US012401395B2

(12) **United States Patent**
Yu et al.

(10) **Patent No.: US 12,401,395 B2**
(45) **Date of Patent: Aug. 26, 2025**

(54) **SATELLITE RADIO ACCESS NETWORK (SAT RAN) BEAM AND GATEWAY SEAMLESS HANDOVER**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 775 days.

(21) Appl. No.: **17/583,992**

(22) Filed: **Jan. 25, 2022**

(65) **Prior Publication Data**

US 2022/0240151 A1 Jul. 28, 2022

Related U.S. Application Data

(60) Provisional application No. 63/141,218, filed on Jan. 25, 2021.

(51) **Int. Cl.**
H04B 7/01 (2006.01)
H04B 7/185 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04B 7/01*** (2013.01); ***H04B 7/18541*** (2013.01); *H04W 36/00692* (2023.05);
(Continued)

(58) **Field of Classification Search**
CPC H04W 36/32; H04W 84/06; H04W 36/18; H04B 7/01; H04B 7/18541; H04B 7/0695
See application file for complete search history.

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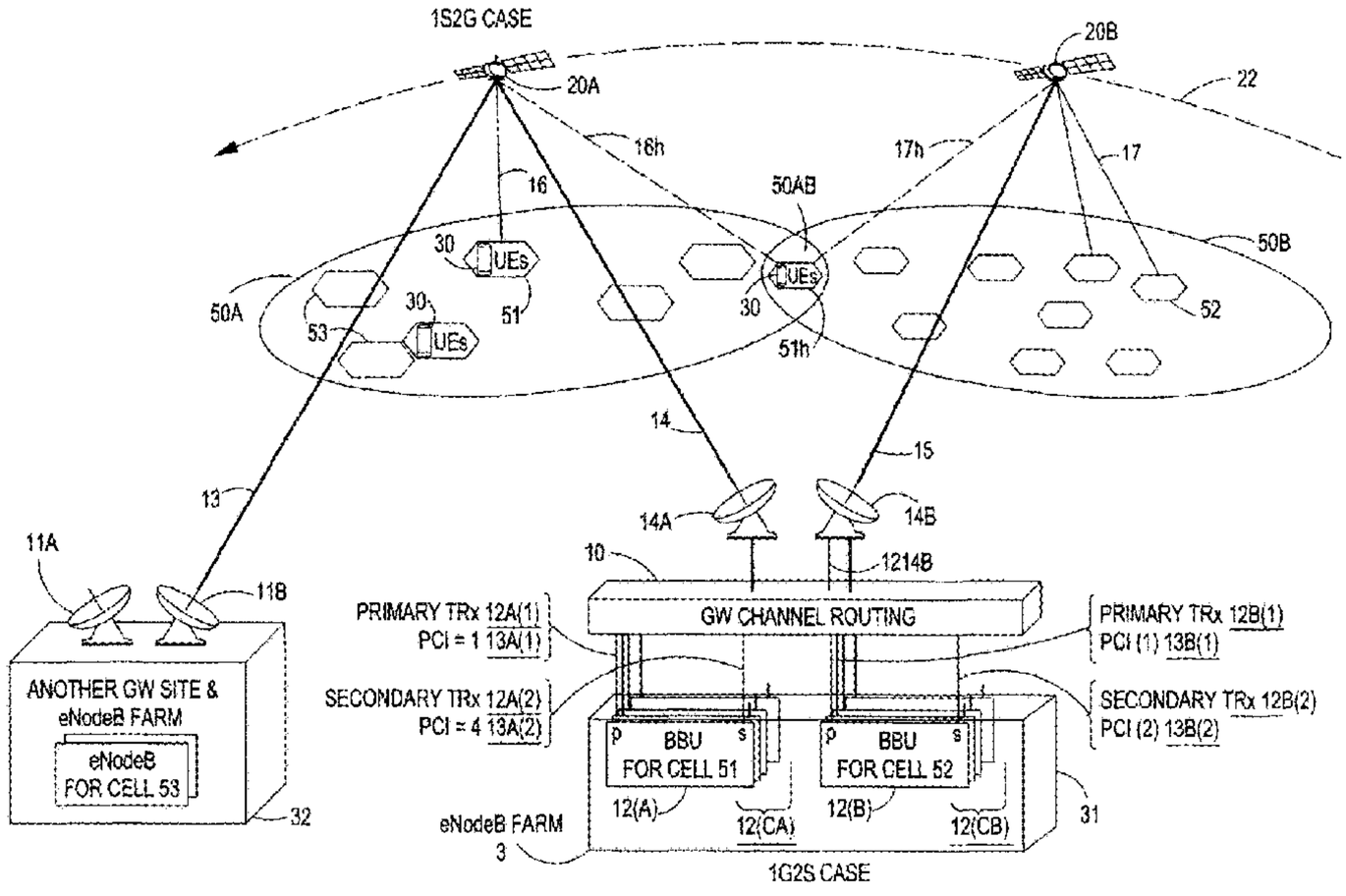
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(57) **ABSTRACT**

A LEO satellite communication system is in communication with a first setting satellite having a first field of view including a first plurality of cells, and a second rising satellite having a second field of view including a second plurality of cells. The first and second satellites have an overlapping field of view having an overlapping plurality of cells located therein. A first processing device has a first communication port communicating with a first cell of the first plurality of cells via said first antenna over a first beam, and a second communication port communicating with an overlapping cell of the overlapping plurality of cells via said second antenna over a second beam. Said first processing device switches from said first communication port to said second communication port in response to the first cell of the first plurality of cells moving into the overlapping field of view.

19 Claims, 7 Drawing Sheets



(51) **Int. Cl.**

H04W 36/00	(2009.01)
H04W 36/32	(2009.01)
H04W 84/06	(2009.01)

(52) **U.S. Cl.**

CPC *H04W 36/326* (2023.05); *H04W 36/328* (2023.05); *H04W 84/06* (2013.01)

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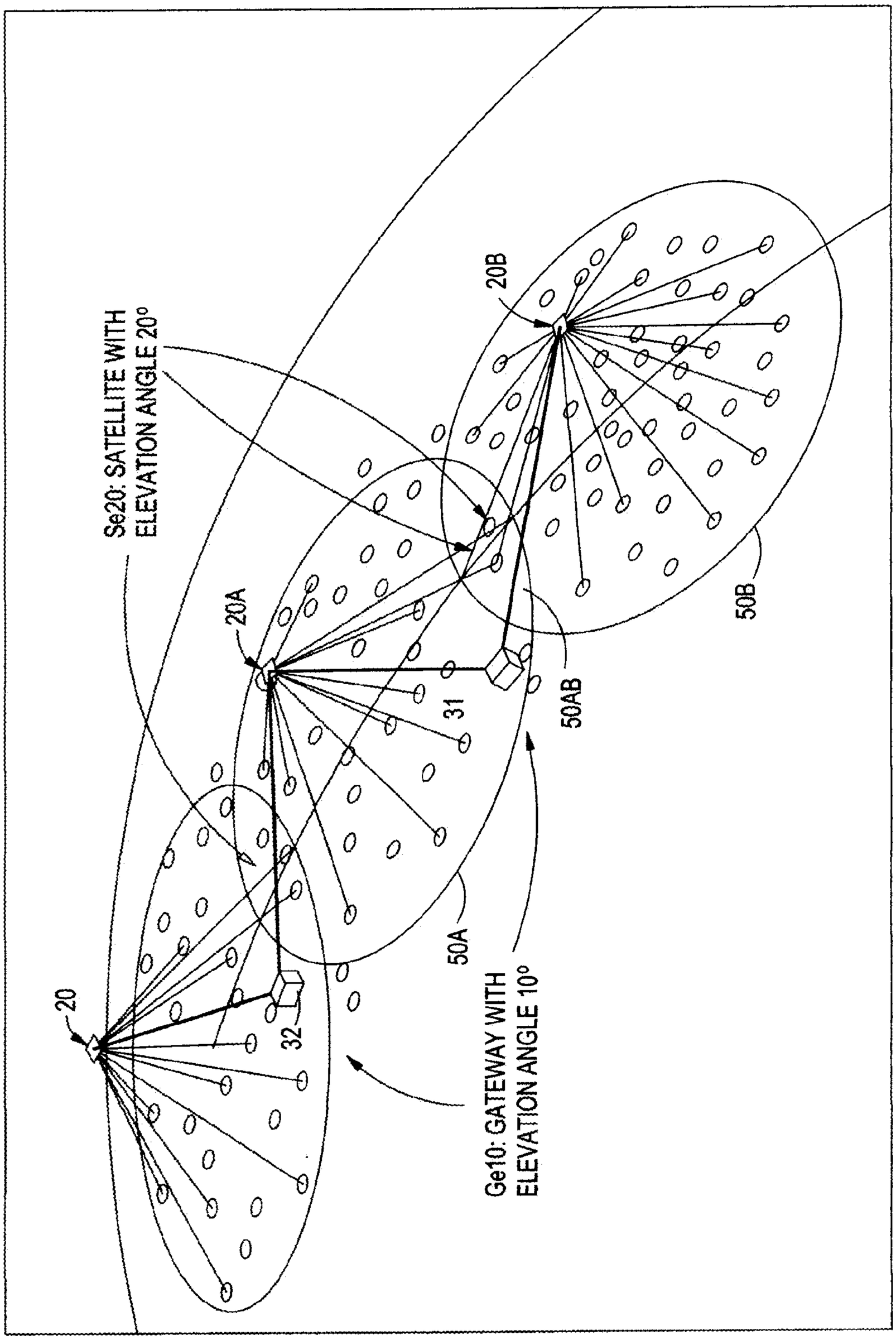

Se20: SATELLITE WITH
ELEVATION ANGLE 20°
Ge10: GATEWAY WITH
ELEVATION ANGLE 10°
20
20A
20B
31
32
50A
50AB
50B

FIG. 1

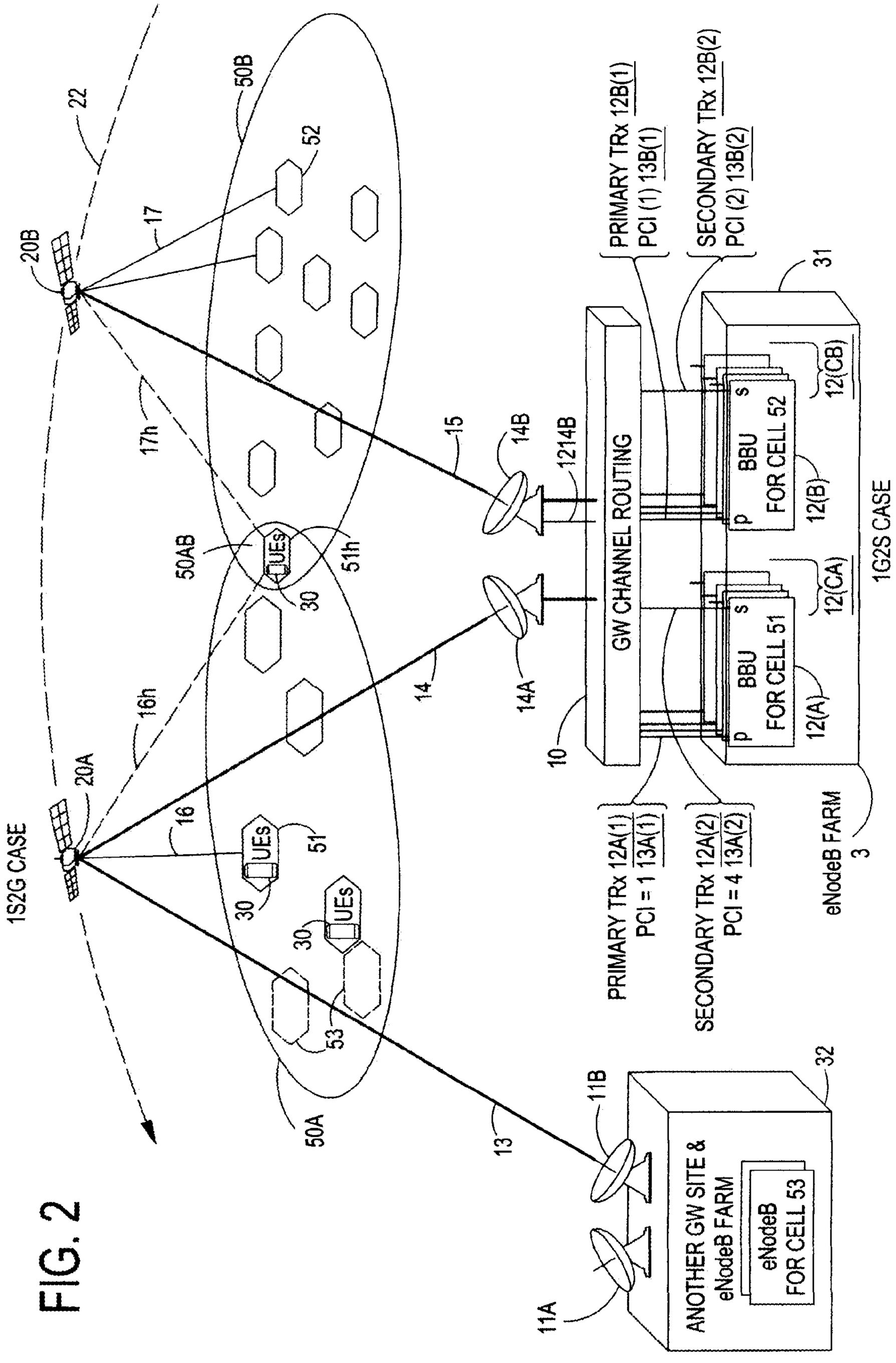

1S2G CASE
20B
22
17
50B
52
20A
16
17h
16h
50AB
UEs
51h
30
51
UEs
30
UEs
30
53
50A
15
14B
1214B
14
14A
13
10
11B
11A
GW CHANNEL ROUTING
PRIMARY TRx 12B(1)
PCI (1) 13B(1)
SECONDARY TRx 12B(2)
PCI (2) 13B(2)
31
p BBU s
FOR CELL 52
12(B)
12(CB)
p BBU s
FOR CELL 51
12(A)
12(CA)
1G2S CASE
PRIMARY TRx 12A(1)
PCI = 1 13A(1)
SECONDARY TRx 12A(2)
PCI = 4 13A(2)
eNodeB FARM
3
ANOTHER GW SITE &
eNodeB FARM
eNodeB
FOR CELL 53
32

FIG. 2

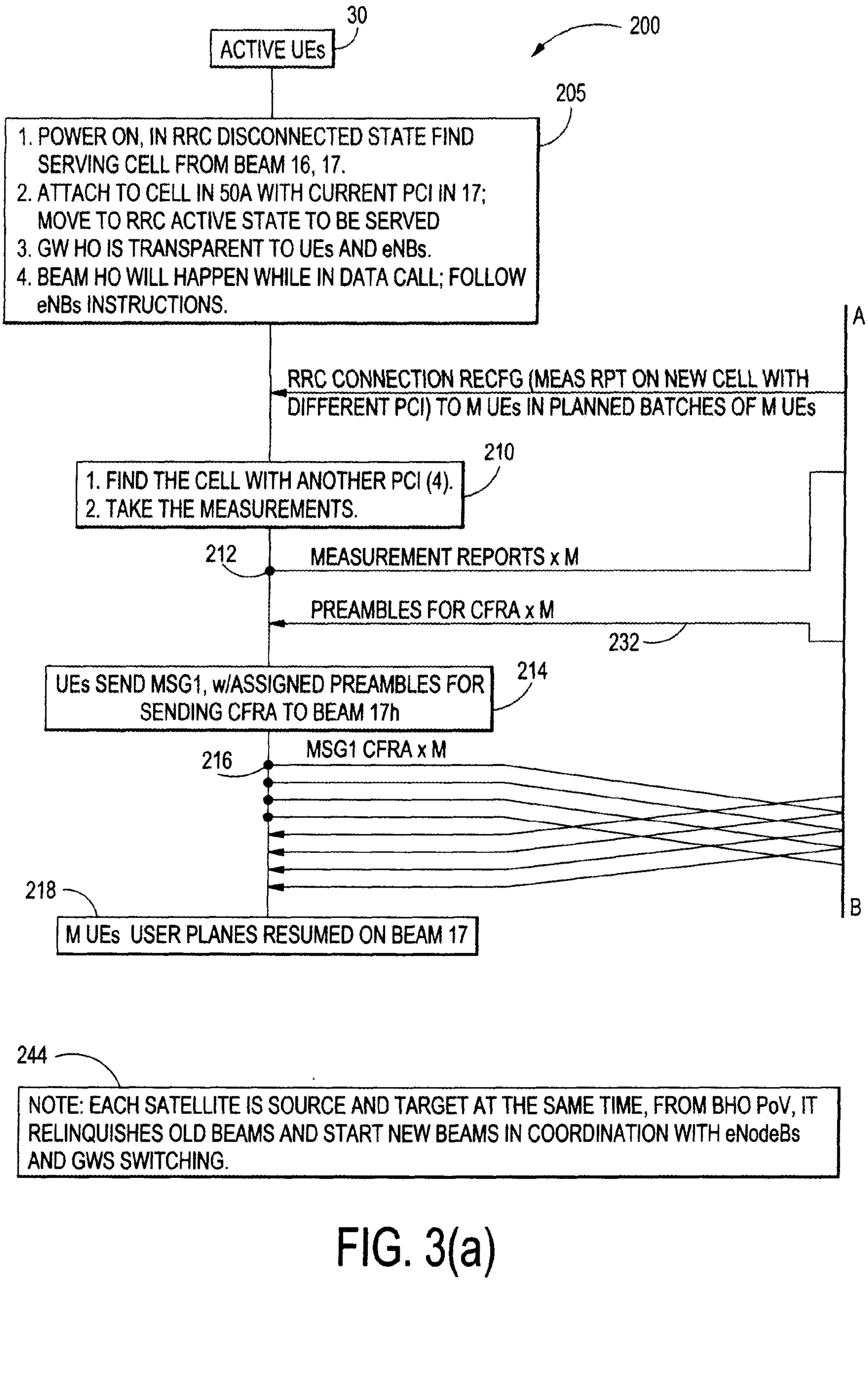

30
ACTIVE UEs
200
205
1. POWER ON, IN RRC DISCONNECTED STATE FIND SERVING CELL FROM BEAM 16, 17.
2. ATTACH TO CELL IN 50A WITH CURRENT PCI IN 17; MOVE TO RRC ACTIVE STATE TO BE SERVED
3. GW HO IS TRANSPARENT TO UEs AND eNBs.
4. BEAM HO WILL HAPPEN WHILE IN DATA CALL; FOLLOW eNBs INSTRUCTIONS.
A
RRC CONNECTION RECFG (MEAS RPT ON NEW CELL WITH DIFFERENT PCI) TO M UEs IN PLANNED BATCHES OF M UEs
210
1. FIND THE CELL WITH ANOTHER PCI (4).
2. TAKE THE MEASUREMENTS.
212
MEASUREMENT REPORTS x M
PREAMBLES FOR CFRA x M
232
UEs SEND MSG1, w/ASSIGNED PREAMBLES FOR SENDING CFRA TO BEAM 17h
214
216
MSG1 CFRA x M
218
M UEs USER PLANES RESUMED ON BEAM 17
B
244
NOTE: EACH SATELLITE IS SOURCE AND TARGET AT THE SAME TIME, FROM BHO PoV, IT RELINQUISHES OLD BEAMS AND START NEW BEAMS IN COORDINATION WITH eNodeBs AND GWS SWITCHING.

FIG. 3(a)

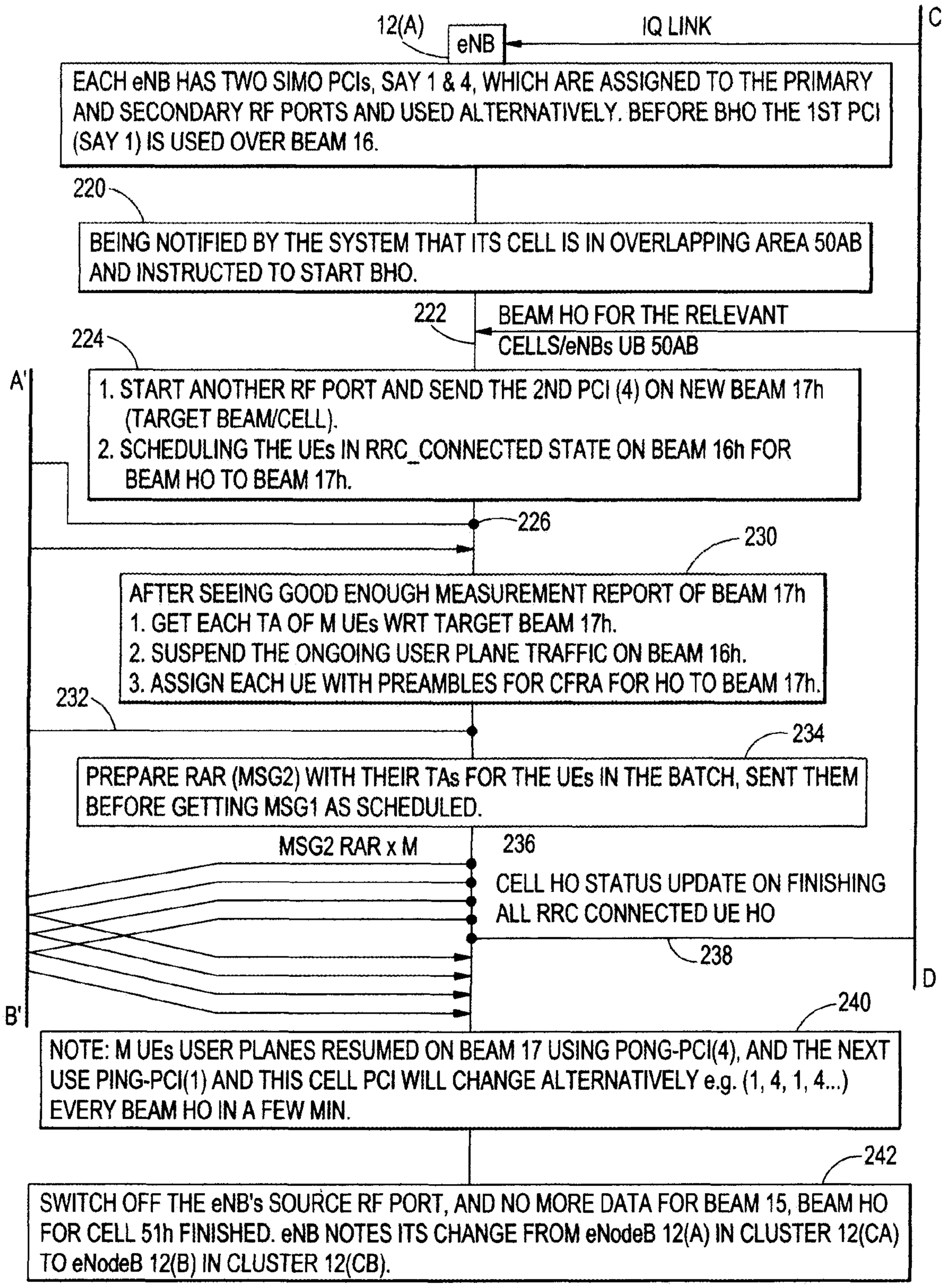

12(A)
eNB
IQ LINK
C
EACH eNB HAS TWO SIMO PCIs, SAY 1 & 4, WHICH ARE ASSIGNED TO THE PRIMARY AND SECONDARY RF PORTS AND USED ALTERNATIVELY. BEFORE BHO THE 1ST PCI (SAY 1) IS USED OVER BEAM 16.
220
BEING NOTIFIED BY THE SYSTEM THAT ITS CELL IS IN OVERLAPPING AREA 50AB AND INSTRUCTED TO START BHO.
222
BEAM HO FOR THE RELEVANT CELLS/eNBs UB 50AB
224
A'
1. START ANOTHER RF PORT AND SEND THE 2ND PCI (4) ON NEW BEAM 17h (TARGET BEAM/CELL).
2. SCHEDULING THE UEs IN RRC_CONNECTED STATE ON BEAM 16h FOR BEAM HO TO BEAM 17h.
226
230
AFTER SEEING GOOD ENOUGH MEASUREMENT REPORT OF BEAM 17h
1. GET EACH TA OF M UEs WRT TARGET BEAM 17h.
2. SUSPEND THE ONGOING USER PLANE TRAFFIC ON BEAM 16h.
3. ASSIGN EACH UE WITH PREAMBLES FOR CFRA FOR HO TO BEAM 17h.
232
234
PREPARE RAR (MSG2) WITH THEIR TAs FOR THE UEs IN THE BATCH, SENT THEM BEFORE GETTING MSG1 AS SCHEDULED.
MSG2 RAR x M
236
CELL HO STATUS UPDATE ON FINISHING ALL RRC CONNECTED UE HO
238
D
B'
240
NOTE: M UEs USER PLANES RESUMED ON BEAM 17 USING PONG-PCI(4), AND THE NEXT USE PING-PCI(1) AND THIS CELL PCI WILL CHANGE ALTERNATIVELY e.g. (1, 4, 1, 4...) EVERY BEAM HO IN A FEW MIN.
242
SWITCH OFF THE eNB's SOURCE RF PORT, AND NO MORE DATA FOR BEAM 15, BEAM HO FOR CELL 51h FINISHED. eNB NOTES ITS CHANGE FROM eNodeB 12(A) IN CLUSTER 12(CA) TO eNodeB 12(B) IN CLUSTER 12(CB).

FIG. 3(b)

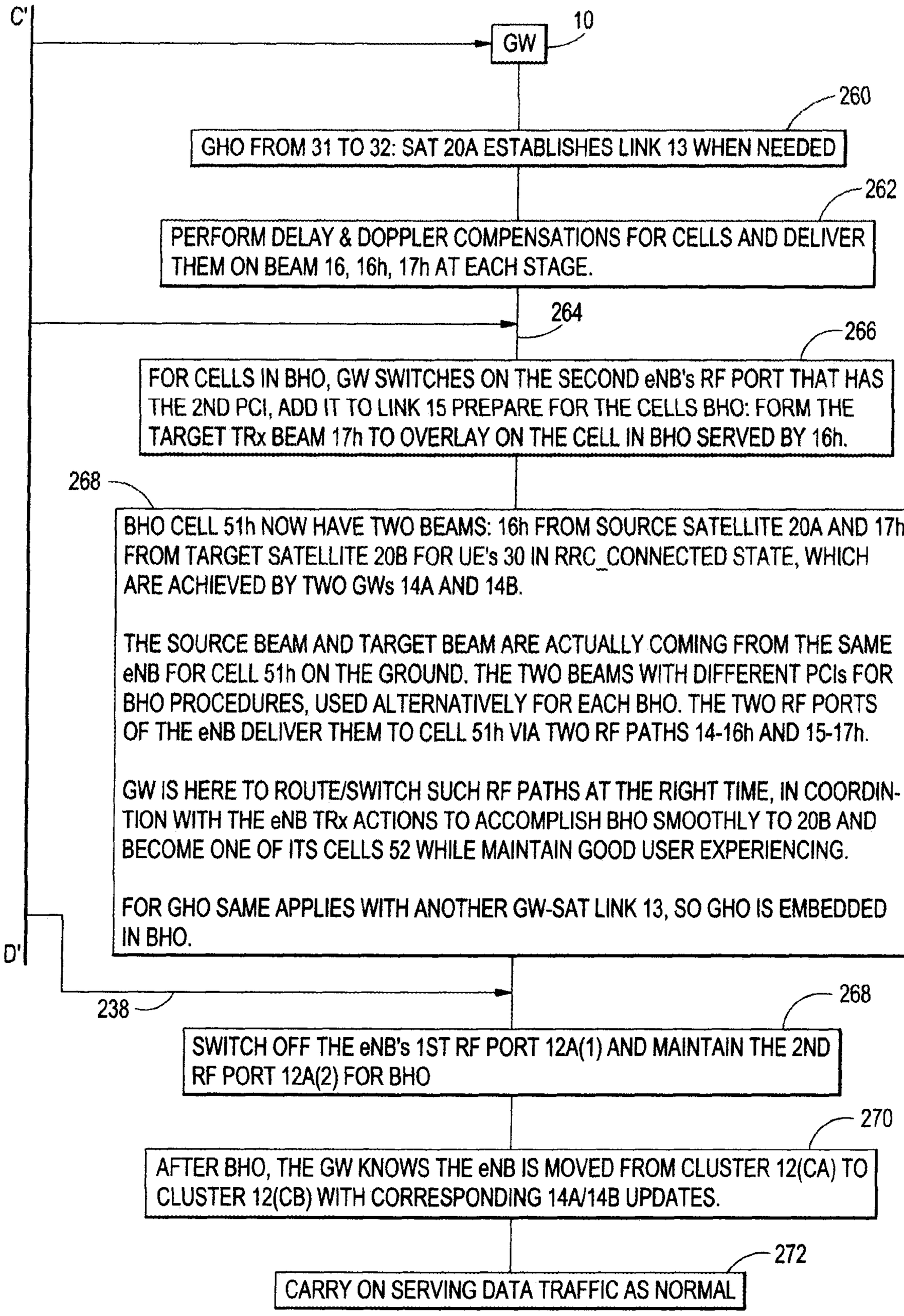

C'
GW
10
260
GHO FROM 31 TO 32: SAT 20A ESTABLISHES LINK 13 WHEN NEEDED
262
PERFORM DELAY & DOPPLER COMPENSATIONS FOR CELLS AND DELIVER THEM ON BEAM 16, 16h, 17h AT EACH STAGE.
264
266
FOR CELLS IN BHO, GW SWITCHES ON THE SECOND eNB's RF PORT THAT HAS THE 2ND PCI, ADD IT TO LINK 15 PREPARE FOR THE CELLS BHO: FORM THE TARGET TRx BEAM 17h TO OVERLAY ON THE CELL IN BHO SERVED BY 16h.
268
BHO CELL 51h NOW HAVE TWO BEAMS: 16h FROM SOURCE SATELLITE 20A AND 17h FROM TARGET SATELLITE 20B FOR UE's 30 IN RRC_CONNECTED STATE, WHICH ARE ACHIEVED BY TWO GWs 14A AND 14B.
THE SOURCE BEAM AND TARGET BEAM ARE ACTUALLY COMING FROM THE SAME eNB FOR CELL 51h ON THE GROUND. THE TWO BEAMS WITH DIFFERENT PCIs FOR BHO PROCEDURES, USED ALTERNATIVELY FOR EACH BHO. THE TWO RF PORTS OF THE eNB DELIVER THEM TO CELL 51h VIA TWO RF PATHS 14-16h AND 15-17h.
GW IS HERE TO ROUTE/SWITCH SUCH RF PATHS AT THE RIGHT TIME, IN COORDINTION WITH THE eNB TRx ACTIONS TO ACCOMPLISH BHO SMOOTHLY TO 20B AND BECOME ONE OF ITS CELLS 52 WHILE MAINTAIN GOOD USER EXPERIENCING.
FOR GHO SAME APPLIES WITH ANOTHER GW-SAT LINK 13, SO GHO IS EMBEDDED IN BHO.
D'
238
268
SWITCH OFF THE eNB's 1ST RF PORT 12A(1) AND MAINTAIN THE 2ND RF PORT 12A(2) FOR BHO
270
AFTER BHO, THE GW KNOWS THE eNB IS MOVED FROM CLUSTER 12(CA) TO CLUSTER 12(CB) WITH CORRESPONDING 14A/14B UPDATES.
272
CARRY ON SERVING DATA TRAFFIC AS NORMAL

FIG. 3(c)

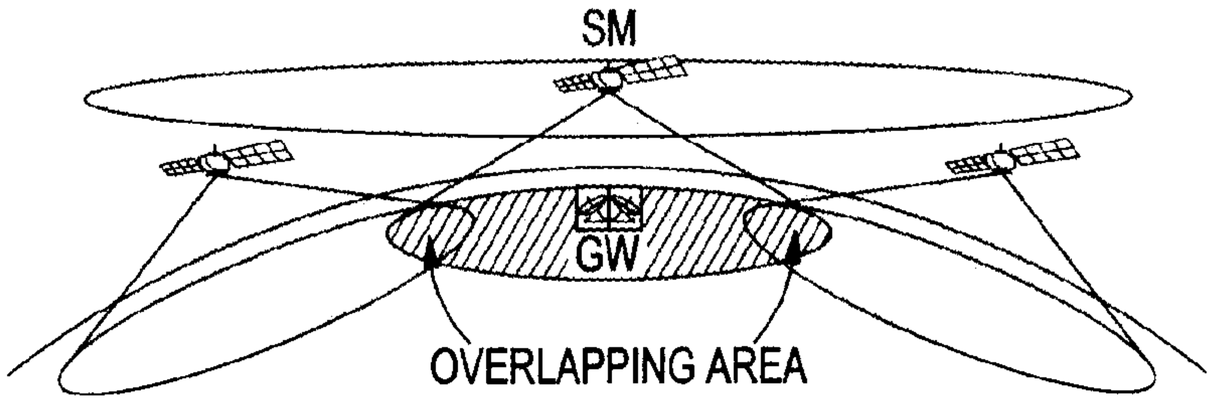


FIG. 4(a)

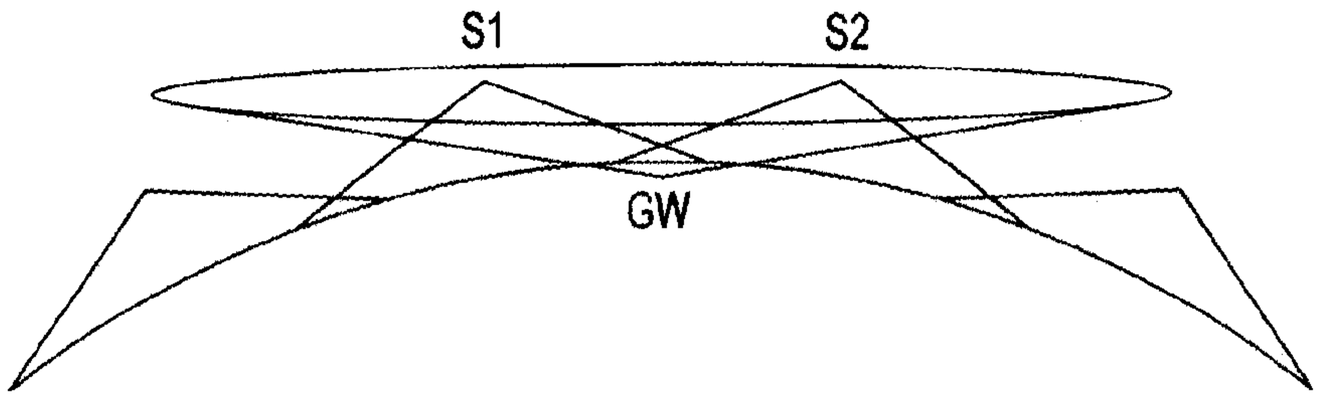


FIG. 4(b)

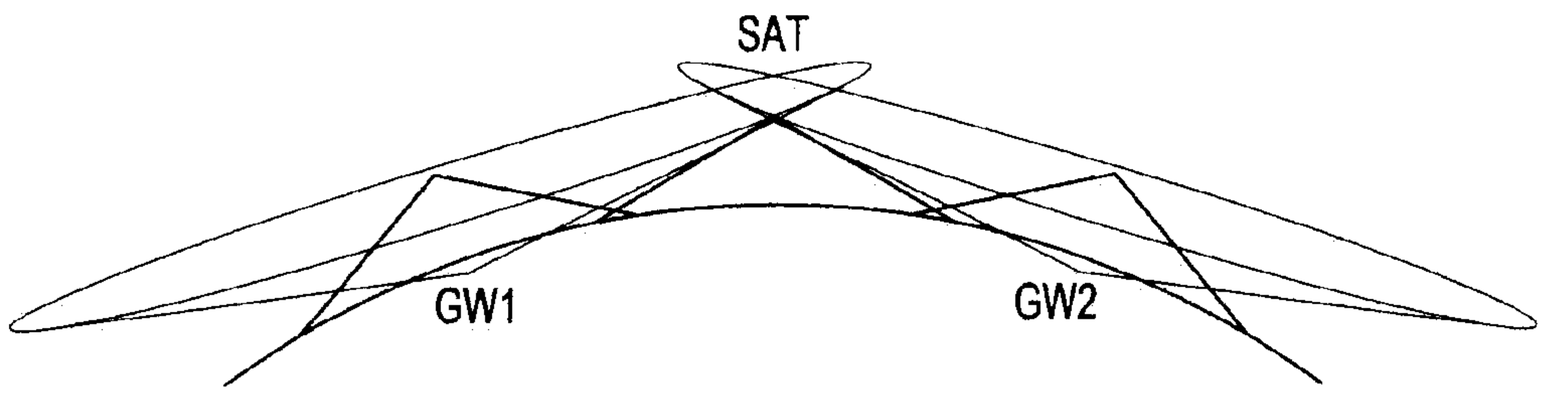


FIG. 4(c)

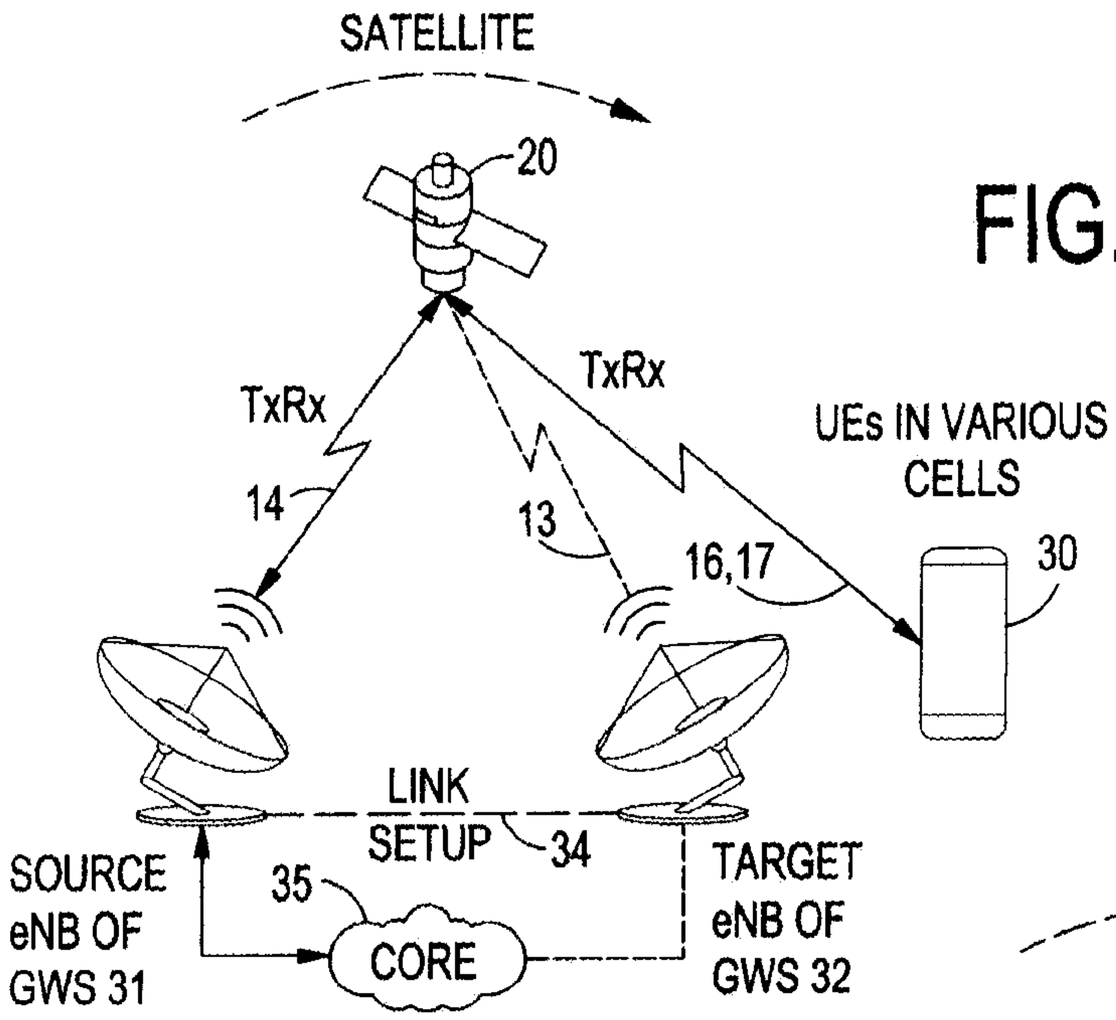


FIG. 5(a)

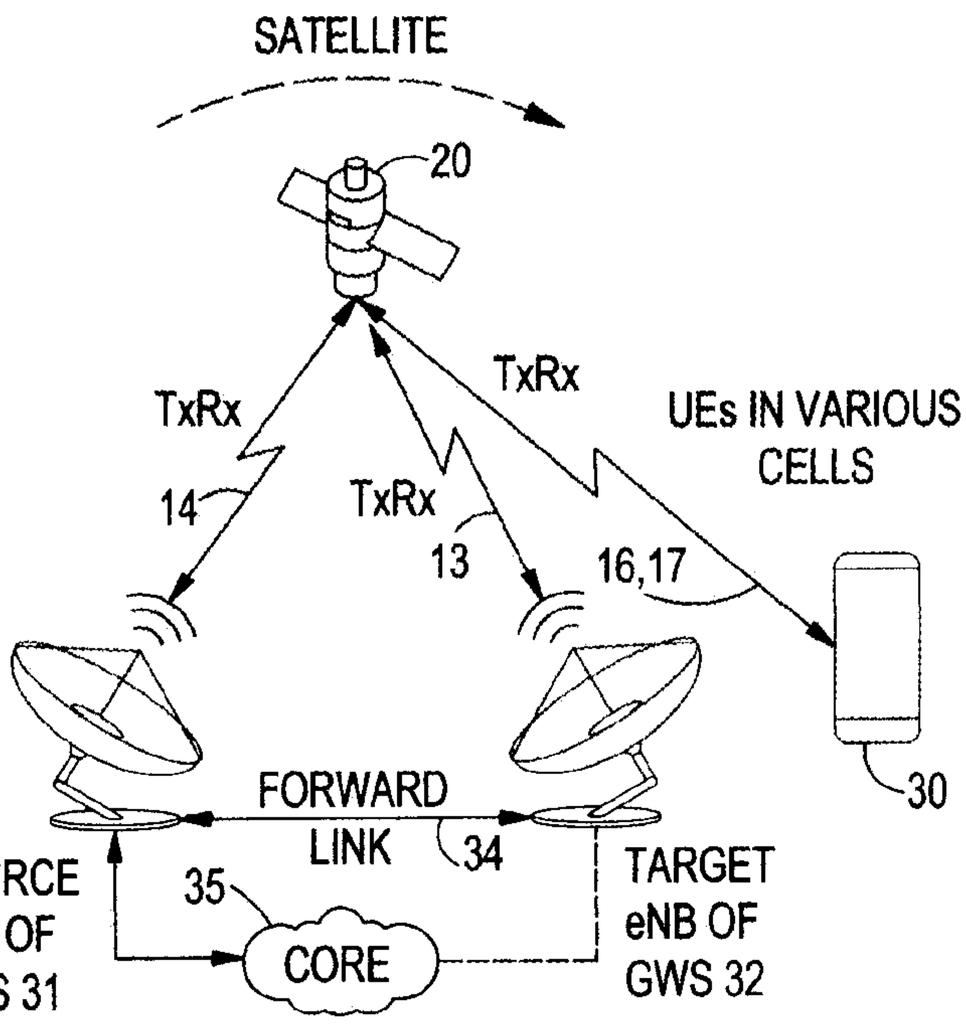


FIG. 5(b)

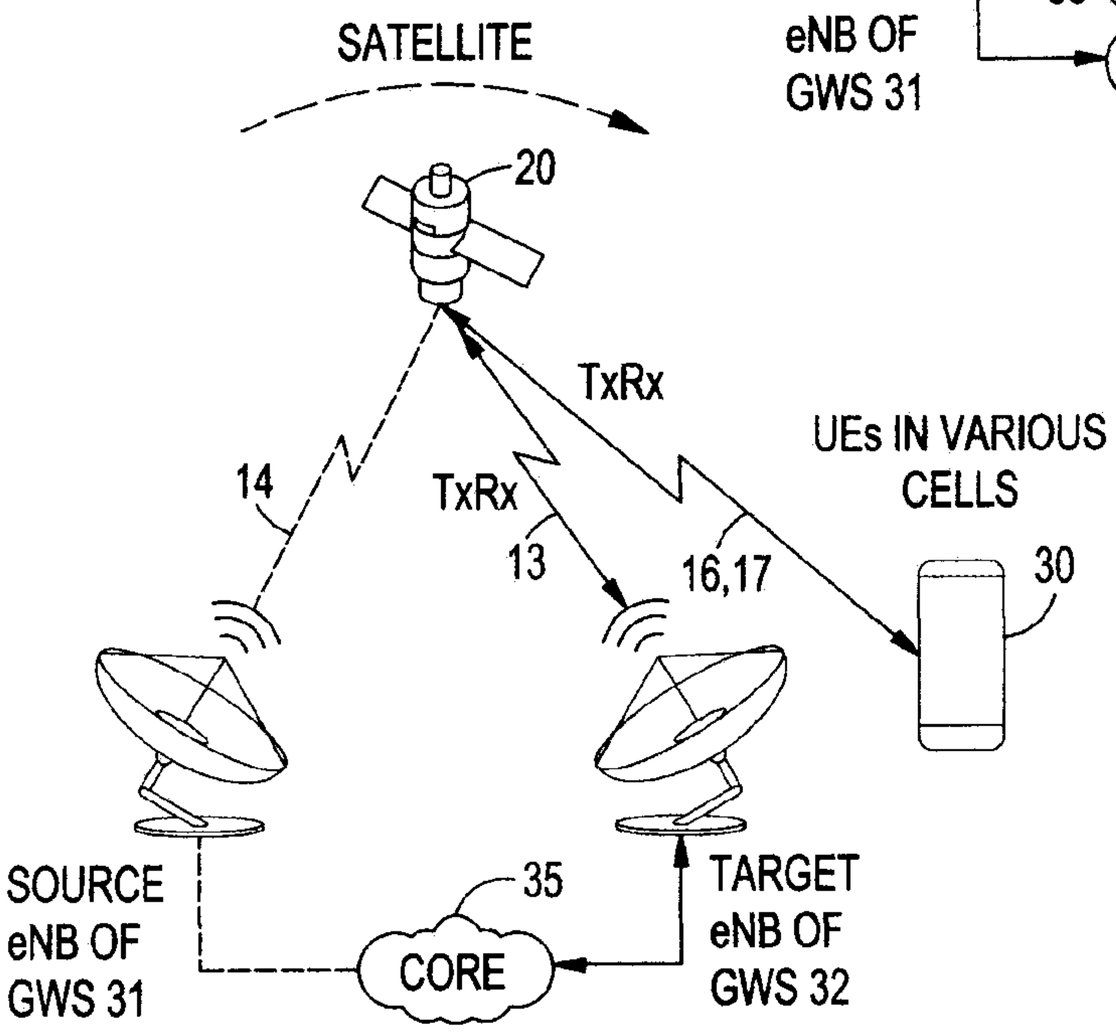


FIG. 5(c)

SATELLITE RADIO ACCESS NETWORK (SAT RAN) BEAM AND GATEWAY SEAMLESS HANDOVER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority of U.S. Provisional Application Ser. No. 63/141,218 filed on Jan. 25, 2021, the content of which is relied upon and incorporated herein by reference in its entirety.

BACKGROUND

There is a global demand for 100% cellular coverage, and Mobile Network Operators (MNOs) are having a hard time to justify the high cost of deploying the backbone connection or infrastructure for very low or no return in particular the remote areas that have not been covered so far. Current radio access network (RAN), such as 2G, 3G, 4G and 5G services with direct connectivity from User Equipment (UEs), such as mobile phones, to satellites (SAT RAN) do not exist.

On the other hand, satcom has never directly talked to normal 3GPP specs compliant UEs due to the vast number of them and weak signals on the uplink. So far, the satcom is used for base station, such as eNodeBs, backhaul, and that is as far as it goes, as the challenges in directly talking to normal UEs that are powered by small batteries are much higher than to the fixed points or customer premises equipment (CPE) with mains supply. In 2019, ATIS started non-terrestrial network (NTN) study item (SI) and work item (WI) for NR aiming for 3GPP Release 17 specs, that would change both 5G NR UEs as well as gNodeBs. This will not cover legacy 4G LTE, 5G NR UEs, and old 2G phones, which are widely used and remain to be so for very long time, as there are billions of GSM (2G) and LTE (4G) and NR (5G) UEs in the world that cannot be changed for satcom operation, and new NTN approach cannot be applied. There is no satcom solution for 2G, 4G and 5G UEs directly. In addition, a standard BTS (the 2G base station), or eNodeB or gNodeB does not work to communicate via satellite, as it had never been the working assumption of their 3GPP specs for the first 30 years. The ongoing NTN SI and WI is not yet finished. So by 3GPP specs there is no commercial sat RAN so far, and until NTN conclude its WI, there is only specialized sat phone that is very expensive with high radiation to users brain, and most people simply never touched such phone. Furthermore their features are no more than a 2G phone, not really comparable with the simplest LTE phone.

However, this filing will change the two changes: one it will enable sat RAN to cover remote area without towers and infrastructure connecting the towers in terrestrial network (TN); two it actually turns the normal 3GPP UEs, including 2G, 4G and current 5G UEs to sat phone without any modifications. This particular filing teaches an important part of this sat RAN innovative approach, in particular the specific beam handover (BHO) and gateway handover (GHO) for Low Earth Orbit (LEO) sat RAN.

BRIEF DESCRIPTION OF THE FIGURES

The accompanying drawings are incorporated in and constitute a part of this specification which describes the satellite mobility that involves both active UEs and its serving gateway site (GWS). It is to be understood that the

drawings illustrate only some examples of the disclosure and other examples or combinations of various examples that are not specifically illustrated in the figures may still fall within the scope of this disclosure. Examples will now be described with additional detail using the drawings, in which:

FIG. **1** is an illustration of cells being served by 2 Ge10 (gateway serving satellites defined by the elevation angles no less than 10 degrees) with 3 Se20 (satellite footprint defined by the elevation angles no less than 20 degrees). In particular it highlights the LEO satcom footprints and the overlapping situation where beam handover between two satellites, the setting and rising satellites, happens. The term footprint here means the area inside the field of view (FoV) of the satellite or gateway with RAN (radio access network) support. Footprint can change, for example, most part of the sea is in satellite FoV, and initially had no footprint, but later become sat RAN footprint, e.g. some small islands or oil rigs are likely to be the first footprint of the satellites and gateways.

FIG. **2** is an illustration diagram of the 1G2S (1 GWS that links with 2 neighbor Satellites simultaneously) case, highlighting one of the cells in 2 satellites footprint overlapping area going through beam handover; and 1S2G (1 Satellite that has RF links with 2 GWS simultaneously) case for gateway handover.

FIGS. **3**(*a*), **3**(*b*) and **3**(*c*) are flow diagram of the BHO and GHO operation concept on the control plane of the system.

FIG. **4** illustrates example handover cases.

FIG. **4**(*a*) is a diagram of 1G1S or 1S1G (1 Gateway that has link with only 1 Satellite).

FIG. **4**(*b*) is a diagram of 1G2S or 2S1G.

FIG. **4**(*c*) is a diagram of 2G1S or 1S2G.

FIGS. **5**(*a*), **5**(*b*), **5**(*c*) are block diagrams showing Gateways interconnectivity link for a UE mobility case.

DETAILED DESCRIPTION

In describing the illustrative, non-limiting embodiments illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the disclosure is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents that operate in similar manner to accomplish a similar purpose. Several embodiments are described for illustrative purposes, it being understood that the description and claims are not limited to the illustrated embodiments and other embodiments not specifically shown in the drawings may also be within the scope of this disclosure.

A well designed sat RAN system that directly serving legacy 2G, 4G and 5G UEs needs following four basic mechanism, otherwise unnecessary amount of satellites and new UE and base station will be necessary as we can see from star link and NTN 3GPP work item (WI).

1. A large phase array that can form hundreds of electronically steerable beams in order to serve hundreds of cells.
2. Delay and Doppler compensation for each beams to normalize the delay to a constant amount no matter where the ground gateway site (GWS), satellite (sat) and cells are, which enable normal base station to work for sat RAN with simple modifications;
3. The processes or sequences of beam handover (BHO) and gateway handover (GHO) that are needed for LEO satellites.

4. A satellite network control center (NCC) that orchestrates the RAN equipment such as base stations, and space equipment including the ground gateway site and satellites.

This filing will focus on the item number 3, the BHO and GHO.

As used here, the term Handover or Handoff (HO) generally refers to a cell/beam changing from a setting serving satellite to a rising serving satellite. There are several types of handover, namely the 3rd Generation Partnership Project (3GPP) specification UE Mobility HO, the present disclosure provides the extra HO as related to satellite beam HO and GWS HO, which is outside of the scope of 3GPP spec pre-release 16 (before NTN). The innovative part of the present disclosure includes reusing the standard protocol for the BHO and GHO without adding new ones yet streamlining the needed BHO and GHO in sat RAN.

Referring to FIGS. **1** and **2**, low-earth-orbit (LEO) satellites **20**A and **20**B are tracking their generic cells **51** and **52** being served by individual electronically steerable beams **16** and **17**. While orbiting the earth on satellite path or orbit **22** at about 7.5 km/s, the satellite **20**A also takes new cells coming into its footprint (or FOV) **50**A and leaves old cells **51***h* that has a period of time in the overlapping area **50**AB, within which the rising satellite **20**B needs to take care of it by providing a new beam to continue the service for UEs in cell **51***h*. Same goes with every satellite in the sat RAN constellation.

Changing the UEs' service beams from one satellite **16***h* to another **17***h* is the beam HO (BHO) and changing between the satellites' feeder links of gateway tracking dishes **13**, **14** and **15** of the same GWS **31** or different GWSs (such as **31**, **32**) is the gateway HO (GHO). LEO satellites need BHO and GHO for changing their serving GWs and the cells they are serving as they orbit over the cells **51***h* or GWSs **31**, **32**. BHO is a process of many active UEs changing the service link for a cell, while GHO is a process of many beams changing the feeder link, e.g. within one GWS, from one gateway tracking dish **14**A to another gateway tracking dish **14**B of the same GWS **31**, or changing from one gateway tracking dish **14**A of one GWS **31** to another gateway tracking dish **11**B of another GWS **32**.

BHO is needed as LEO satellites move in and out of communication with a cell during orbiting while GHO is needed as satellites move in and out of the space where it can communication with a GWS during orbiting. BHO generally refers to the cells **51***h* changing the satellite with which it communicates, which means that the cell changes the beam that it utilizes to communicate with the satellites. This happens when the cells are in the two satellites field of view (FoV) overlapping area **50**AB of the setting satellite **20**A and the rising satellite **20**B in 1G2S condition, where two HO beams **16***h* and **17***h* are overlaid on the BHO cell **51***h*. Before the BHO, the cells (such as **51**) communicate over a first tracking beam **16** for a descending or setting satellite **20**A. During handover, the cells (such as **51***h*) switch from beams **16***h* of the setting satellite **20**A to beams **17***h* of the ascending or rising satellite **20**B. For example, eNodeBs (such as eNodeB **12**(A)) may be configured to communicate with the UE in cell **51***h* to control the UE in cell **51***h* to directly communicate with the second rising satellite **20**B. BHO is done or performed on active UEs, and on UE by UE basis. Accordingly, after BHO, the cells communicate over the beams **17** for the rising satellite **20**B and become one of its cells **52** being served. The respective eNodeB (such as **12**(A)) may switch its interface (such as gateway antenna) from **14**A to **14**B, and the corresponding cell downlink (DL) and uplink (UL) data change from feeder link **14** to **15** accordingly. This is an important procedure in forming GHO, as a GHO is done through many BHOs.

eNodeB (eNB) is the 4G base station that can serve one or more 4G cells. In this description we use eNodeB for one cell base station as well as a number of cells whichever is relevant. Also it is interchangeable with 2G BTS and 5G gNodeB (2G and 5G base stations)

In some examples, a gateway, in sat RAN, may has a tracking dish antenna that serves a satellite. Since the satellites are directly talking to normal UEs on ground, LEO satellite is needed rather than MEO and GEO satellite, and satellites are tracking their serving geographical cells on the ground using their beams. GHO can refer to the satellite feeder link change from **14** to **15**, and this is on the granularity of a cell, hence is "on the cell-by-cell basis", while BHO is on the UE-by-UE basis. So GHO can be between GW tracking dishes in one or more GWSs.

GHO in one GWS may refer to the cells' signal moving from one tracking dish **14**A to another, **14**B, within the same GWS **31**; while GHO between two GWSs **31** and **32** may refer to a satellite changing GWS-satellite (GW-SAT) feeder link from feeder link **14** to feeder link **13** while satellite **20**A orbiting on the orbit or path **22**. Before GHO, the satellite **20**A communicates with a first GWS **31** over a first GW-SAT link **14**. During the GHO, the satellite **20**A also communicates with the second GWS **32** over a second GW-SAT link **13** as shown in FIG. **2** in 1S2G condition.

GHO is performed on a cell by cell basis over the period when the satellites cover the cells served by the eNB farms belong to the GWS. After GHO, the satellite **20**A communicates over the second GW-SAT link **13** with the second GWS **32**.

GHO can be done or performed in 1S2G (1 satellite in communication with 2 GWSs) condition and 1G2S condition. Se20 refers to Satellite with its Footprint defined by the minimum elevation angle of 20°. GWe10 refers to a gateway dish antenna with minimum elevation angle of 10°. An elevation angle refers to the angle between the horizontal surface at the point under the concern on earth to the intended direction of the subject. GW elevation angle refers to the tracking dish angle with respect to the horizontal surface at the GW sitting point, while satellite elevation angle refers to the angle of the beam coming down from the satellite with respect to the horizontal surface on the observation point (such as the cell center).

HO Failure (HOF) refers to Handover failure (R12 enhancement to be used). A 1G1S (1 gateway in communication with 1 satellite) is the satellite and GWS relative position where a GWS only has one link with one satellite, a case that requires serving area is smaller than the satellite footprint in the period when satellite beams only need to track the cells in the serving area and eNBs for those cells are hosted in one GW site.

Both of the two types of GHO are done over a period of time, on cell-by-cell basis, composed of many BHOs.

The present disclosure handles satellite mobility which relay GSM (2G), LTE (Long Term Evolution, such as 4G) and 5G new radio (NR) signals to and from unmodified GSM/LTE/NR UEs as an extra BTS/e/gNodeB functionality. The satellite mobility management is outside 3GPP specifications and will be a new base station background activity that involves standard UE handover procedures, while satellites and gateways coordinates, but no further complexity as to manage which sat and GW it needs to link with. The RF paths are handled by satellites ground station. Neither the feeder link, nor the service link details are

handled by eNB and UE (The 3GPP equipment for 2G/4G/5G). The sat RAN design disclosed here makes those satellite complexity totally transparent to base stations and UEs, while maintaining their RF connections.

The present disclosure provides Low HOF and achieves synchronized HO, Efficient eNodeB and GWS distribution, Quality of Experience (QoE), reduce or minimize voice and data calls interruptions and provide a good user experience.

A single satellite orbital plane is shown in the figures, such as the equatorial one, though any suitable orbit can be handled. This approach can also be applied to Inter-plane HO.

Beam Handover

Turning to the drawings, FIG. **2** shows a gateway site or ground station **31** in accordance with one embodiment of the present disclosure. The gateway site **31** includes gateway channel routing block **10** that provides the right channels signal for corresponding to two antennas **14**A and **14**B, which are directional antennas tracking the satellites, and a plurality of eNodeBs, like **12**(A) and **12**(B) for every geographical cell. The gateway site **31** is in communication with User Equipment (UEs) via a setting satellite **20**A and a rising satellite **20**B. The satellites **20**A, **20**B communicate with the UEs over a respective setting TRx beams **16** and rising TRx beams **17**. UEs can be in an idle state and those UEs would only monitor the cells and carry out cell reselection and tracking area update when needed (e.g., for paging), there is no need for the eNodeBs to take care of them in BHO. The BHO takes care of the active UEs only. The active UEs are or include the UEs in a call, and need eNodeB dedicated control to move from setting satellite beam to the rising satellite beam. The gateway channel routing block **10** manages the required channels for satellites **20**A, **20**B, so that they provide the scheduled services to the cells intended dynamically. All the channels/cells signal served by a satellite is packed together and passed between GW and satellite via feeder link (different from the MVO's LTE spectrum) beams **14** and **15**, while each cell being served by the satellite uses MNO's spectrum via electronic steerable beams The gateway site **32** includes gateway antennas **11**A, **11**B, with respective to their serving eNodeBs (such as BBUs for cells **53**). The feeder link beams **14** and **15** may, for example, have a wide bandwidth with frequency of 40-50 GHz. And the service link beams are controlled by a Network Mobile Operator (NMO).

FIG. **1** shows the satellites **20**A, **20**B's RAN (radio access network, e.g., GSM, LTE and 5G NR) signal footprints or field of Views (FoV) **50**A, **50**B on the Earth surface. The setting satellite **20**A has a setting satellite FoV **50**A, and the rising satellite **20**B has a rising satellite FoV **50**B. The setting and rising FoVs **50**A and **50**B, in which that satellites communicate with UEs directly in their cells with serving beams on downlink (DL) and uplink (UL). The setting and rising FoVs **50**A and **50**B overlap (or at least partially overlap) in the overlapping area **50**AB. In accordance with one embodiment, BHO occurs for the cells **51***h* located inside the overlapping FoV area **50**AB.

FIG. **2** shows the ground cells being served by the two satellites **20**A, **20**B, which are linked to the gateway channel routing block **10**, via gateway antennas **14**A, **14**B that interface with the respective processing devices (i.e., eNodeBs) **12** serving those ground cells. The processing devices **12** control communication with the UEs via the satellites **20**, **20**A, **20**B (also see FIG. **1**). In particular, FIG. **2** illustrates one embodiment of a system, including a 1G2S (1 Gateway links with 2 Satellite) mobile communication system **5**, though other configurations can also be handled. As shown, the satellite communication system **5** includes a base or ground station **31**, which contains a farm (such as an eNodeB farm) **3** and GW channel routing block **10** that communicate over two satellites **20**A, **20**B, and multiple UEs **30** in a beam HO cell **51***h* in the satellite overlapping area **50**AB (here, overlapping ground cells are labelled **51***h* and non-overlapping cells are labelled **51**, **52**. The cells **51** will change to cells **52** as the satellites orbit around the earth on path **22**). In certain examples, a gateway may include gateway antennas **14**A, **14**B and the gateway channel routing block **10**.

In some examples, the ground station **31** has many base station BBUs, e.g. eNB farm and minimum of two directional antennas **14**A, **14**B via a gateway-satellite feeder link **14**, **15** respectively carrying the BTS/LTE/5G downlink (DL) and uplink (UL) signals for their footprints **50**A, **50**B. The drawing highlights one of the HO cells **51***h* in the overlapping area **50**AB, to illustrate where BHO happens. One or more UEs are in the BHO cells **51***h*. The processing device **12** can be, for example, a server or computer such as RAN base station forms, such as BTS for GSM, eNodeB for LTE and gNodeB for 5G, which transmit (Tx) and receive (Rx) LTE signals and can communicate with a GWS device that is located at the ground station. The satellites **20**A **20**B are in communication with the ground station antennas **14**A, **14**B. The first satellite **20**A is setting, i.e., leaving the current footprint **50**A for the ground station antenna **14**A, and the second satellite **20**B is rising or ascending, serving the footprint **50**B for the ground station antenna **14**B.

GWS **31** may use feeder link tracking antenna **14**A and **14**B in Q/V bands, for example, for the gateway-satellites feeder links **14**, **15**. Satellites **20**A and **20**B use operators' LTE spectrum as the service links for UEs via RF beams, like **16**, **17** for respective cells in their footprints.

In FIG. **1**, **2**, for the cells in the overlapping area **50**AB, the serving BBU is told by sat RAN control center the period for BHO for active UEs in polarity of HO cells **51***h*, e.g., in one or more HO cells **51***h*. That is, as the cells **51** enter the overlapping area **50**AB, a satellite beam handover process is triggered to switch communication for those overlapping cells **51***h* from the setting satellite beams **16***h* to the rising satellite beams **17***h*. It is noted that beams **16***h* and **17***h* are slightly different from other beams of **16** and **17**, as beams **16***h* and **17***h* are from the same eNodeB in BHO, which used to be associated with the setting satellite **20**A, but in beam HO, the eNodeB is associated with both setting and rising satellites **20**A and **20**B. The beam **16***h* keeps the same as beam **16** keeping the first PCI (Physical Cell ID) **13**A(**1**), except during BHO its top priority is not on data traffic, but the active UEs HO to beam **17***h* could be one of the cells MIMO RF port, or newly started BBU/cell by the same serving eNodeB, so that **16***h* and **17***h* form coherent Rx signals just like MIMO signals. on the other RF port or BBU with a different PCI **13**A(**2**) via rising satellite **20**B, and the choice of the PCI pair are such they don't interfere with each other, which enable them work like MIMO, enhancing each other. So beam **17***h* is newly added to the rising satellite beams and **16***h* and **17***h* coexist for the BHO period. Hence the BHO only happens in satellites' overlapping cells of the setting satellite **20**A and the rising satellite **20**B. The HO beam **17***h* keeps the same configuration for user traffic and becomes one of the beams **17**. The 3GPP specifications only have mobility management for UEs moving between the cells. Satellites relay and their mobility are not part of 3GPP specifications. Most active UEs in HO beam or cell will end

up Radio Link Failure (RLF) if HO is not successful when instant hard switching from setting satellite **20**A to rising satellite **20**B is used.

To enable satellite mobility, the present disclosure provides a BHO condition or method that applies existing 3GPP HO procedures to achieve BHO. According to 3GPP specs each eNodeB by default has a minimum of two RF ports, the signals of which go through two separate TRx GWS-satellite feeder links **14**, **15**, and then satellite uses MNO's spectrum for beams, the service links **16***h*, **17***h* (both DL and UL) from the two satellites **20**A, **20**B, where **16***h* and **17***h* are overlaid onto the BHO cells **51***h* in the overlapping area **50**AB during the BHO period. FIG. **2** shows a cell's eNodeB **12**(A) with two RF ports **12**A(**1**) and **12**A(**2**) delivers the DL and UL LTE signals through two GW antennas **14**A and **14** B that serve two satellites **20**A and **20** B, each baseband unit (BBU) of a cell providing a beam signal for HO service link **16***h*/**17***h* via feeder link **14**/**15** for two TRx path to the two RF ports **12**A(**1**) and **12**A(**2**) on the eNodeB **3** BBU **12**(A). Note that the newly added beam **17***h* starts communicating with the target GW antenna **14**B shown as a thin line interface **1214**B, which is the new BHO signal newly applied to BHO cell **51***h* by the new beam **17***h* from target satellite **20**B purely for BHO from **20**A to **20**B. To UE this appears as a new cell, as **1214**B uses another PCI **13**A(**2**) in contrast to the source cell's PCI **13**A(**1**). The two beams **16***h* and **17***h* act as serving cell and neighbor cells respectively during BHO period, and **16***h*, as the source cell should set access barring state on system information, so that it will inform UE(s) to leave it as soon as they can (idle UEs make cell reselection; and UEs just finished BHO will not coming back to it; newly powered on UE would not RACH to it), so that **16***h* will relinquish the service to **51***h* and totally HO to **17***h*. On **20**B side, when all the active UEs are moved over to **17***h*, BHO procedure for the cell is finished and cell **51***h* becomes a generic cell **17** in **20**B's FoV. The new target cell is born, and core network will keep the same tracking area code/location area code (TAC/LAC) so that UEs moved to new cell will be paged via beam **17***h* instead of **16***h*, as **16***h* after the BHO no longer serves the UEs.

There are two PCIs (or cell color codes or BTS color code or training sequence code in 2G) assigned to each cell, and they are used alternatively at each BHO instance. For PCI deployment their reference signals RE position needs to be carefully considered so that the source and target cells; reference signal are not on the same RE to cause interference on UE side. The two cells should work like the two layers in MIMO setup, so that they help each other rather than cause trouble to each other.

It is worth mentioning that BHO is mainly the procedure for PRACH channel, and all the traffic channel PDSCH and PUSCH can carry on as standard HO does, so that BHO is seamless.

Further, after the BHO and when the beam **17***h* becomes one of the beam **17**, it will be packed with the current cells in **50**B, and become an integral part of the eNodeB **12**(B), and feed to the gateway antenna **14**B interface in the IQ stream, and such signal is handed over from eNodeB **12**(A) to eNodeB **12**(B) and from GW Antenna **14**A to GW antenna **14**B, and from feeder link **14** to feeder link **15** to achieve BHO from satellite **20**A to satellite **20**B. The data for the BHO cell is no longer needed from **20**A and will come from **20**B. This can be treated as 2 cell HO as well. Note that no extra hardware is needed as by default there are two RF port for each cell and BHO can just borrow one of them for short period of time, assuming the initial sat RAN of providing coverage on global scale uses 1T1R to save feeder link bandwidth. In MIMO operation, one port can be temporarily used for BHO.

The power levels from the two RF ports (e.g., two communication ports) **12**A(**1**) and **12**A(**2**) via setting and rising satellites are similar, and there is no HO cell edge condition as for a terrestrial network. The BHO has such beam overlay on top of each other, so the whole cell has equally good signals from symmetrical beams of two satellites. The geometry of the overlapping area is such that most of the RF paths (or beams) **16***h*, **17***h* are symmetrical to the cell, however the locality could make some difference when terrain is uneven. But for remote area coverage there are mostly the same statistically. So the majority of BHO is smooth, except perhaps when one side has a blocked path (such as by a mountain), say on beam **17***h*. Although this should be handled at cell planning to avoid such situation, there are always some exceptional cases, such as a tunnel or building may have the same effect, as all wireless communications have.

In operation, the cells **51**, **52** in the FoV of each satellite **20**A, **20**B communicate with a respective eNodeB BBU **12**(A), **12**(B) over a designated RF port. Specifically, the cells **51** in the FoV for the setting satellite **20**A communicate over a first beam **16** via the setting satellite **20**A. The setting satellite **20**A, in turn, communicates with eNodeB farm's one or more first BBUs **12**(A) of cluster **12**(CA) at the gateway site **31** over a primary RF Transmit/Receive (TRx) port **12**A(**1**), via the first GW antenna **14**A. And the cells **52** in the FoV for the rising satellite **20**B communicate over a second beam **17** via the rising satellite **20**B. And the rising satellite **20**B communicates with eNodeB farm's one or more second BBUs **12**(B) of cluster **12**(CB) over a primary RF TRx port **12**B(**1**), via the second antenna **14**B. Each eNodeB communicates with a single cell **51**, **52**.

A smooth and seamless BHO is triggered as cells enter the overlapping region **50**AB. In the beam HO moment, the two RF ports (such as **12**A(**1**) and **12**B(**1**)) are utilized separately, but for simplicity we just illustrate SIMO (Single Input Multiple Output) configuration for both satellites. All of the cells **51**, **52** in non-overlapping areas are using just one of the two RF TRx ports **12**A(**1**) or **12**B(**1**) respectively, and each footprint has their own beams **16**, **17** for normal user data traffic operation.

However, within the overlapping area **50**AB, the cells **51***h* are engaged in beam HO and gateway handover. In the example embodiment of FIGS. **2**-**3**(*a*)-(*c*), the beam handover refers to the process for moving from the first set of eNodeBs **12**(A) to the second set of eNodeBs **12**(B) and switching from satellite **20**A to satellite **20**B. The gateway handover (GHO) can refer to the process for moving from the first antenna **14**A to the second antenna **14**B.

At the outset, the cells **51** are communicating with the first eNodeB farm **3** BBU **12**(A) of cluster **12**(CA) for the satellite **20**A over the primary ports **12**A(**1**) using PCI **13**A(**1**) via the first GW antenna **14**A. Once the cells **51** enter the overlapping area **50**AB, they also communicate with the secondary port **12**A(**2**) of the same eNodeB farm **3** BBU **12**(A) but with a different PCI **13**A(**2**) via the GW antenna **14**B and rising satellite **20**B. At this point, the eNodeB **12**(A) enables the secondary TRx port **12**A(**2**), which communicates via the second GW antenna **14**B to the rising satellite **20**B over beam **15** and with the cell via a new beam **17***h*. In this way, the beam from the satellite **20**A can start the HO from serving beam **16***h* to serving beam **17***h*.

Accordingly, as the setting satellite **20**A continues to set and the rising satellite **20**B continues to rise, the cells **51** will

move from the setting FoV **50**A into the overlapping region **50**AB, and into the rising FoV **50**B. As they pass into the overlapping region **50**AB, the ground cells **51** is changed to **51***h* when BHO procedure is performed. The essential part of the BHO is to provide another "fake cell" from the rising satellite **20**B with a different PCI to the same geographically the same cell to **51***h*—the new target cell from the rising satellite **20**B. The new cell needs another process device called base band unit (BBU) in eNB farm **3**, and generally by default there are 2 BBUs, each with their RF port form primary and secondary TRx, for each cell. The illustration below make use of the two TRx of a cell, but any other BBU resources from the eNB farm can also be used to provide the new BHO cell **17***h*.

For example, BBU-p **12**(A) in the eNodeB farm **3** is serving the cell **51**, and the satellite network control center (NCC) informs eNB and BBU-p that **51** becomes **51***h*, so that eNB switches on or turn the secondary BBU-s and RF port **12**A(**2**) to a target cell in addition to the primary RF port **12**A(**1**) of the eNodeB in **12**(A). The first antenna **14**A still carries the setting beam **16** for the BHO purpose and is labelled as **16***h* in the BHO process, the secondary RF port **12**A(**2**) for the same eNodeB **12**(A), is now taking the target beam route, i.e., the second antenna **14**B (which tracks that rising satellite **20**B). Once it is communicating over the secondary port **12**A(**2**) via the second antenna **14**B and the rising satellite **20**B to the active UEs in cell **51***h*, it ceases communication over the primary port **12**A(**1**) and the first antenna **14**A. Those cells will continue to communicate with the eNodeB **12**(A) over the secondary RF port **12**A(**2**) and the second antenna **14**B (where the respective BBU **12**(A) may become or be taken as BBU **12**(B), and the respective secondary RF port **12**A(**2**) of the BBU **12**(A) may become or be taken as the primary RF port **12**B(**1**) of the BBU **12**(B)), until a new rising satellite comes along, at which point it will switch to communicating with the new rising satellite over the first antenna **14**A and the port **12**A(**1**) for the first BBU **12**(A). BBUs **12**(A) and **12**(B) are one of the signal processing unit in the cluster of them **12**(CA) and **12**(CB) respectively, which illustrate the processing devices that dynamically service GW tracking dish **14**A and **14**B respectively on most cells in their FoVs, except for BHO cells there are two RF ports for each HO cell, hence the source cell will use both **14**A and **14**B simultaneously via the two RF ports p and s as shown in BBUs. After the BHO the BBU of the cell will be conceptually transitioned from **12**(CA) to **12**(CB). The pool of BBUs serving the tracking dishes are not static as the satellites serve different ground cells under its orbit, where GW channel routing block **10** carries out the channel routing function under the supervision of NCC. The gateway channel routing block **10** at the gateway site **31** routes or connects the port **12**A(**1**), **12**A(**2**), to beams **16***h* and **17***h* respectively, with the appropriate antennas **14**A, **14**B, where beam **17***h* signal on GW antenna **14**B is shown as (or corresponds to) a separate thin line **1214**B (e.g., a separate thin line interface) in the GW or GW antenna **14**B's IQ interface streaming, meaning the corresponding eNB starts to handle its cell **51***h* BHO.

By default, an eNB (i.e., eNodeB) **12** has two RF ports, in terrestrial network (TN) they are transmitting signals for one cell (the same PCI). we are using two ports in beam HO but each of the 2 ports labelled as (**1**) & (**2**), sending signal from the same eNB but with two different Physical cell IDs PCIs (**13**A(**1**), **13**A(**2**)). However, they can be the same cell from one eNB that operationally are distinct to be associated with different cells, as one PCI needs to correspond to satellite **20**B and gateway antenna **14**B. So the beam can come from the rising satellite **20**B, and a different PCI would cheat UE to think that another neighbor cell is available, and HO procedures and protocol can be used to let the current beam of **12**A(**1**) HO to **12**A(**2**), it may be just the same cell from the same eNB, but using its 2 RF ports via 2 GWs and 2 satellites are "Ncell" for the purpose of beam HO.

Each eNB's RF ports can be switched to any GW antenna (**14**A or **14**B), and the items associated with the two GW antennas **14**A, **14**B in FIG. **2** are distinguished by A & B respectively, so **12**(A) is one of the eNBs that sends its signal to GW antenna **14**A, while **12**(B) is another eNB sends its signal to GW antenna **14**B normally. However, during the beam HO, **12**A(**2**) can start to stream to GW antenna **14**B, as a step of HO, and ports (**1**) & (**2**) can start to map to A & B, which are the Sat/GW antenna labelling, reflecting the innovative part of the BHO mechanism for UE to have a smooth HO.

So **12**(B) refers to those eNB serving the cells **52** in the footprint **50**B, while RF port **12**A(**2**) corresponds to the BHO cell **51***h* that is in the transition from cell **51** in the footprint **50**A to cell **52** in the footprint **50**B via the 2nd RF port **12**A(**2**), pretending that the BHO cell **51***h* is a cell **52**. RF port **12**A(**1**) corresponds to cells **51** in the footprint **50**A, and goes or communicates through GW antenna **14**A. RF port **12**A(**2**) is added one by one to GW antenna **14**B for BHO when respective cells **51***h* are in the overlapping area **50**AB. For handling unmodified UEs, RF port **12**A(**2**) is used during BHO.

FIGS. **3**(*a*), **3**(*b*) and (*c*) shows the interaction between the active UEs **30**, the eNodeB **12**(A), and the gateway channel routing block **10**, and how they work or operate together for BHO. The BHO uses CFRA (contention free random access) under eNodeBs control for smooth and seamless BHO. UEs in idle state does not need any eNodeB help like that. After BHO, UEs in idle state perform cell reselection, as mentioned above, and use CBRA (contention based random access) to be served by the eNodeB when needed.

Just as what CFRA intended by 3GPP specs for UE HO between cells, the arrow diagram shows how the condition is formed so that CFRA are pre-scheduled and MSG1 to MSG2 are well prepared to have the proper TA for each UE in BHO, which makes the HO perform as a perfect synchronized HO.

In certain examples, when overlaying two HO beams **16***h* and **17***h* to the BHO cell **51***h*, PCI values on the two RF ports are selected to avoid CRS RE overlay and minimize or reduce the interference to each other, and two beams frame structure is given time offset such as 1.5 ms to avoid MIB, SSS, PSS SSB (for 5G) and SIBs overlapping, so that active UEs can easily tell them apart and get the two cells details distinguished.

In other examples, the gateway site **31** may be configured to, e.g., via eNodeB **12**(A), identify active user equipment (UE) in the cell **51***h* in the overlapping area **50**AB (or to determine whether there is active user equipment (UE) in the cell **51***h* in the overlapping area **50**AB), and apply a hard beam handover from the setting satellite **20**A to the rising satellite **20**B (e.g., switching off the source beam such as **16***h* and at the same time switching on the target beam such as **17***h*), in response to no active UE being identified.

One Gateway Site Links to Two Satellites at the Same Time (1G2S)

FIGS. **1**, **2** show one gateway site **31** and two satellites **20**A, **20**B. The two satellites **20**A, **20**B are served by the same GWS (1G2S), the gateway site **31** can have multiple gateway antennas (the tracking dish antennas) **14**A and **14**B serving multiple satellites. BHO from satellite **20**A to sat-

ellite **20**B can use two dish antennas **14**A, **14**B to track their serving satellites **20**A, **20**B, respectively. The beam **16** serves the cells in FoV (or footprint) **50**A of satellite **20**A, and the beam **17** serves the cells in FoV (or footprint) **50**B of satellite **20**B. In the embodiment shown, each satellite (e.g., **20**A, **20**B) communicates with an eNodeB farm **3**, at any time each satellite needs or can communicate with a cluster of one or more eNodeBs **12**(A) or a cluster of one or more eNodeBs **12**(B) in eNodeB farm **3** (e.g., on the ground co-located with the GW antennas **14**A, **14**B to form the GWS **31**) to provide LTE services where each cell is served by an eNodeB in the respective cluster of eNodeBs. Cells **51** in the setting satellite FoV **50**A have been served by the cluster of eNodeBs **12**(A) via satellite **20**A during its pass. Near the end of satellite **20**A's service (before the cells being left outside of its FoV), cells **51** are on satellite overlapping region **50**AB, and can go through BHO in the example processes as described below.

1. Two overlapping beams **16***h* and **17***h* can be applied to the BHO cells, and the BHO cells are now labelled **51***h*.
2. The serving beams **16** are changed to the HO sourcing beams **16***h*. The HO sourcing beams **16***h* are almost the same as beam **16**, and continue using PCI **13**A(**1**), but the priority of the beam **16***h* is now for BHO. FIG. **3** illustrates the main function of beam **16***h*, and beam **16***h* can work with its counterpart of **17***h* to accomplish BHO smoothly.
3. Target HO beams **17***h* are also similar to the beams **16**, but with alternative PCI **13**A(**2**) and come from another RF port of the same eNodeB **12**(A).

As shown in FIG. **2**, beam **16***h* is served as usual by the eNodeB **12**(A)'s primary TRx port **12**A(**1**) with PCI **13**A(**1**), while target beam **17***h* is new HO beam from the same eNodeB **12**(A), but from the secondary TRx port **12**A(**2**) using new PCI **13**A(**2**) via the target satellite **20**B. After the HO, beam **17***h* from the 2nd RF port of the same BBU (no eNodeB HO here if the cell BW is the same, but beam HO. This is satellite mobility, not UE mobility handling, hence keep the same eNodeB) can become new target beam **17**. Further, the same serving eNodeB BBU can leave cluster **12**(CA) for BBU **12**(A) and join the cluster **12**(CB) for BBU **12**(B) to become one of the BBU serving the rising satellite **20**B. The BHO is achieved by overlaying the target HO beam **17***h* on the same cell that is currently covered by the source HO beam **16***h*. In the case when cell BW needs to be changed BHO is a good opportunity to use another BBU that is configured for the new demanded cell BW (CBW), where the example of primary and secondary RF ports of the same CBW above need necessary adaptation for the new CBW. However the ping-pong PCI deployment and mechanism will be the same.

The beams **16***h*, **17***h* are used for both downlink (UE Rx) and uplink (UE Tx). For a HO cell in **50**AB, a pair of ping-pong PCIs **13**A(**1**), **13**A(**2**) are assigned to the two Tx RF paths and delivered to the same cell **51***h* by the same eNodeB. A different PCI is used when BHO happens, as UE would not HO to the cell with the same PCI. Hence each cell has two PCIs, say 1 and 4, so that there are different PCIs for each BHO. A cell can have PCI=1, then the HO beam would have PCI=4, then next beam HO would go back to PCI=1. Accordingly, a cell's PCI can be alternating as 1-4-1-4-1-4, and the ping-pong PCI design enables the eNodeBs and UEs to use 3GPP defined HO procedures for BHOs to solve satellite mobility issues.

The overlapping beam **17***h* from the rising satellite are almost the same as **16***h* but with different PCI. Initially, the different PCI for the overlapping beam **17***h* is there for the UE to do CFRA to the target beam from satellite **20**B, commanded by the source beam **16***h* serving the UE. The BHO beams **16***h* and **17***h* are coming from the same eNodeB. Once the UE is synchronized with the new beam **17***h*, active UEs read the broadcast information and selects a suitable cell. The UEs use the system information block (SIB) to understand where and when the PRACH should happen. In addition, the source beam **16***h* sends RRC connection_reconfiguration, which commands the active UEs to measure the target beam with the PCI of the rising satellite **50**B. RSRP and RSRQ of the target beam are measured and report back to eNodeB, so that eNodeB knows the condition is right for the BHO.

At the eNodeB **12**(A) for cell **51***h*, the target satellite **20**B delivers a new target HO beam **17***h* with another PCI, while Tx signals on source HO beam **16***h* provides UEs with target beam **17***h* PCI for the UE to measure, and accordingly UEs can sync with the target beam **17***h*. The Rx on the target beam provides the eNodeB with the Timing Advance (TA) values needed in CFRA Random Access Response (RAR). The source satellite Tx sends the target PCI **13**A(**2**) to UEs for CFRA. Multiple cells' eNodeBs **12**(A) may perform this in parallel for each of the HO cells **51***h*, sharing the HO tasks in the overlapping the overlapping area **50**AB. BHO is on top of usual eNodeB scheduling and tasks, including UEs mobility, changing the beams and cells as needed when UEs move between them.

One Satellite Links to Two Gateway Sites (1S2G)

The 1S2G is the condition for GHO, as shown to the left-hand side of FIG. **2** when satellite **20**A FoV has two or more GW footprint (GFP) and services are needed from both GFPs. To serve the cells **53** (dash lined cells), whose eNodeBs are on another gateway site **32**, GHO starts when the first cell **53** in **50**A requests for a service from satellite **20**A and the second GW-SAT link **13** is needed. Accordingly, the 1S2G condition is needed for satellite **20**A.

FIG. **5** further shows the GW links with each other, and the core network associated with GHO involving two GWSs, including a UE mobility case between cells **51** and **53** that are served by different GWSs shown in FIG. **2**.

Operation

The eNodeB farms host thousands of cells with hundreds of eNodeBs serving corresponding cells fixed on the earth surface. The high speed of satellites means that some cells dynamically come into the satellite footprint while other cells are dynamically out of it. This means the satellite-serving GWS (i.e., the GWS that serves satellite) also changes the cluster of eNodeBs as the satellite moves, and eNodeBs are changing its GW-Sat link. To meet such dynamic cell change challenges, in some cases, the eNodeB software runs on an eNodeB's farm hardware, may need to float to another hardware (HW) which is a few hundred km away (in GWS diversity design), which involves an eNodeB mirrored image quickly when the GWS and its eNodeB farm hardware is the best configuration (or suitable configuration) for the software to carry on serving the cell. For example, in GWS diversity design, two GWS can be a few hundreds km apart, and the redundant site can quickly involve mirroring the GWS in action, so as to improve the user experience. Any fixed cell can be served by any eNodeB hardware in any GWS location while keeping the software's context for the fixed cell running on different hosts, which is referred to here as eNodeB mirroring. In some example, eNodeB hardware for servicing fixed cell can be changed from a first eNodeB hardware to a second eNodeB hardware, so the software's context is moved from the first eNodeB hardware to the second eNodeB hardware. The core network would

need to have corresponding changes to deliver paging and system information according to the serving eNB changes. This can be particularly useful in certain exceptional cases.

Another way of using GWS diversity without duplicating the eNB HW is to use long distance fronthaul fiber link between the GWS. This is a cheaper option but will need to count the fiber TRx latency which normally are fixed and stable once the fiber link is configured and working as expected.

Turning to FIGS. **3**(*a*), **3**(*b*) and **3**(*c*), operation **200** of the system is shown, and specifically at the UEs **30**, their serving eNodeB **12**(A), and relevant serving gateway that includes gateway channel routing block **10**. BHO begins in active cell served by an eNodeB **12**(A), where the active UEs **30** get the services with IQ streaming of GW antenna **14**A for DL and UL, and satellite **20**A tracks all the cells like **51** in its FoV. That means GWs are in good working order, i.e., step **260**, the gateways **10**, on one or more or all GWSs, establish the connections to their eNodeBs and satellites. A GWS (such as **31**, **32**) knows or recognizes that the upcoming satellites and relevant GWs are ready for necessary links with any satellites at any time to fulfill GHO needs. This is pre-scheduled and related to the locations of GWSs and satellites paths. On step **262**, GW (such as GW channel routing block **10**) performs delay compensation (or delay normalization) and Doppler compensation for cells **51**, **52**, **53** so that the delay variations and Doppler effect caused by satellite **20**A, **20**B are no longer a factor for eNodeB to handle, i.e., compensates the Delay and the Doppler to the center of each cell to provide a near zero differential delay and Doppler, e.g., dynamically. The compensation is to the cell centers and at the cell edge the residual delay and Doppler effect are within UE pulling range, and acceptable for getting LTE services. In some examples, GW (such as GW **10**) may be configured to perform the delay normalization so that at the cell center UE can have its Timing Advance (TA) equal a midpoint (i.e., mid-point) timing-advance (TA) value. That is, for example, at the cell center (e.g., beam center), UE can have its timing advance equal a midpoint timing-advance (TA) value that is a midpoint value of a range of TA value.

When the active cell enters the overlapping area **50**AB at step **220**, the satcom system tells (or instructs) the eNodeB to start the BHO. For example, the eNodeB may start the BHO, in response to receiving a start instruction signal sent from the satcom system when the active cell enters the overlapping area **50**AB. Step **222** and **264** are the handshake signals and actions on eNodeB and GW for subframe by subframe coordination of switching the IQ streams to the right GW with right satellites.

At some time point, the cells **51** are in the overlapping area **50**AB, that is, the overlapping area of the FoVs (or footprints) of two satellites **50**A, **50**B. The BHO is ON and the cell become a BHO cell **51***h*. BHO must happen in area **50**AB. The process of moving all the active UEs from setting satellite beam **16** to the rising satellite beam **17** is started. At that time point, the gateway **10**, and eNodeB **12** are told or notified at step **264**, that beam handover is to begin with beam **16** changed to **16***h* and **17***h* as eNodeB now need to perform BHO functions. At steps **222**, **266**, the eNodeB **12**(A) and gateway **10** switch on the 2^{nd} RF port **12**A(**2**) of the eNodeB **12**(A) for beam **17***h* while **16***h* keeps the same as **16**, and start to take care of newly added beam **17***h*. With BHO from **20**A to **20**B finished, and both satellites (**20**A, **20**B) orbiting over it, cell **51***h* is no longer part of the FoV **50**A of the setting satellite **20**A, but in the FoV **50**B of the rising satellite **20**B. Accordingly, **51***h* is a newly added cell under the rising satellite **20**B, and becomes a cell like **52** under satellite **20**B's service, and beam **17***h* is changed to beam **17**.

The BHO procedure is described below. Deliver the target TRx beam **17***h* to the beam HO cells **51***h*. The GWS **31** takes intermediate-frequency (IF) signal of the extra RF port **12**A(**2**) and maps it to the GW-SAT link **15** for satellite **20**B to provide new beam **17***h* to overlay it on cell **51***h*. The cell **51***h* (in the overlapping area **50**AB of both satellites **20**A, **20**B) has two beams **16***h*, **17***h*, one from the source satellite **20**A and one from the target satellite **20**B, for active UEs (in RRC_connected state) to know the target beam **17***h* on BHO procedure starting from eNodeB (command or Step **226**). The RRC has three states, idle, disconnected, and connected. When it is connected it essentially means a connectivity between eNodeB and UE has been established and ready to serve the UE. If the UE has no further service needs for a period of time, the inactivity timer expires and the UE will go into idle state, so does eNodeB service reservation of the radio resources (RRs) for the UE (as that radio resource will be allocated to other active UEs).

The source beam **16***h* and target beam **17***h* are overlaid on to the same physical cell **51***h*, fixed on the ground, with two different PCIs **13**A(**1**) and **13**A(**2**), respectively. Therefore, UEs **30** in cell **51***h* can recognize beams **16***h* and **17***h* as corresponding to two different cells, and satellites BHO can be realized by using the PCIs alternatively. The eNodeB's two RF ports **12**A(**1**), **12**A(**2**) deliver the ping-pong PCIs to the cell **51***h* via two RF paths **16***h*, **17***h* from two satellites **20**A, **20**B.

The gateway **10** routes or switches such RF paths at the right time between step **260** to **266**, in coordination with the eNodeB. With TRx actions on step **224**, the satellites BHO is started smoothly, and good user experience is maintained by steps in FIG. **3** under eNodeB's control. In some examples, TRx actions on step **224** may include transmitting the new PCI, and receiving UEs' responses for the BHO scheduling. When UEs are completely HO-ed to beam **17***h*, the BHO is finished, and the UEs are under satellite **20**B's service or in one of the cells under satellite **20**B's service, the serving beam is one of the beam **17**. The BBU is still the same one for the same CBW, but can also be different one for a different CBW (e.g., in terms of hardware) in the GWS **31**, but is changed from cluster **12**(CA) to cluster **12**(CB) conceptually, and accordingly the eNodeB (or its labeling) is changed from eNodeB **12**(A) to eNodeB **12**(B). The satellite is now changed from satellite **20**A to satellite **20**B before overlapping region moves forward leaving cell **51***h* and becomes one of the cells **52**. All the cells in **50**AB go through this BHO procedures in parallel with their serving eNodeBs, and there are many seconds to do that (should have enough time by design of satellites constellation).

Also, in FIG. **3**, the eNodeB **12**(A) starts as a source eNodeB and with PCIs preparation, and handover begins at step **222**. Further, at step **224**, the eNodeB **12**(A) uses the source cell PCI **13**A(**1**) (with, e.g., value of 1) on one RF port **12**A(**1**), gets another RF port **12**A(**2**) ready and send another PCI **13**A(**2**).

On active UEs **30** side, the UEs **30** start their services just like UEs in TN cells. Step **205** shows the general starting point on UEs for BHO and GHO. eNodeB at step **226** starts scheduling the UEs in RRC_connected state as step **210** shows, telling or instructing the UE to find the target beam PCI **13**A(**2**) and report the measurement for BHO.

The multiple (M) UEs further send their measurement reports **212** (M Multiple UEs can be scheduled for efficiency). The BHO eNodeB **12**(A) in cluster **12**(CA) receives

the measurement reports and know beam **17***h* satisfy the HO condition and is in good position to take over. At the same time, UL signals **212** (e.g., measurement reports) enable the eNodeB **12**(A), in step **230**, to get the new RF path TA of each of M UEs in the batch with respect to (WRT) beam **17***h*. The eNodeB **12**(A) then suspends the ongoing user plane traffic on beam **16***h* and assigns them with preambles for contention free random access (CFRA) for BHO. The BHO eNodeBs then send preambles for CFRA×M, to the M UEs **30**, at step **232**, so that CFRAs can happen to beam **17***h* and eNodeB knows or recognize each UE by the assigned preambles. At step **234**, the BHO eNodeBs **12**(A) also prepares RAR with the correct TA for every UEs in the batch, send them before getting MSG1 as scheduled on **236**. The way to get BHO UEs' TAs of the handover beam **17***h* are based on their TAs of the setting satellite serving beam. The two beams are both processed by the same eNB baseband signal processing unit which knows by UL grant commands to those UEs which RBs are for which UEs, by correlating the two received signals of the RBs, it is able to pre-calculate the new TAs for the rising satellite beam without waiting for their RACH with CFRA, and pre-emptively send the RAR (MSG2) to meet the UEs' expectation of the MSG2. If there is any new error of TA developed, the TA changes can be tracked from the MSG1s that will be received after MSG2. This is an important innovative addition to resolve the BHO speed, a challenge when many active UEs go through the BHO every few minutes.

At step **214**, in response to signal **232**, the UEs **30** send MSG1 that includes the CFRA to beam **17***h* for PRACH (e.g., the spec defined procedure) and to notify the eNodeB **12**(A) that the UE **30** is going to move from source HO beam **16***h* to target HO beam **17***h*. Preambles are used or included to help beam **17***h* to identify and distinguish between the UEs **30**. Thus, the UEs **30** send MSG1 CFRA×M to the eNodeB **12**(A) in cluster **12**(CA), at step **216**. Further, the eNodeB **12**(A) in cluster **12**(CA) sends MSG2 RAR×M to the UEs **30**, at step **236**.

In response to MSG2, the M UEs **30** knows or identifies the new TA to use with the beam **17**, and user planes (i.e., data traffic) are resumed, at step **218**. And in response to MSG1, at step **240**, M UEs User planes (with the BHO eNodeB **12**(A)) are resumed on PCI **13**A(**2**) (value of 4), and the next BHO will use PCI **13**A(**1**) (value of 1), and this cell PCI will change periodically e.g. [1,4,1,4 . . .] every few minutes when the next rising satellite take the services.

In addition, at step **238**, the eNodeB **12**(A) sends cell HO status update on finishing all RRC_connected UE HO to the gateway **10**. The gateway **10** then switches off the eNodeB's RF port **12**A(**1**) with PCI **13**A(**1**) for BHO, and uses RF port **12**A(**2**) and PCI **13**A(**2**) for ongoing user plane under the service of satellite **20**B. The coexisting beams **16***h* and **17***h* from two RF ports **12**A(**1**) and **12**A(**2**) via two GW antennas **14**A, **14**B and two satellites **20**A and **20**B improve the reliability of the BHO, and in case of the failed CFRA for some UEs, the above procedure can be repeated until all the scheduled CFRAs are handled successfully. From step **238**, via control channel in the eNodeBs and GWS interface, the BBUs that are behind the two overlapping beams know that all active UEs are HO to new beam **17***h*/**17**, and no need to have the old beam **16**/**16***h* and take them off in step **268**. The eNodeB also stops sending signals via the older port. This ends the BHO and the BHO eNodeB is now registered itself as eNodeB **12**(B) in cluster **12**(CB) in step **242** and **270** on eNodeB farm and GWS, back to user plane traffic data handling as usual via satellite **20**B in step **272**. In some examples, the eNodeB may end the BHO in response to receiving an end instruction signal sent from the satcom system.

It is worth mentioning that each LEO satellite can, depending on where they start from an initialization together with its serving GWs and eNodeBs, provide the services for cells in its FoV. As a LEO satellite it always has constant relative move with the cells being served, hence it is not only steering the beams for tracking the existing cells all the time, but also doing the BHOs with neighbor satellites as cells are coming into its FoV as well as leaving from it constantly. Step **244** of FIG. **3** notes the overall ongoing procedures in handling the satellite-cell dynamics. Each satellite is source and target at the same time, from BHO point-of-view (PoV), and relinquishes old beams and start new beams in coordination with eNodeBs and GWS switching.

GWe10 for 18 Equatorial Se20 at 700 km LEO

Referring to FIGS. **4**(*a*), **4**(*b*), **4**(*c*), just enough density of GWSs and satellites is desirable. Then for BHO and GHO, 3 cases are considered here as non-limiting illustrative examples of the present disclosure. FIG. **4**(*a*) represents the 1G1S (one gateway, one satellite) scenario. In this case, one satellite can only connect to one gateway. FIG. **4**(*b*) represents 1G2S cases where two satellites can be connected to one gateway station simultaneously.

In FIG. **4**(*c*), 2G1S is shown, where two gateways connect to one satellite in order to have gateway HO (GHO), for example where a satellite flies through a big county. The eNodeB farm is either located in each gateway or in a datacenter between gateways, which enable GWS diversity to deal with rain or other situations. To achieve this, both GWSs of both GWs (or both GWs) are connected via high bandwidth CPRI or eCPRI fibber link (the fronthaul) to pass the IQ data for DL and UL of hundreds of cells for both Gateways whichever is needed by two GWSs. Otherwise the cells in between the two GWSs will have to have duplicated eNodeBs on both GW sites to serve those cells.

The satellite overlapping areas need the action alignment of active UEs, BHO beams, satellite, GWS, eNodeB, BHO scheduling, different eNodeBs in rising satellite and GWS with inter GWS eNodeB Gateway Interconnectivity Link (such as X2) passing UEs TA for the target cell, on top of arranging the CU and DU rerouting. The inter GWS 10-15 ms Gateway Interconnectivity Link (GIL) delay is considered as part of delay normalization, as pre-scheduling is done, and UE can recognize the new DL frame. The system compensates the main time delay, while the TA handles the residual part that is related to UE location in a cell. X2 is commonly used on LTE, and is used here as an example of GIL. GIL enables the communication between gateways and supports handover cases.

FIG. **4**(*b*) shows the 1G2S case, where satellite beams HO while keeping the same GWS as shown in, e.g., FIG. **2**. The HO scheme introduces two simple information elements (IEs) in Gateway Interconnectivity Link eNodeB link for UE HO procedure, in order to enable UE mobility HO needs by standard 3GPP procedures. The two key modifications are: ping-pong PCIs for the two RF ports of the cell eNodeB.

The embodiments (or examples) of the BHO of the present disclosure include that, by faking the PCIs, the BHO is turned into a standard UE HO event for each UE, so that a normal UE does not need to take care of which satellites and gateway is serving it, nor does the eNodeB. This procedure significantly simplified the sat RAN requirement to UEs and base stations, making the satellite complexity transparent (e.g., completely transparent) to both of the RAN parties which turn every normal phone into the sat

phones or satphones (e.g., satellite phones that can communicate with satellites), and transparent satellites are enabled and directly communicate with a modified base-station low PHY (i.e., physical layer) and un-modified standard 3GPP compliant UEs. In some examples, base station is configured to implement functions to work with sat RAN. Since it is not changing the cell as a matter of fact, the core network does not need to divert any dataflow and no real cell HO really happen, and no extra load for the system.

It is worth mentioning that such change may be treated as handover between two cells from the first look of system architecture, it can be done using two RF ports of one cell itself without extra hardware. By default, 2 RF ports are available for each cell, the MIMO operation for the UEs that go through BHO can be suspended for a few frames for its BHO, then resume its MIMO after BHO.

The above functions described are the SW modifications needed on the base station (BTS for 2G, eNB for 4G and gNB for 5G). In addition to the BHO procedure related SW changes, there are some generic sat RAN SW changes. A brief summary of the major baseline changes for BHO are:

1. since the RF path on feeder link and service link are over 1000 km, there will be extra delay, on DL and UL signal, that we normalize to particular value, on delay function mentioned earlier. This impacts the base station Rx but would be known in the system configuration, so sat RAN base station Rx scheduling will be modified with such a delay.
2. for time sensitive procedure, like PRACH for LTE, try to use CFRA as much as possible (see the description in this disclosure), and CBRA are used for the initial random access and need a set of pre-emptive MSG2 with good probability of meeting the needs of the UE is employed, that include the use of limited preambles for CBRA and estimating the TA by previously sent PRACHs; For 2G this will just need to adjust the Rx time.
3. System configuration with timer that sensitive to the long round trip time (RTT) all needs to be changed so that they would tolerate more RTT.
4. CN changes for accommodating the two cells for one geographical cell, and assign two sets of same parameters them accepting two PCIs, and avoid redirecting the user data when there is no real change of the BBU. CN understand the fact that there is an additional fack cell for each real cell.

FIGS. **4***a*, **4***b*, **4***c* show the cases of system implemented in 1G1S, 1G2S, and 2G1S, respectively. They are suited for different cases. However, the information between gateways flows through the GIL, not through the satellite as there is no inter-satellite relay that may violate the data security law and regulation of the region. In an example 1G1S period or case of FIG. **4**(*a*), no beam HO is needed. For example, when a Satellite FoV is much larger than the region needs to be served and 1S can cover the region completely. As a more specific example, an island country like UK and Japan can be covered by one satellite FoV at certain period of time. However when the region is near the FoV edge, then 1G2S in FIG. **4**(*b*) may be needed, as BHO is needed to continue the service. 1S1G will terminate and transition to 1G2S when the FoV edge come close to the area it covers, as another satellite needs to take over the cells on this edge. FIG. **4**(*c*) illustrates the case of the next moment or another case. A satellite also needs to cover new cells in its FoV as the satellite fly over them. The GWS that hosts the new cells needs 1S2G to fulfill the extra service. So 1G1S is temporary and will be, for example, followed by 1G2S and 1S2G.

Backhauling

Referring to FIGS. **5**(*a*), **5**(*b*), **5**(*c*), Gateway Interconnectivity Link backhauling is shown, where Gateway Interconnectivity Link (e.g., inter-gateway link) is a type of interface introduced by the LTE Radio Access Network. Here, backhauling refers to connectivity to the core network, basically where the traffic from/to the UE goes/come. GIL connects neighboring eNodeBs in a peer to peer fashion to assist UE mobility handover (the traditional TN cell HO due to UE moving across cells) and provide a means for rapid coordination of radio resources. The Gateway Interconnectivity Link does not require a dedicated physical connection between eNodeBs. It is a logical interface that can pass over the existing IP transport network. The Gateway Interconnectivity Link does not require L3 Routing. Where possible, switching can be used and is preferable for the higher performance achieved.

The Gateway Interconnectivity Link interfaces are not needed between ALL eNodeBs in a TN (Terrestrial Network), NTN beam HO needs the Gateway Interconnectivity Link for neighbor GWSs' eNodeB Gateway Interconnectivity Link for passing target UEs info. Clarification for the Gateway Interconnectivity Link between eNodeB farms is needed and started.

The Gateway Interconnectivity Link interfaces are only needed between neighboring eNodeBs (i.e. those that control cells with overlapping coverage areas in 1G2S+1G1S+1G2S case). It is only between neighbors that handovers will occur, or interference co-ordination will be needed.

FIGS. **5**(*a*), **5**(*b*), **5**(*c*) show a case of UE mobility handling between two cells served by one satellite however the source cell and target cell are served by two gateways respectively. The Core Network **35** needs to handle the user data flow from source eNB of the GWS **31** to the target eNB of the GWS **32** in such active UE cell handover.

In some examples, gateway site handover is done or performed on cell granularity, and a cell is associated with a GWS, as the satellite moves from one gateway coverage area (or one gateway-site coverage area) to another during orbiting. Satellites may transfer (or switch) communications from the source satellite **20**A to the target satellite **20**B in 1G2S conditions (see FIG. **2**), and/or transfer communications from gateway antenna **14**A of gateway site **31** to gateway antenna **11**B of gateway site **32** for satellite **20**A in 1S2G condition where gateway antennas **11**B and **14**A belong to two GWSs **32**, **31**, respectively. Hence the GHO is embedded in BHO, and Soft HO is applied to BHO; and GHO, on the granularity of UE, takes a much longer time (many seconds), as it involves seamless HO of each active UE, one by one under eNBs control, for each cell running in parallel. The GHO is a function of satellite, and when a satellite (such as **20**A of FIG. **2**) orbits over a GWS, another GWS will serve it, which has to happen gradually and happens naturally with many BHOs.

That is to say that the GHO is at the granularity of BHO. When all the beams from one GWS is moved from a satellite (such as **20**A of FIG. **2**) to another satellite (such as **20**B of FIG. **2**), the satellite (such as **20**A) can have the resource availability to take new cells below to another GWS (such as **32**). BHO and GHO are both "make before break" for each active UE. eNodeB would switch off **16***h* only when **17***h* has taken over, and more importantly BHO does not change eNB for the cell, so all the active UEs context are kept and seamlessly take effect as needed making **17***h* to **17** transition super smooth, as it is the same eNB before and after BHO (e.g., BHO shown in FIG. **2**).

The satellite has a footprint which has the front edge and back edge. BHO happens at the two semi-circle edge. The front edge of the satellite may take new cells, as another satellite in front of the satellite HOs the cells to the satellite. The back edge of the satellite may relinquish cells, as the satellite HOs those cells to another sat behind it. The edges are defined by the elevation angle >=20 degrees in general but can be stretch to cover cells with a lower elevation angle when necessary.

In some examples, GWS also has a footprint, which may be smaller or much smaller than its FoV. FoV of a GWS means the area that the GWS can cover or reach. But an operator may normally choose or configure to cover some portions of the FoV, rather than all portions of the FoV (although it can), so as to save cost. The area that the operator assigns eNB of GWS to cover or reach in the FoV is called footprint, which is the area that the GWS not only can reach, but also have its "foot" on.

One of the GHO process is for UE mobility as mentioned, from cell **51** to cell **53** as shown in FIG. **2**. It has three phases: preparation (FIG. **5**(*a*)), execution (FIG. **5**(*b*)), and completion (FIG. **5**(*c*)). During the preparation phase (FIG. **5**(*a*)), the UE **30** is connected to the source eNodeB in GWS **31** and from there to the core network **35** (e.g., the core is formed by multiple nodes, which offer multiple functionality such as mobility management, authentication, session management, setting up bearers and application of different Quality of Services). At some point, when UE moves to cell **53** whose target eNodeB is in GWS **32**, the eNodeB receives a handover notification of beam HO. During the execution phase (FIG. **5**(*b*)), the UE **30** is connected to the target eNodeB in GWS **32** but the traffic is routed via the gateway interconnection link (forward link) **34** to the source GWS **31** and then the core **35**. Finally, at the completion phase (FIG. **5**(*c*)), the UE **30** is connected to the target GWS eNodeB **32** and from there to the core **35**. Thus, communication between the satellite **20** and the core **35** is originally through the eNodeB in GWS **31** at the source gateway site, and transferred to the eNodeB in GWS **32** at the target gateway site.

In the embodiments shown, the gateway (or the gateway site) can include a processing device to perform various functions and operations in accordance with the invention, such as the eNodeB **12**. The processing device can be, for instance, a computing device such as a computer, processor, application specific integrated circuits (ASIC), or controller. The processing device can be provided with one or more of a wide variety of components or subsystems including, for example, wired or wireless communication links, and/or storage device(s) such as analog or digital memory or a database. All or parts of the system, processes, and/or data utilized in the invention can be stored on or read from the storage device. The processing device can execute software that can be stored on the storage device. Unless indicated otherwise, the process is preferably implemented in automatically by the processor substantially in real time without delay. The system and method of the present disclosure can be implemented using standard UEs by computer software that accesses data from an electronic information source. A medium also includes one or more non-transitory physical media that together store the contents described as being stored thereon.

In some examples, in the satellite communication system of present disclosure, one to one mapping of the base station with its serving cell is kept via tracking of fixed cells while satellite passes them dynamically at high speed (7-8 km/s). In certain examples, in the satellite communication system of present disclosure, gateway placement is such that the satellites serving cells of the gateways have the line of sight (LOS) to the gateways for smooth GW HO.

In one example, the satellite communication system is configured to mirror and cause base-station software to be transparent to UE, embedded GW HO, GW/base-station (BTS, eNodeB, gNodeB) core network proper support on tracking area code, paging and system information X2 links, including the phases and timing changes due to GWS changes to meet 3GPP specs, where the phases and timing may refer to (or is related to or corresponds to) a long delay caused by the feeder links and service links. Those are to be adjusted or configured to make the system working and be able to work with unmodified UEs. In certain examples, core network proper support may refer to or include the eNB modifications and PCI assignment changes; and phases and timing may refer to the long delay caused by the feeder links and service links. Those can be adjusted to make the system work with unmodified UEs.

In some examples, base station is adapted to support a configurable fixed round trip latency, set various timer accordingly related to a long RF path delay.

In certain examples, the beam handover on the active UEs uses standard UE HO procedures to achieve synchronised seamless handover, one by one; without UEs and base-stations handling which satellite and which gateway are their serving entities, a function that is taken care of by the satellite network control centre. The gateway handover on the cell-by-cell basis may be achieved via many beam handovers over the orbiting course.

In certain examples, in the satellite communication system of present disclosure, multiple gateways are linked by long distant fronthaul optic fibbers, far more than those used in terrestrial network, such as a few hundred km to over one thousand of km, to enable gateway sites handover as well as GWS diversity and the coverage efficiency.

In the present disclosure, a LEO satellite communication system, turning legacy normal UEs to satphone resolving the satellite mobility by reusing UE handover procedures to resolve one of the most challenging issue in sat RAN, is in communication with a first setting satellite having a first field of view including a first plurality of cells, and a second rising satellite having a second field of view including a second plurality of cells. The first and second satellites have an overlapping field of view having an overlapping plurality of cells located therein. A first processing device has a first communication port communicating with a first cell of the first plurality of cells via said first antenna over a first beam, and a second communication port communicating with an overlapping cell of the overlapping plurality of cells via said second antenna over a second beam. Said first processing device switches from said first communication port to said second communication port in response to the first cell of the first plurality of cells moving into the overlapping field of view.

Accordingly, as disclosed above, a satellite communication handover system is in communication with a first setting satellite having a first field of view including a first plurality of cells in which an active User Equipment (UE) is located that is in direct communication with the first setting satellite, and a second rising satellite having a second field of view, the first and second satellites having an overlapping field of view where the first field of view overlaps with the second field of view, and an overlapping plurality of cells located in the overlapping field of view. The satellite communication handover system has a first feeder link and a first tracking antenna configured to communicate with the active UEs via a first setting satellite directly serving the first plurality of

cells and a second feeder link and a second tracking antenna configured to communicate with the second rising satellite serving the active UEs directly in the second plurality of cells. The system also has a processing device configured to communicate with the active UEs to control the active UEs to communicate directly with the second rising satellite.

The processing device can also be configured to start or end beam handover in response to an instruction signal from the first setting satellite and the second rising satellite. The active UE communicates directly with the first setting satellite over a first service link beam, and the active UE communicates directly with the second rising satellite over a second service link beam. The first antenna communicates with the first setting satellite over a first feeder link beam, and the second antenna communicates with the second rising satellite over a second feeder link beam. The processing device is further configured to control the active UE to cease communicating with the first setting satellite. The first antenna stops communicating with the first setting satellite. The processing device is configured to communicate with the active UE with a first physical cell ID (PCI) and via the first setting satellite, and communicate with the active UE with a second PCI and via the second rising satellite, when the active UE becomes in the overlapping field of view.

The satellite communication handover system determines the TA for each active UE, needed for the BHO destination beam of the rising satellite, by two feeder links and overlapping service links received signals of each UE's uplink RB receiving time correlations, before getting the UEs CFRA in the destination beam and achieve the efficiency of many active UEs BHO. The system has application in 2G, 4G and 5G without any modification to legacy UEs, and the CFRA (MSG1) is used for further TA tracking when needed in the target beam. The first setting satellite and the second rising satellite are transparent and directly communicate with a modified base-station low PHY and un-modified standard 3GPP compliant UEs.

Smart satellites layer 0 relay with large phase arrays that form electronically steerable beams for tracking many cells on the ground. One to one mapping of the base station with its serving cell is kept via tracking of fixed cells while satellite passes the fixed cells dynamically at high speed (7-8 km/s). Gateway placement is such that the satellites serving cells of gateways have the LOS to the gateways for smooth GW HO. A gateway is configured to perform delay normalization and Doppler compensation to the center of each cell dynamically. The gateway can be configured to perform the delay normalization so that a UE at a cell center has its timing advance (TA) equal a midpoint TA value. The system is adapted to support a configurable fixed round trip latency, set various timer accordingly related to a long RF path delay. The system performs seamless beam handover with two physical cell identities (PCIs) assigned to two radio-frequency (RF) ports that serve as the first and second communication ports or cells respectively, generates two radio-frequency (RF) downlink signals, each carrying one of the two PCIs assigned, and forms two beams and overlay the two beams on an overlapping cell of for beam or cell handover, via the first setting satellite and the second rising satellite.

Two PCIs are selected in such a way similar to neighbor cell PCI deployment, so that they are orthogonal to each other, to avoid interference, and MIMO principles apply so that the two overlapping handover beams work together without interfere with each other. The beam handover on the active UEs uses standard UE HO procedures to achieve synchronized seamless handover, one by one; without UEs and base stations handling which satellite and which gateway are their serving entities, a function that is taken care of by the satellite network control centre. And to perform a hard BHO for an idle cell without any active UEs, wherein the same beam/PCI/RF port is shifted from one feeder link to another for serving the same idle cell, without changing the PCI. Gateway handover is on the cell-by-cell basis is achieved via multiple beam handovers over an orbiting course.

The satellite communication handover system is mirroring base station software to be transparent to the active UE, embedded GW HO, GW/base station core network proper support on tracking area code, paging and system information X2 links, including the phases and timing changes due to GWS changes to meet 3GPP specs. An inter-gateway link supports the active UE mobilities for both voice and data calls. Multiple gateways are linked by long distant fronthaul optic fibbers, far more than those used in terrestrial network, from a few hundreds km to over one thousand km, to enable gateway sites handover as well as GWS diversity and the coverage efficiency. The system relays the 3GPP downlink and uplink signal between base stations and user equipment and turn normal phones to satellite phone without any modifications and reaching normal UEs on global scale. And, provides 3GPP RAN coverage to a remote place that is not covered by a constellation of LEO satellites without a huge cost of building the ground based infrastructure.

Changes to base station are according to satellite RAN's new feature requirement by reusing 3GPP specs to enable satellite RAN without UE and base station managing satellites and gateway connections. The satellite RAN system makes the satellite and gateway management totally transparent to them, and let them perform the RAN function with modifications on base station. The satellite communication handover system achieves BHO for serving the normal active UEs by standard 3GPP HO process without any modification on the active UEs. The base station is modified to have alternative cell IDs in supporting beam handover (BHO). The two cell IDs are used alternatively, with core network support on corresponding changes. The base station is modified such that BHO starts from network side, either by changing the two beams RF level, or NW initiated UE HO. And, LEO sat RAN beam handover is turned to standard UE mobility handover by faking a phantom cell to every geographical sat RAN cell; and assigning two PCIs to each sat RAN cell for the BHO that does not interfere with each other; and making the active UEs believe there is another cell, so that the BHO is streamlined and the active UEs are naturally changing their serving beams.

The satellite communication handover system has a long distance fronthaul that uses fiber link to enable gateway site diversity and enlarge gateway FoV and footprint. The fiber latency is encapsulated into the delay compensation, which can support fronthaul far longer than normal terrestrial network fronthaul, in a range of a few hundred km to over a thousand km. The satellite communication handover system can use standard HO mechanism to achieve satellite beam handover. The system handles the satellite mobility by a way that is compatible with a standard UE handover mobility procedure and using the standard UE mobility handover procedure for sat RAN beam handover (BHO) due to satellite mobility. The base station includes at least one of BTS, eNodeB, or gNodeB.

It is further noted that the system and method of the present disclosure can be used in a large phased array, such

as for example as disclosed in U.S. Pat. Nos. 10,979,133 and 11,121,764, the entire content of which is hereby incorporated by reference.

The foregoing description and drawings should be considered as illustrative only of the principles of the disclosure, which may be configured in a variety of ways and is not intended to be limited by the embodiment herein described. Numerous applications of the disclosure will readily occur to those skilled in the art. Therefore, it is not desired to limit the disclosure to the specific examples disclosed or the exact construction and operation shown and described. Rather, all suitable modifications and equivalents may be resorted to, falling within the scope of the disclosure.

What is claimed is:

1. A satellite communication handover system configured for communication with a first setting satellite having a first field of view including a first plurality of cells in which an active User Equipment (UE) is located that is in direct communication with the first setting satellite, and also configured for communication with a second rising satellite having a second field of view, the first and second satellites having an overlapping field of view where the first field of view overlaps with the second field of view, and an overlapping plurality of cells located in the overlapping field of view, the overlapping plurality of cells including a cell in which the active UE is located, the satellite communication handover system comprising:

a first feeder link and a first tracking antenna configured to communicate with the active UE via the first setting satellite directly serving the first plurality of cells and a second feeder link and a second tracking antenna configured to communicate with the second rising satellite serving the active UE directly in the second plurality of cells;

a processing device configured to communicate with the active UE to control the active UE to communicate directly with the second rising satellite; and

a gateway configured to perform delay normalization so that a UE at a cell center has its timing advance (TA) equal to a midpoint TA value.

2. The satellite communication handover system of claim **1**, wherein the processing device is configured to start or end beam handover in response to an instruction signal from at least one of the first setting satellite and the second rising satellite.

3. The satellite communication handover system of claim **1**, wherein:

the active UE is able to communicate directly with the first setting satellite over a first service link beam; and

the active UE is able to communicate directly with the second rising satellite over a second service link beam.

4. The satellite communication handover system of claim **3**, wherein:

the first antenna is configured to communicate with the first setting satellite over a first feeder link beam; and

the second antenna is configured to communicate with the second rising satellite over a second feeder link beam.

5. The satellite communication handover system of claim **1**, wherein the processing device is further configured to control the active UE to cease communicating with the first setting satellite.

6. The satellite communication handover system of claim **4**, wherein the first antenna is configured to stop communicating with the first setting satellite.

7. The satellite communication handover system of claim **1**, wherein the processing device is configured to:

communicate with the active UE with a first physical cell ID (PCI) and via the first setting satellite; and

communicate with the active UE with a second PCI and via the second rising satellite, when the active UE becomes visible in the overlapping field of view.

8. The satellite communication handover system of claim **1**, wherein the first feeder link and first tracking antenna are part of a base station, and wherein one to one mapping of the base station with a serving cell is kept via tracking of fixed cells while either the first or the second satellite passes the fixed cells dynamically at a speed of between 7-8 km/s.

9. The satellite communication handover system of claim **1**, further comprising:

a gateway configured to perform delay normalization and Doppler compensation to the center of each cell dynamically.

10. The satellite communication handover system of claim **1**, the first feeder link and the first tracking antenna being at a base station, the system being configured to:

perform seamless beam handover with two physical cell identities (PCIs) assigned to two radio-frequency (RF) ports that serve as first and second communication ports respectively,

generate two radio-frequency (RF) downlink signals, each carrying one of the two PCIs assigned, and

form two beams and overlay the two beams on an overlapping cell for beam or cell handover, via the first setting satellite and the second rising satellite, wherein:

two PCIs are selected so that they are orthogonal to each other, to avoid interference, and MIMO principles apply so that the two overlapping handover beams work together without interfering with each other; and

the two PCIs are PCIs for the same or different cell bandwidth, so that beam handover with the same and different cell bandwidth are both supported.

11. The satellite communication handover system of claim **1**, wherein the satellite communication handover system:

is configured to relay 3GPP downlink and uplink signal between the first feeder link and first tracking antenna; and

is configured to provide 3GPP RAN coverage to a remote place that is not covered by a constellation of LEO satellites.

12. The satellite communication handover system of claim **1**, wherein the satellite communication handover system achieves beam handover for serving the active UE by a 3GPP handover process without any modification on the active UE.

13. The satellite communication handover system of claim **1**, wherein the first feeder link and the first tracking antenna are at a base station, and the base station includes at least one of a BTS, an eNodeB, or a gNodeB.

14. The satellite communication handover system of claim **1**, further comprising the first settling satellite and the second rising satellite, wherein each of the first setting satellite and the second rising satellite has a large phase array that is configured to form at least one hundred electronically steerable beams in order to serve at least one hundred cells.

15. The satellite communication handover system of claim **1**, wherein the satellite communication handover system is configured to perform delay and Doppler compensation for each beam to normalize delay to a constant amount.

16. The satellite communication handover system of claim 1, wherein the satellite communication handover system further includes a satellite network control center (NCC) that is configured to orchestrate communication operations of a base station, a ground gateway site, and the first and second satellites and wherein satellite radio access network (RAN) base station receive (Rx) scheduling is modifiable with a delay.

17. A satellite communication handover system configured for communication with a first setting satellite having a first field of view including a first plurality of cells in which an active User Equipment (UE) is located that is in direct communication with the first setting satellite, and also configured for communication with a second rising satellite having a second field of view, the first and second satellites having an overlapping field of view where the first field of view overlaps with the second field of view, and an overlapping plurality of cells located in the overlapping field of view, the overlapping plurality of cells including a cell in which the active UE is located, the satellite communication handover system comprising:

a first feeder link and a first tracking antenna configured to communicate with the active UE via the first setting satellite directly serving the first plurality of cells and a second feeder link and a second tracking antenna configured to communicate with the second rising satellite serving the active UE directly in the second plurality of cells; and

a processing device configured to communicate with the active UE to control the active UE to communicate directly with the second rising satellite;

wherein the first setting satellite and the second rising satellite are transparent and configured to directly communicate with a modified base-station low PHY and un-modified standard 3GPP compliant UEs.

18. A satellite communication handover system configured for communication with a first setting satellite having a first field of view including a first plurality of cells in which an active User Equipment (UE) is located that is in direct communication with the first setting satellite, and also configured for communication with a second rising satellite having a second field of view, the first and second satellites having an overlapping field of view where the first field of view overlaps with the second field of view, and an overlapping plurality of cells located in the overlapping field of view, the overlapping plurality of cells including a cell in which the active UE is located, the satellite communication handover system comprising:

a first feeder link and a first tracking antenna configured to communicate with the active UE via the first setting satellite directly serving the first plurality of cells and a second feeder link and a second tracking antenna configured to communicate with the second rising satellite serving the active UE directly in the second plurality of cells; and

a processing device configured to communicate with the active UE to control the active UE to communicate directly with the second rising satellite;

wherein the system is configured to support a configurable fixed round trip latency, and to set one or more timers accordingly related to a long RF path delay.

19. A satellite communication handover system configured for communication with a first setting satellite having a first field of view including a first plurality of cells in which an active User Equipment (UE) is located that is in direct communication with the first setting satellite, and also configured for communication with a second rising satellite having a second field of view, the first and second satellites having an overlapping field of view where the first field of view overlaps with the second field of view, and an overlapping plurality of cells located in the overlapping field of view, the overlapping plurality of cells including a cell in which the active UE is located, the satellite communication handover system comprising:

a first feeder link and a first tracking antenna configured to communicate with the active UE via the first setting satellite directly serving the first plurality of cells and a second feeder link and a second tracking antenna configured to communicate with the second rising satellite serving the active UE directly in the second plurality of cells;

a processing device configured to communicate with the active UE to control the active UE to communicate directly with the second rising satellite; and

a long distance fronthaul that is configured to uses a fiber link to enable gateway site diversity and enlarge gateway field of view and footprint; and

wherein fiber latency is encapsulated into delay compensation.

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