starts (e.g. TCP SYN), the ABR-UE and Wi-Fi access point 108 NATs using an IP address that is reverse routable to this SAE-GW2 104C. As a large majority of user flows are TCP, this logic works. For UDP flows, there is no session start, therefore more work is needed. In these cases, the DPI of higher level protocol identifies new sessions and then the same logic can be applied.

[0020] The same logic is applied at SAE-GW3 104H and so on until a flight ends. Figure 3 illustrates the flows at time T_3.

[0021] The operation of the ABR-UE and Wi-Fi P 108 is illustrated in Fig. 4A. In step 402, the ABR-UE and Wi-Fi AP 108 is turned on, the initial cellular connection is made and the access point is activated. In step 404 the ABR-UE and Wi-Fi AP 108 determines if there is a new Wi-Fi connection request, such as a request for a new transmission control protocol (TCP)/IP connection. The request can be a request to connect to a new IP address or a request for a new TCP port at an IP address that is used for an existing connection of the device. Conventionally this is done based on a message from a Wi-Fi AP program looking for TCP SYN or using DPI as described above. If there is a new Wi-Fi connection request, in step 406 the ABR-UE and Wi-Fi

AP 108 determines the closest SAE-GW, based on the location and the enodeB 102. In step 408, an IP address is obtained from the SAE-GW. In step 410, a local IP address is assigned to the Wi-Fi request, if one is not already assigned to the requesting device, and a NAT relationship is made with the IP address obtained from the nearest SAE-GW. This is a many-to-many NAT situation, the IP addresses from the various SAE-GWs to local, internal IP addresses. The Wi-Fi process then continues normally.

[0022] Operations are slightly different for separate S-GWs and P-GWs. The ABR-UE 108 communicates with a mobile management entity (MME) to obtain the closest relevant P-GW and closest S-GW and then obtains an IP address from the P-GW.

[0023] Relevant operation of the SAE-GW 104 is shown in Fig. 4B. The SAE-GW 104 receives a connection request from the ABR-UE 108. In step 454 the SAE-GW 104 determines if this is a new connection request, as described above. If a new request, in step 456 the SAE-GW 104 obtains an IP address for the APN of interest. In step 458 the IP address is provided to the ABR-UE 108. Normal operations resume in step 460.

[0024] If not a new connection request, in step 462 the connection is tunneled to the anchor SAE-GW 104.

[0025] As known to one skilled in the art and shown in Fig. 5, SAE-GWs, S-GWs and P-GWs are complicated and expensive computer systems and packet routers, which include a processor 502, network interfaces or ports 508, a packet switch 506 for packet routing and a memory 504 to store programs and data. The operations, such as those described here, are performed by programs stored in the memory and executing on the processor. Because the structure and operation of an SAE-GW, an S-GW and a P-GW are so well known, further details of their construction, configuration and operation are not provided here.

[0026] Fig. 6 is an exemplary block diagram of a combined ABR-UE and Wi-Fi AP 600 according to the present invention. A processor 602 manages the operation and executes program contained in memory 606, such as flash memory. A RAM 604 provides working storage. A Wi-Fi network processor and RF chip 608 is connected to the processor 602 and handles the Wi-Fi communications. An LTE modem and RF chip 610 is connected to the processor 602 and handles the cellular communications.

[0027] The memory 606 contains various programs executed on the processor 602. First is an operating system 612. Second is a W-Fi access point program 616 that performs the normal access point and Wi-Fi functions. An LTE program 614 that handles the cellular communications. An airborne program 618 handles the special operations of an ABR-UE and Wi-Fi access point, including most of the operations described herein including obtaining IP addresses from the P-GWs, providing the NAT operations and determining the closest P-GW. It is understood that the functions of the ABR-UE and Wi-Fi AP are substantially separate even though they may be located in the same device and share components, such as a processor, so that the functions may be referred to separately even though the ABR-UE and Wi-Fi AP are integrated into a single device.

[0028] The system 700 of Figure 7 is similar to the system 600 of Figure 6 except that the ABR-UE and Wi-Fi access point functions have been separated. The Wi-Fi access point 703 includes a processor 702A that manages the operation and executes program contained in memory 706A, such as flash memory. A RAM 704A provides working storage. A Wi-Fi network processor and RF chip 708 is connected to the processor 702A and handles the Wi-Fi communications. The memory 706A contains various programs executed on the processor 702A. First is an operating system 712. Second is a W-Fi access point program 716 that performs the normal access point and Wi-Fi functions. An airborne program 718A handles Wi-Fi access point special operations described herein including providing the NAT operations.

[0029] An ABR-UE 701 includes a processor 702B that manages the operation and executes program contained in memory 706B, such as flash memory. A RAM 704B provides working storage. An LTE modem and RF chip 710 is connected to the processor 702B and handles the cellular communications. The memory 706B contains various programs executed on the processor 702B. First is an operating system 712. Second is an LTE program 714 that handles the cellular communications. An airborne program 718B handles the ABR-UE special operations, including obtaining IP addresses from the SAE-GWs and determining the closest SAE-GW.

[0030] The Wi-Fi access point processor 702A is connected to the ABR-UE processor 702B so that the two processors can communicate. The airborne programs 718A and 718B contain the programs to allow this communication and the programs that handle the cooperative portions of operation.

[0031] It is understood that these are highly simplified block diagrams for illustration purpose and many different configurations can be developed by those skilled in the art and perform the operations described above.

[0032] By having the ABR-UE obtain IP addresses from SAE-GWs (or S-GWs and P-GWs) along the flight path, any new connections are anchored or sent to the nearest SAE-GW or P-GW as the airplane crosses the country, thus reducing back haul and congestion on SAE-GWs or P-GWs near airports.

[0033] The above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments may be used in combination with each other. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein."

CLAIMS

1. An air-to-ground communication system comprising:

a plurality of packet data network gateways (P-GWs), each P-GW having a pool of Internet Protocol (IP) addresses and being associated with a plurality of a plurality of base stations, the plurality of base stations and the plurality of P-GWs located along a flight path of an aircraft, the flight path extending a multiplicity of kilometers;

an airborne radio user equipment (ABR-UE) located on the aircraft for communicating with the plurality of P-GWs; and

a Wi-Fi access point located on the aircraft and coupled to the ABR-UE for connecting a plurality of user Wi-Fi devices located on the aircraft to the ABR-UE and performing network address translation (NAT) operations,

wherein the ABR-UE and Wi-Fi access point cooperate to obtain an IP address from the nearest P-GW and provide a connection between the nearest P-GW and a user Wi-Fi device when the user Wi-Fi device requests a new IP connection, the nearest P-GW changing as the aircraft proceeds along the flight path, and

wherein the plurality of P-GWs provide IP addresses from their respective IP address pools for new IP connections requested by the ABR-UE and tunnel existing IP connections.

2. The system of claim 1, wherein the plurality of P-GWs are provided in system architecture evolution gateways (SAE-GWs).

3. The system of claim 1, further comprising the aircraft on which the ABR-UE and the Wi-Fi access point are located.

4. The system of claim 3, further comprising:

the plurality of base stations located along the flight path of the aircraft, the flight path extending a multiplicity of kilometers.

5. The system of claim 1, further comprising:

the plurality of base stations located along the flight path of the aircraft, the flight path extending a multiplicity of kilometers.

6. A method comprising:

communicating, by an airborne radio user equipment (ABR-UE) located on an aircraft, with a plurality of base stations located along a flight path and a plurality of packet data network gateways (P-GWs) associated with the plurality of base stations, the plurality of P-GWs also located along the flight path, each P-GW having associated Internet protocol (IP) addresses;

obtaining, by cooperation of the ABR-UE and a Wi-Fi access point located on the aircraft, the Wi-Fi access point coupled to the ABR-UE for connecting a plurality of user Wi-Fi devices located on the aircraft to the ABR-UE and for performing network address translation (NAT) operations, an IP address from the nearest P-GW when a user Wi-Fi device requests a new IP connection, the nearest P-GW changing as the aircraft proceeds along the flight path;

providing, by cooperation of the ABR-UE and a Wi-Fi access point, a connection between the nearest P-GW and the user Wi-Fi device requesting the new IP connections;

providing, by the plurality of P-GWs, IP addresses from their respective IP address pools for new IP connections requested by the ABR-UE; and

tunneling, by the plurality of P-GWs, existing IP connections.

7. The system of claim 6, wherein the plurality of P-GWs are provided in system architecture evolution gateways (SAE-GWs).

8. A packet data network gateway (P-GW) for an air-to-ground communication system, the P-GW comprising:

a processor;

a plurality of network ports coupled to the processor;

a non-transitory processor readable storage medium coupled to the processor and containing program code to cause the processor to perform the method comprising the steps of:

providing Internet Protocol (IP) addresses from an IP address pool of the P-GW for new IP connections requested by an airborne radio user equipment (ABR-UE) on behalf of a user Wi-Fi device requesting a new IP connection; and

tunneling existing IP connections provided by the ABR-UE.

9. The P-GW of claim 8, wherein the P-GW is provided in a system architecture evolution gateway (SAE-GW).

10. A device comprising:

an airborne radio user equipment (ABR-UE) located on an aircraft for communicating with a plurality of packet data network gateways (P-GWs), each P-GW having a pool of Internet Protocol (IP) addresses and being associated with a plurality of the plurality of base stations, the plurality of plurality of base stations and the plurality of P-GWs located along a flight path of an aircraft, the flight path extending a multiplicity of kilometers; and

a Wi-Fi access point located on the aircraft and coupled to the ABR-UE for connecting a plurality of user Wi-Fi devices located on the aircraft to the ABR-UE and performing network address translation (NAT) operations,

wherein the ABR-UE and Wi-Fi access point cooperate to obtain an IP address from the nearest P-GW and provide a connection between the nearest P-GW and a user Wi-Fi device when the user Wi-Fi device requests a new IP connection, the nearest P-GW changing as the aircraft proceeds along the flight path.

11. The device of claim 10, wherein theP-GW is provided in a system architecture evolution gateway (SAE-GW).

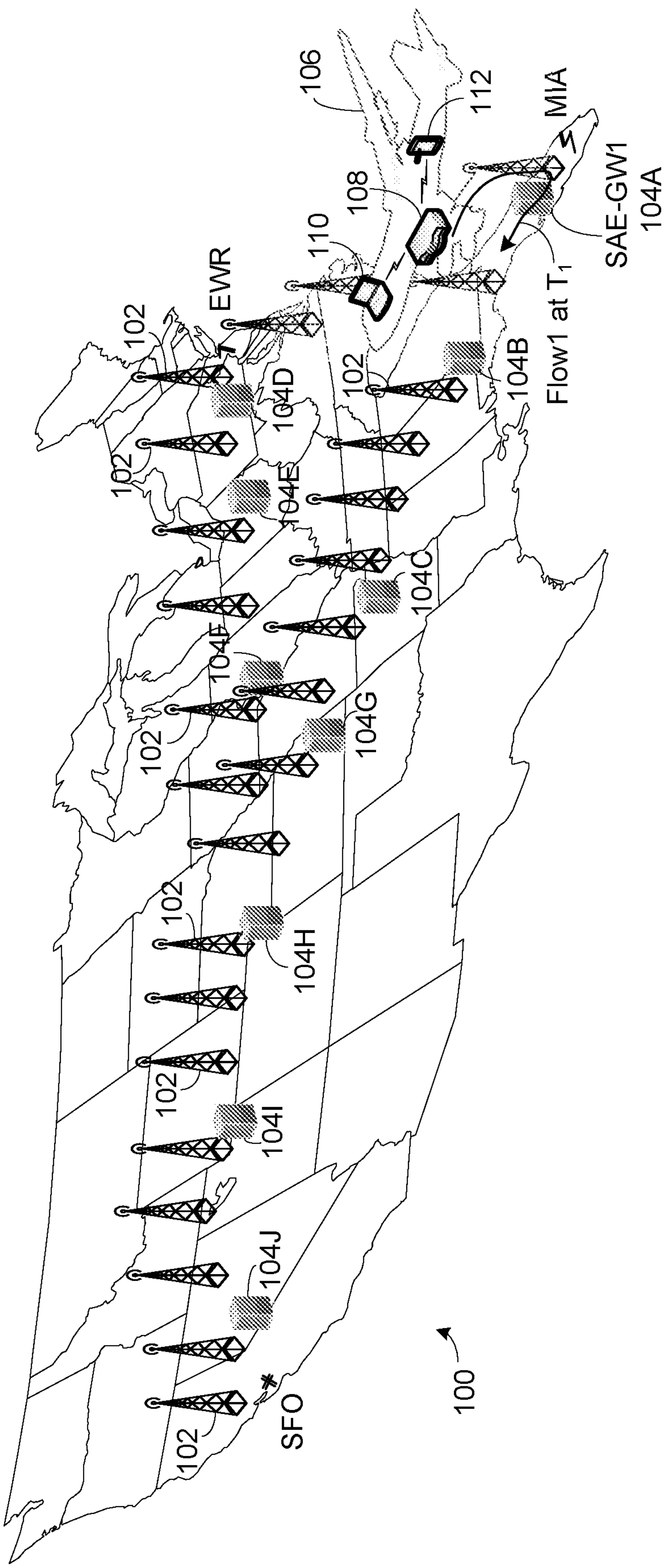
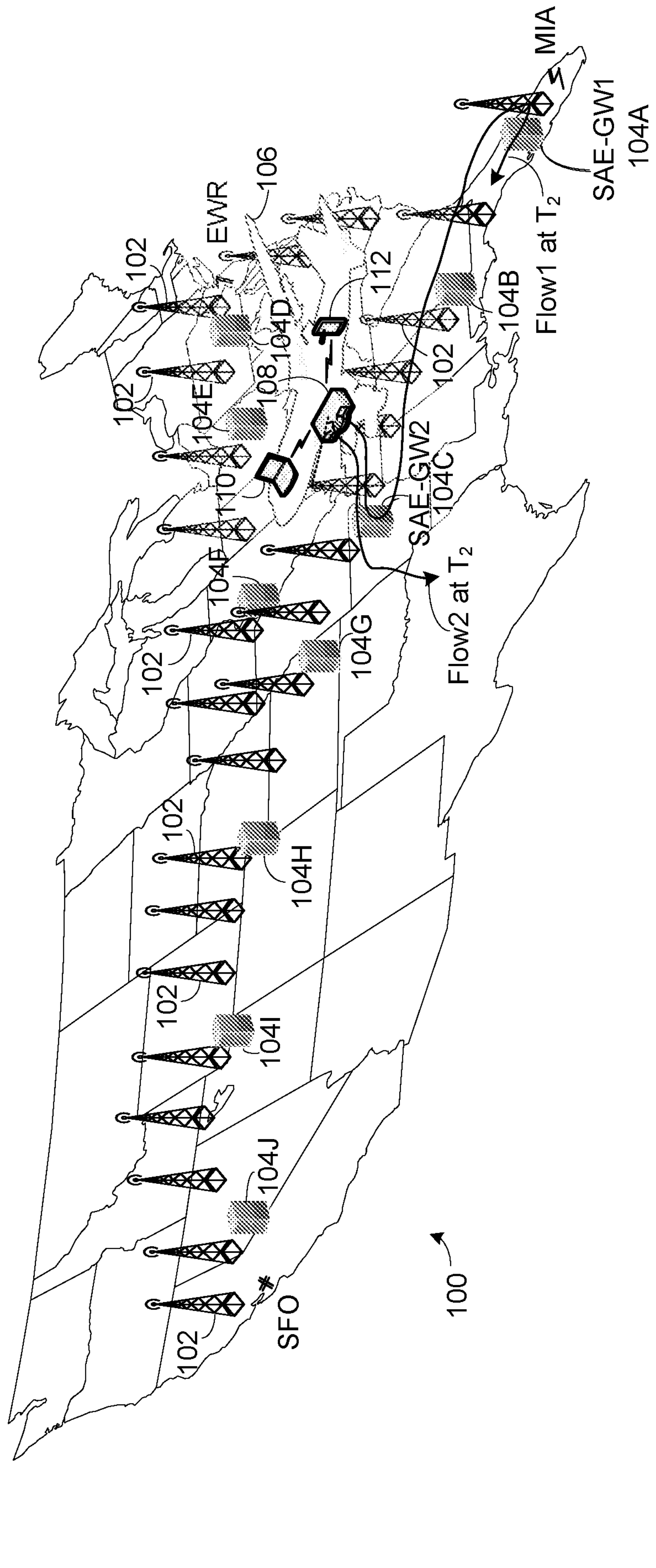

106
112
MIA
108
110
EWR
SAE-GW1
104A
Flow1 at T_1
102
104D
104B
104E
104C
104F
104G
104H
104I
104J
SFO
100

Fig. 1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104A
Flow1 at T_2
106
EWR
102
104B
112
104D
108
104E
110
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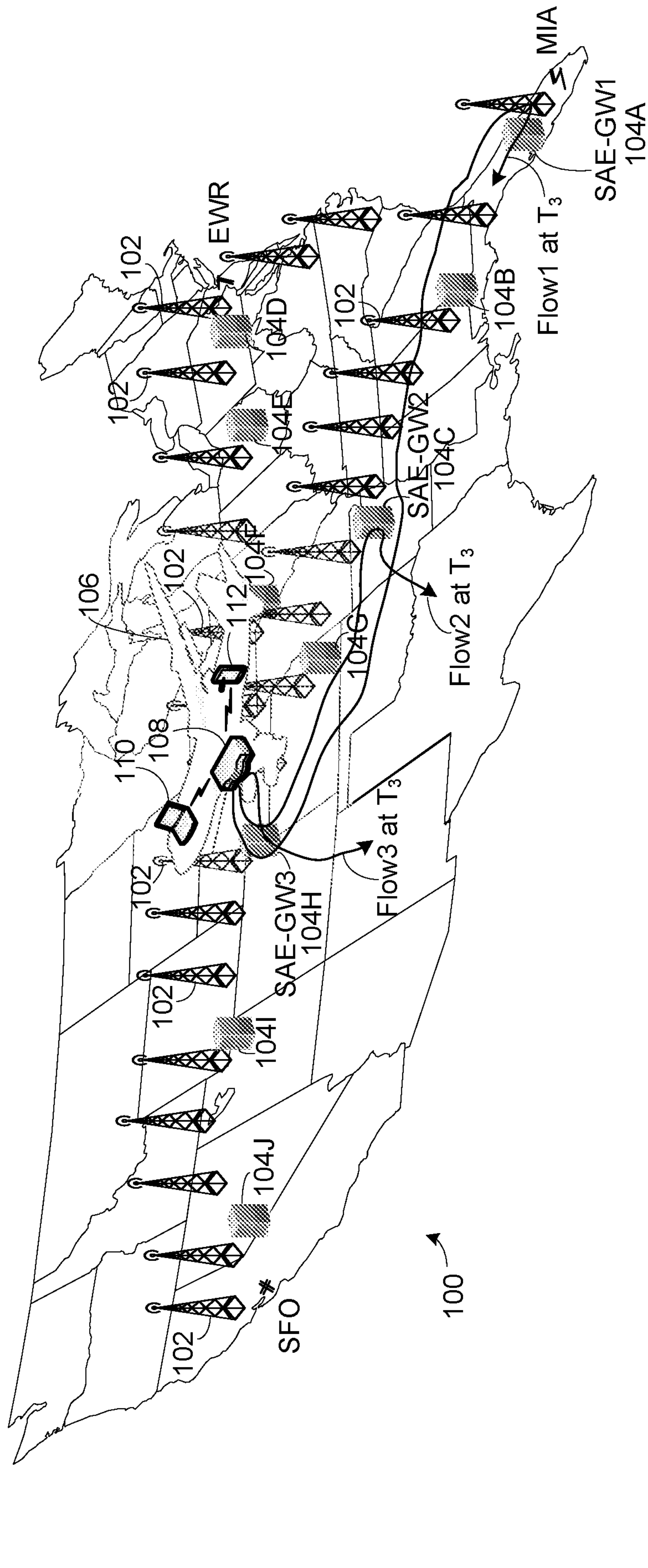
104C
Flow2 at T_2
104F
104G
104H
104I
104J
SFO
100

Fig. 2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Flow1 at T_3
EWR
102
104D
104B
102
104E
SAE-GW2
104C
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102
112
104F
Flow2 at T_3
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104I
104J
SFO
100

Fig. 3

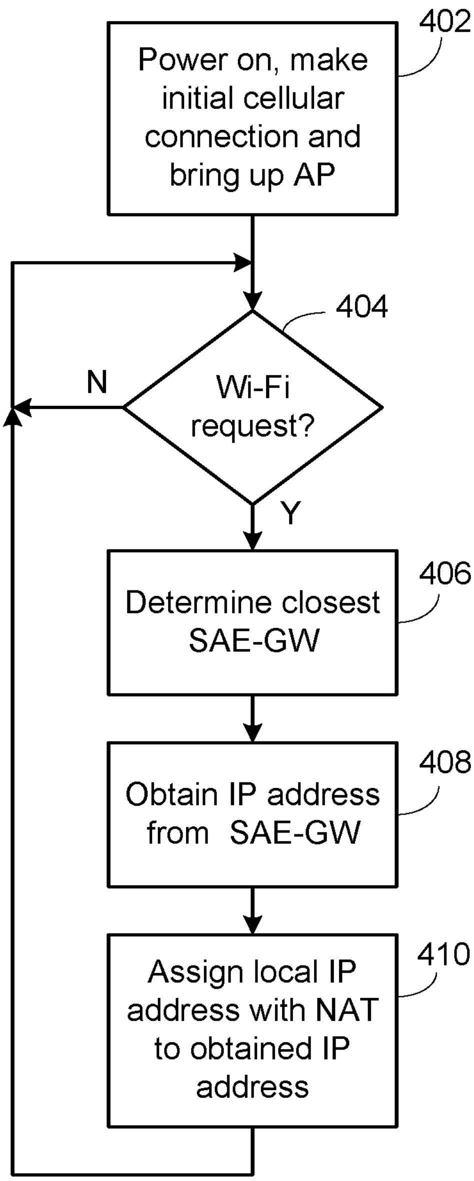


Fig. 4A

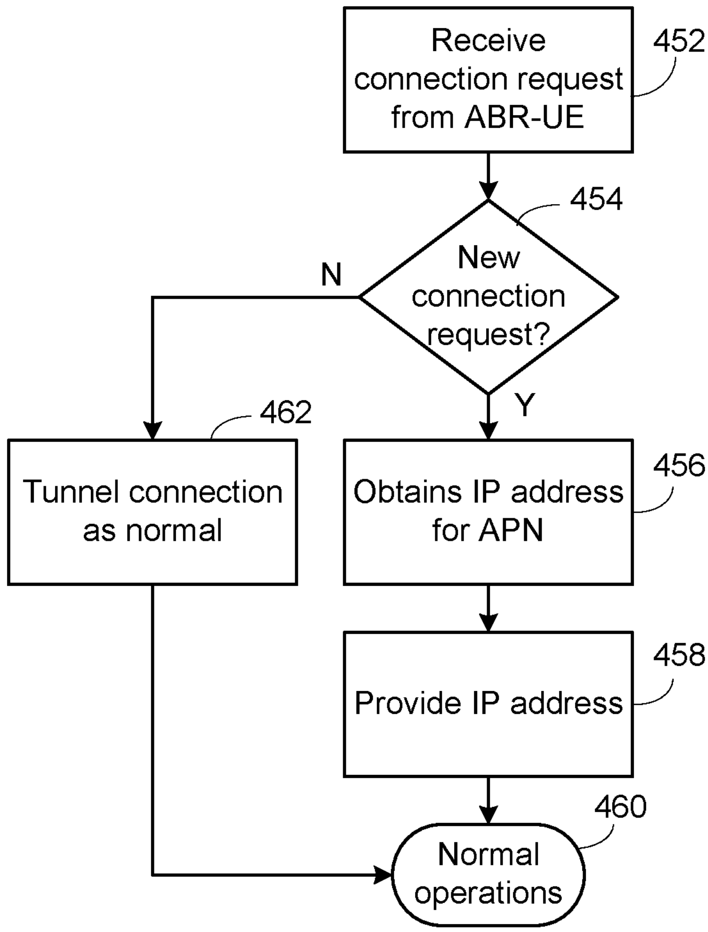
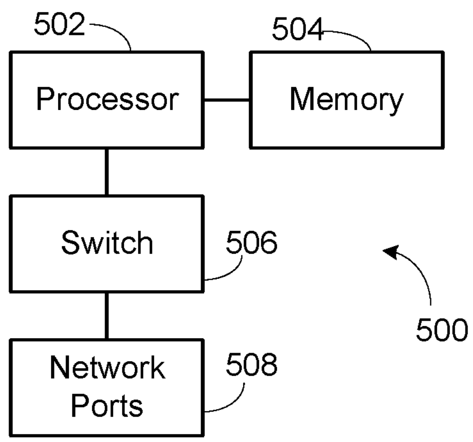


Fig. 4B

Fig. 5



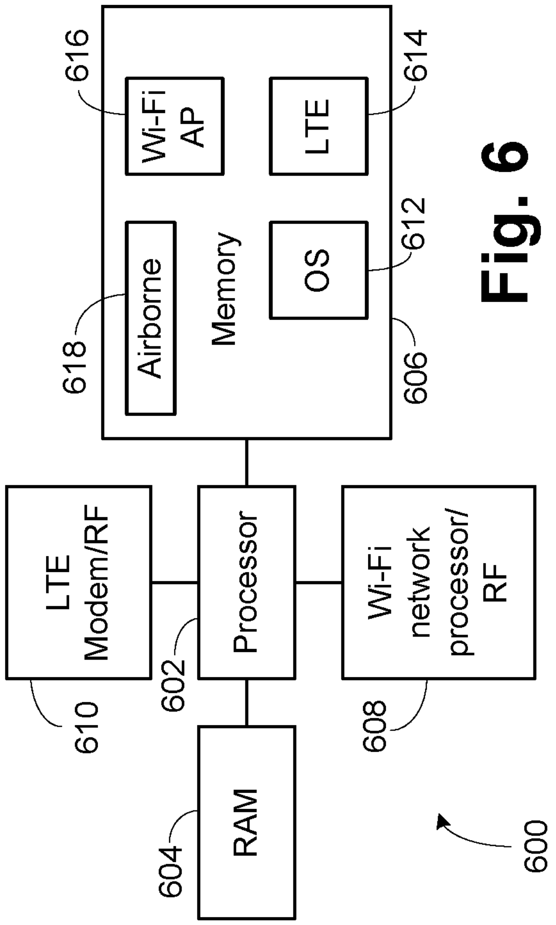
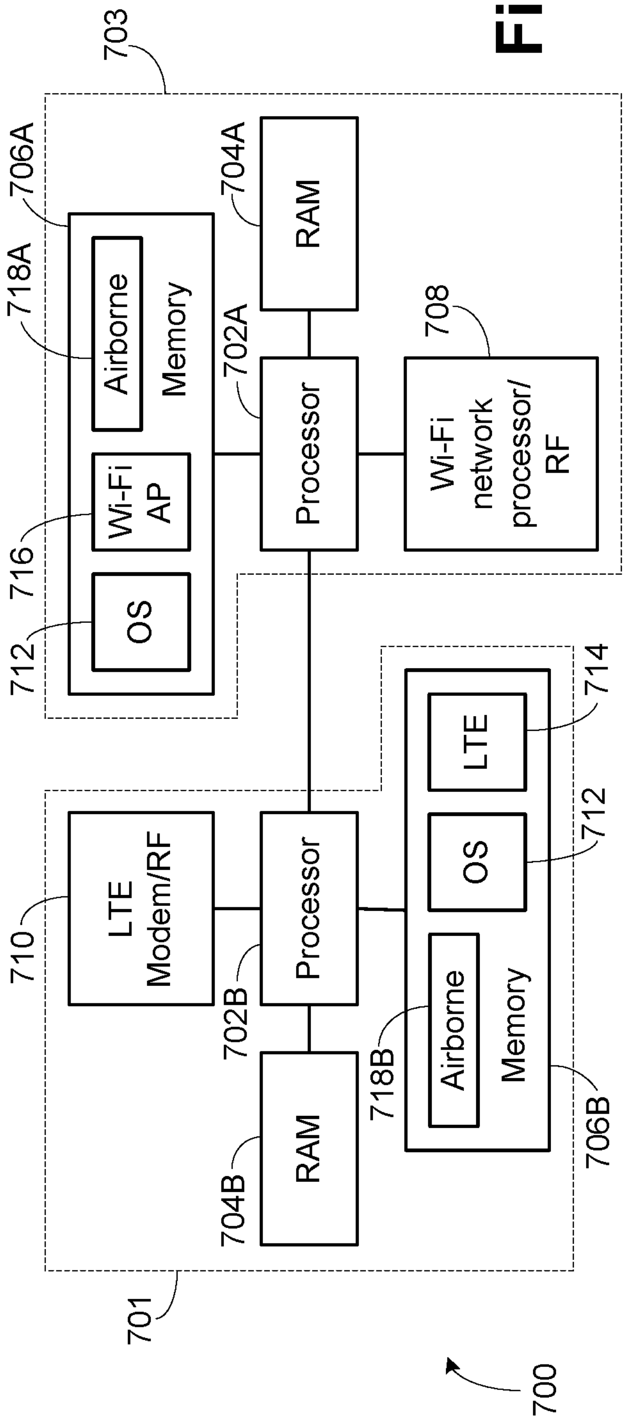

Wi-Fi AP
LTE
Airborne
Memory
OS
616
614
612
618
606
LTE Modem/RF
Processor
Wi-Fi network processor/ RF
RAM
610
602
608
604
600

Fig. 6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Wi-Fi AP
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704A
RAM
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Processor
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LTE
OS
Airborne
Memory
714
712
718B
706B
LTE Modem/RF
Processor
RAM
710
702B
704B
701
700

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/024587

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04B 7/185; H04Q 7/20; H04W 4/02; H04W 12/08 (2017.01)
CPC - H01Q 3/24; H04B 7/18506; H04W 84/005; H04W 84/06 (2017.02)

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)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 340/945; 370/338; 455/431 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2009/0186611 A1 (STILES et al) 23 July 2009 (23.07.2009) entire document	1, 3-6, 8, 10 --- 2, 7, 9, 11
Y	US 2010/0202375 A1 (RYDNELL et al) 12 August 2010 (12.08.2010) entire document	2, 7, 9, 11
A	US 2009/0082013 A1 (ECKERT et al) 26 March 2009 (26.03.2009) entire document	1-11
A	WO 2014/158766 A1 (FLEXTRONICS AP, LLC) 02 October 2014 (02.10.2014) entire document	1-11
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