US 20170005719A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2017/0005719 A1**

Krebs (43) **Pub. Date: Jan. 5, 2017**

(54) **SATELLITE CONSTELLATION**

(71) Applicant: **Google Inc.**, Mountain View, CA (US)

(72) Inventor: **Mark Krebs**, Niwot, CO (US)

(73) Assignee: **Google Inc.**, Mountain View, CA (US)

(21) Appl. No.: **15/268,121**

(22) Filed: **Sep. 16, 2016**

Related U.S. Application Data

(63) Continuation of application No. 14/501,859, filed on Sep. 30, 2014.

Publication Classification

(51) **Int. Cl.**

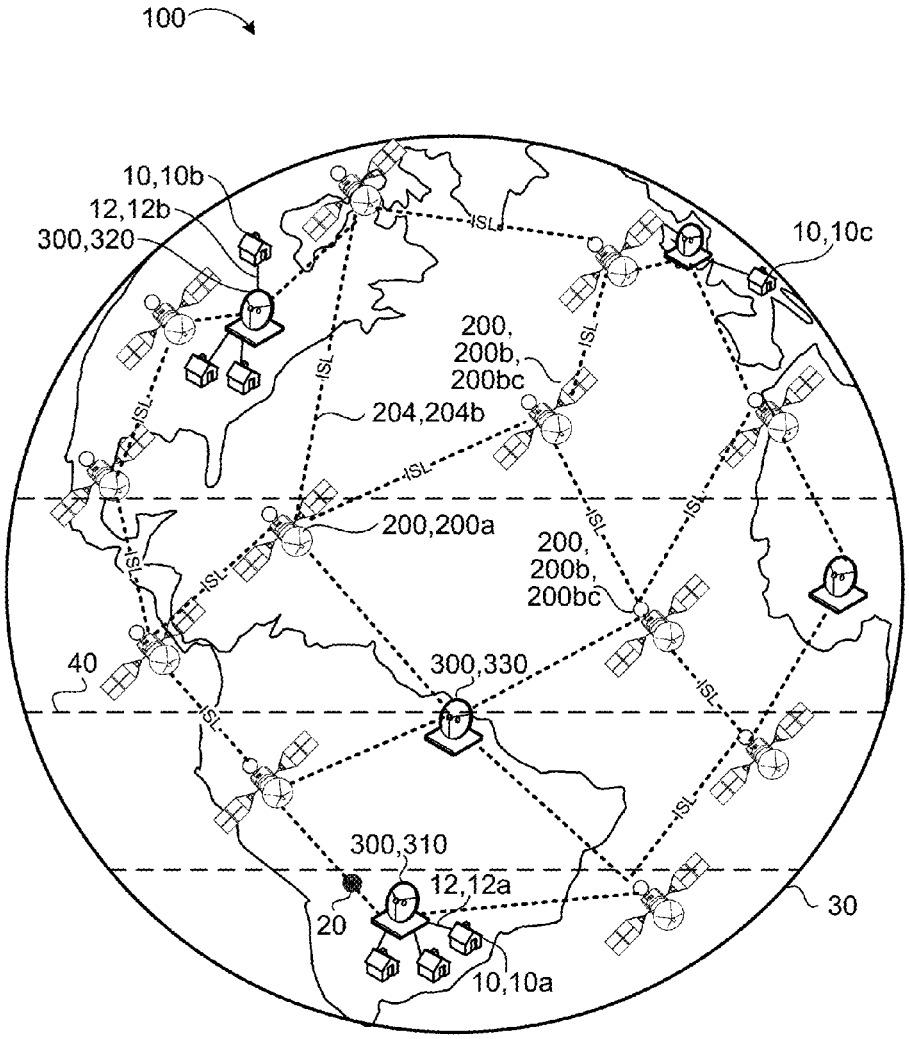
H04B 7/185	(2006.01)
H04B 7/19	(2006.01)

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

CPC ***H04B 7/18521*** (2013.01); ***H04B 7/18584*** (2013.01); ***H04B 7/19*** (2013.01)

(57) **ABSTRACT**

A communication system includes a constellation of communication devices orbiting the earth. Each communication device has a corresponding orbital path or trajectory with an inclination angle of less than **90** degrees and greater than zero degrees with respect to the equator of the earth. The constellation includes a first group of communication devices orbiting at a first altitude from the earth and at a first inclination angle. The constellation also includes a second group of communication devices orbiting at a second altitude from the earth lower than the first altitude and at a second inclination angle different from the first inclination angle.



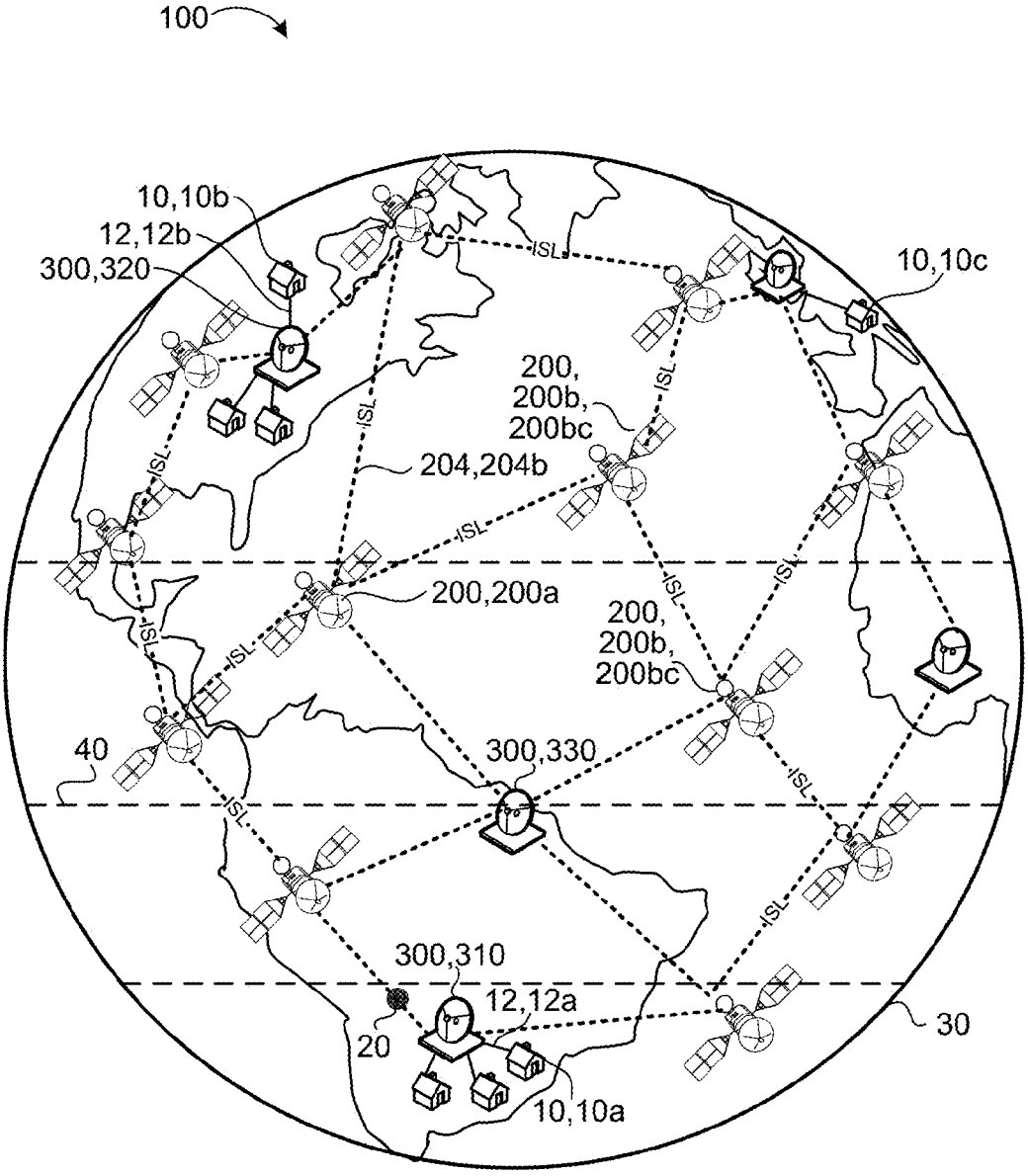

100
10,10b
12,12b
300,320
ISL
10,10c
200,
200b,
200bc
204,204b
200,200a
40
300,330
300,310
12,12a
20
10,10a
30

FIG. 1A

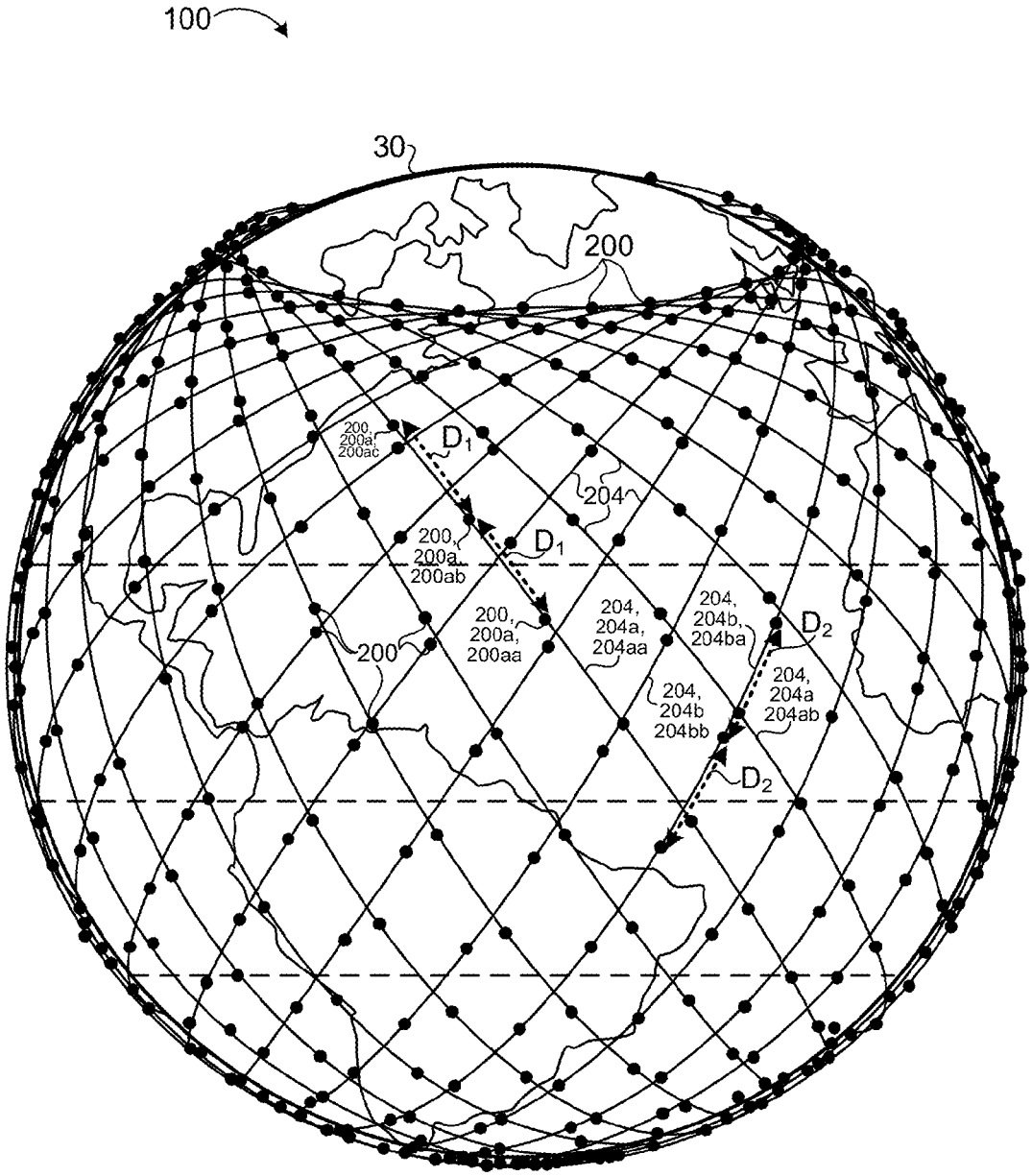

100
30
200
200, 200a, 200ac
D1
204
200, 200a, 200ab
D1
200
200, 200a, 200aa
204, 204a, 204aa
204, 204b, 204ba
D2
204, 204b 204bb
204, 204a 204ab
D2

FIG. 1B

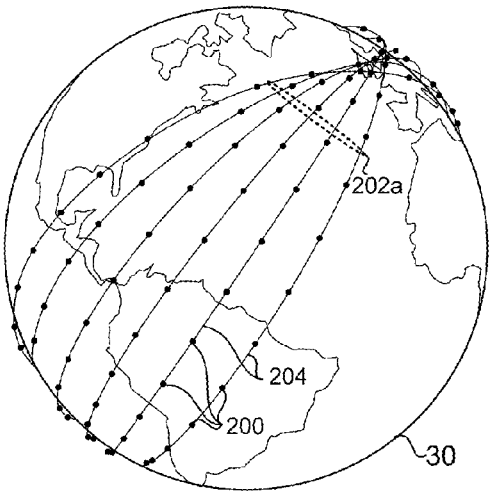


FIG. 2A

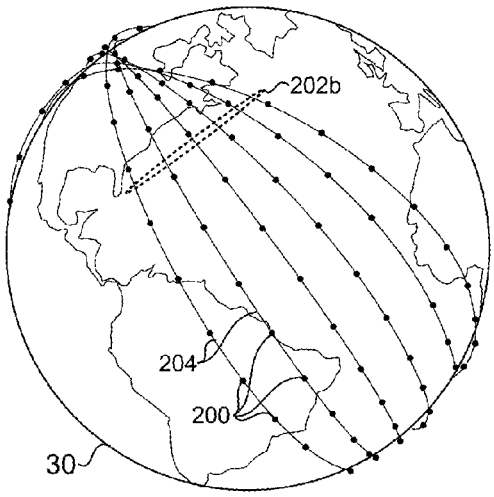


FIG. 2B

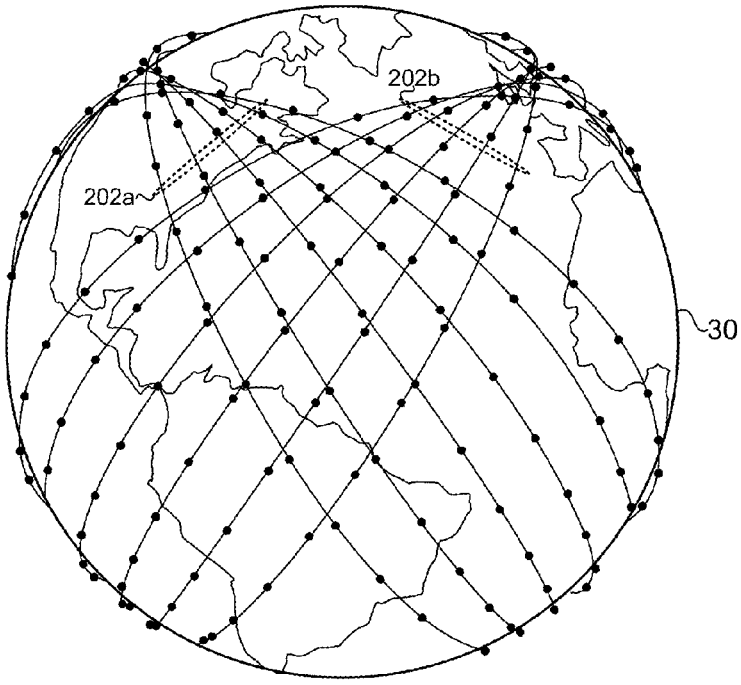


FIG. 2C

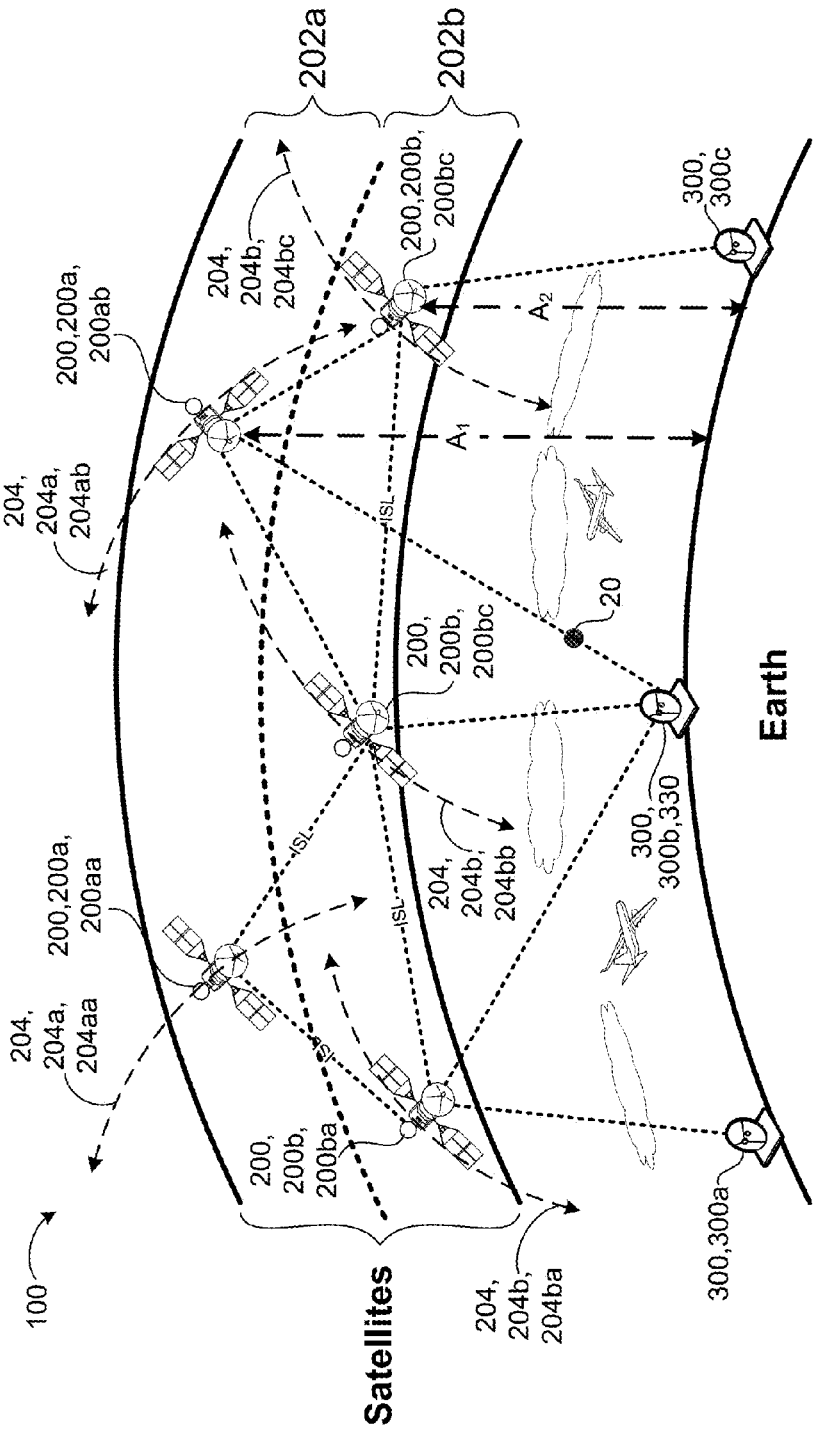

202a
202b
200,200a,
200ab
204,
204a,
204ab
204,
204b,
204bc
200,200b,
200bc
300,
300c
A2
A1
ISL
ISL
ISL
ISL
20
200,
200b,
200bc
Earth
200,200a,
200aa
204,
204a,
204aa
200,
200b,
200ba
204,
204b,
204bb
300,
300b,330
100
Satellites
204,
204b,
204ba
300,300a

FIG. 3A

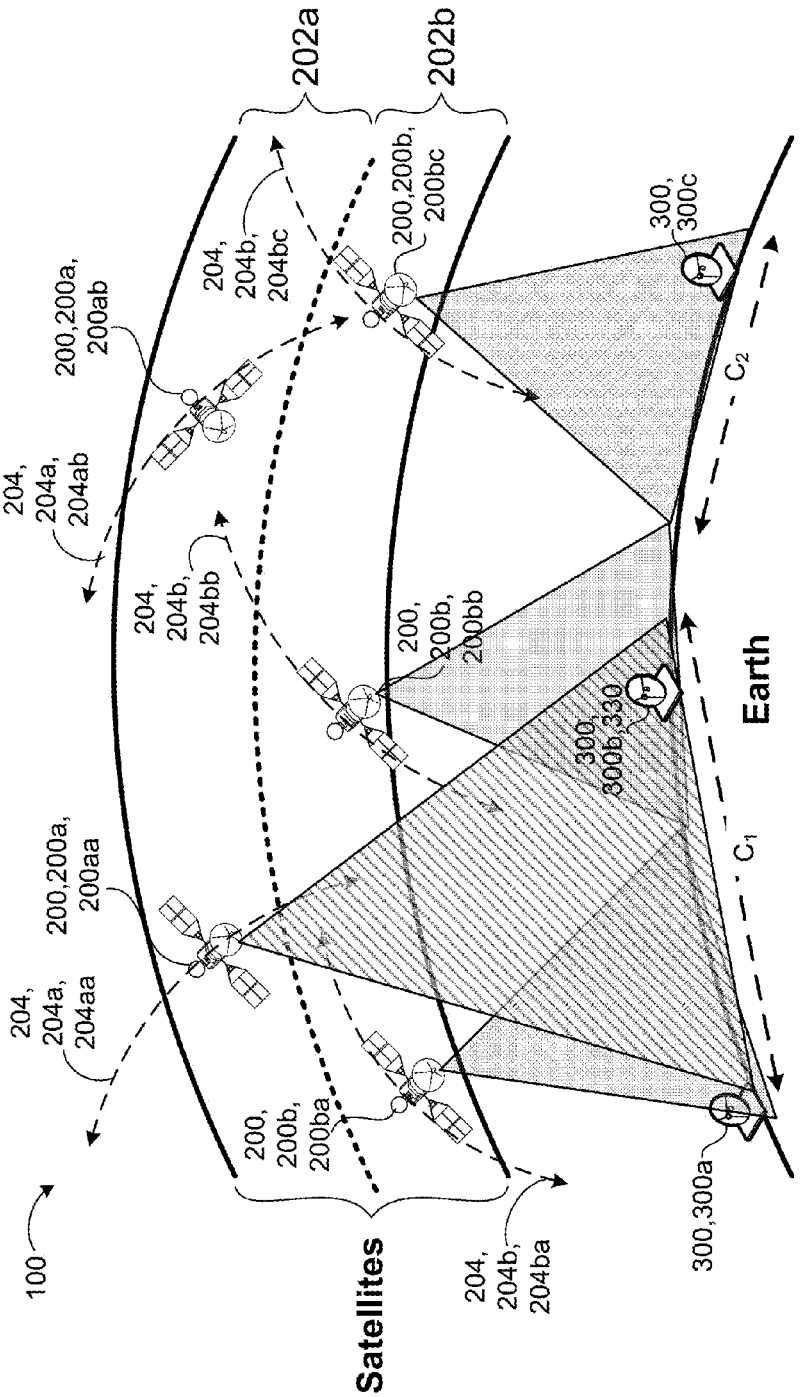

202a
202b
200,200a,
200ab
204,
204a,
204ab
204,
204b,
204bc
200,200b,
200bc
300,
300c
C_2
204,
204b,
204bb
200,
200b,
200bb
300,
300b,330
Earth
200,200a,
200aa
204,
204a,
204aa
C_1
200,
200b,
200ba
100
Satellites
204,
204b,
204ba
300,300a

FIG. 3B

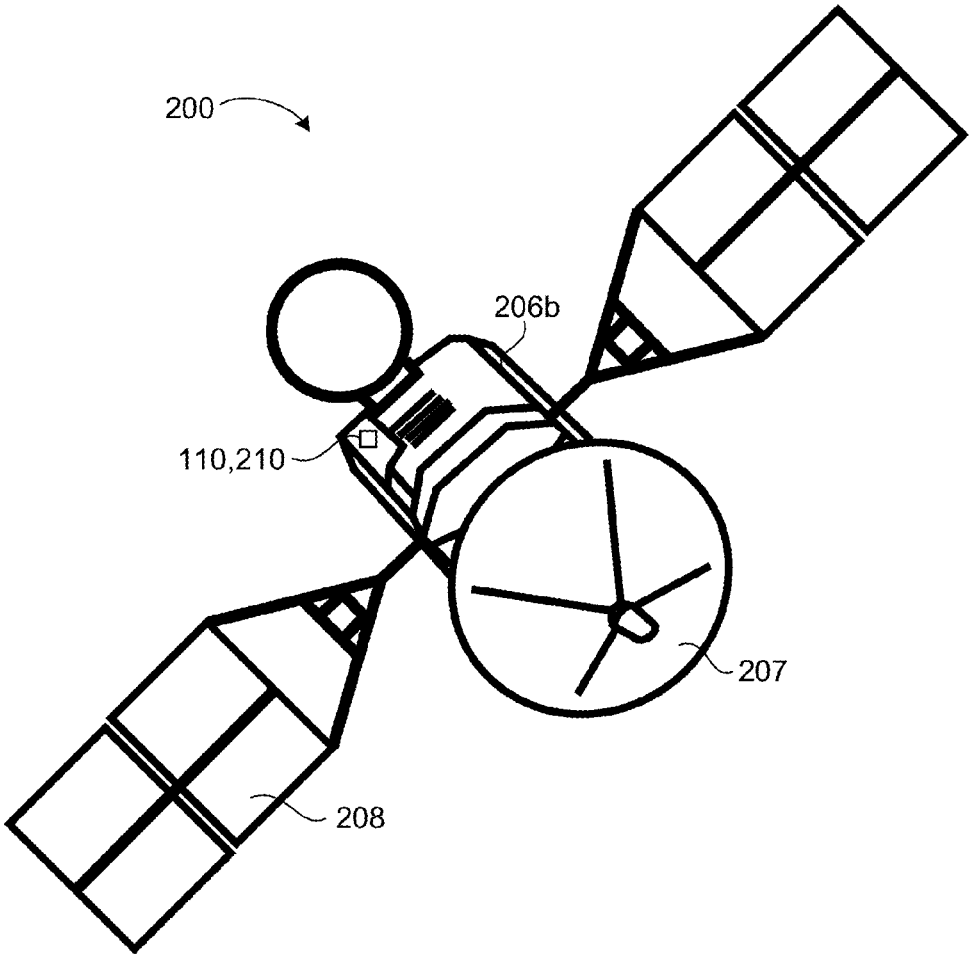


FIG. 4

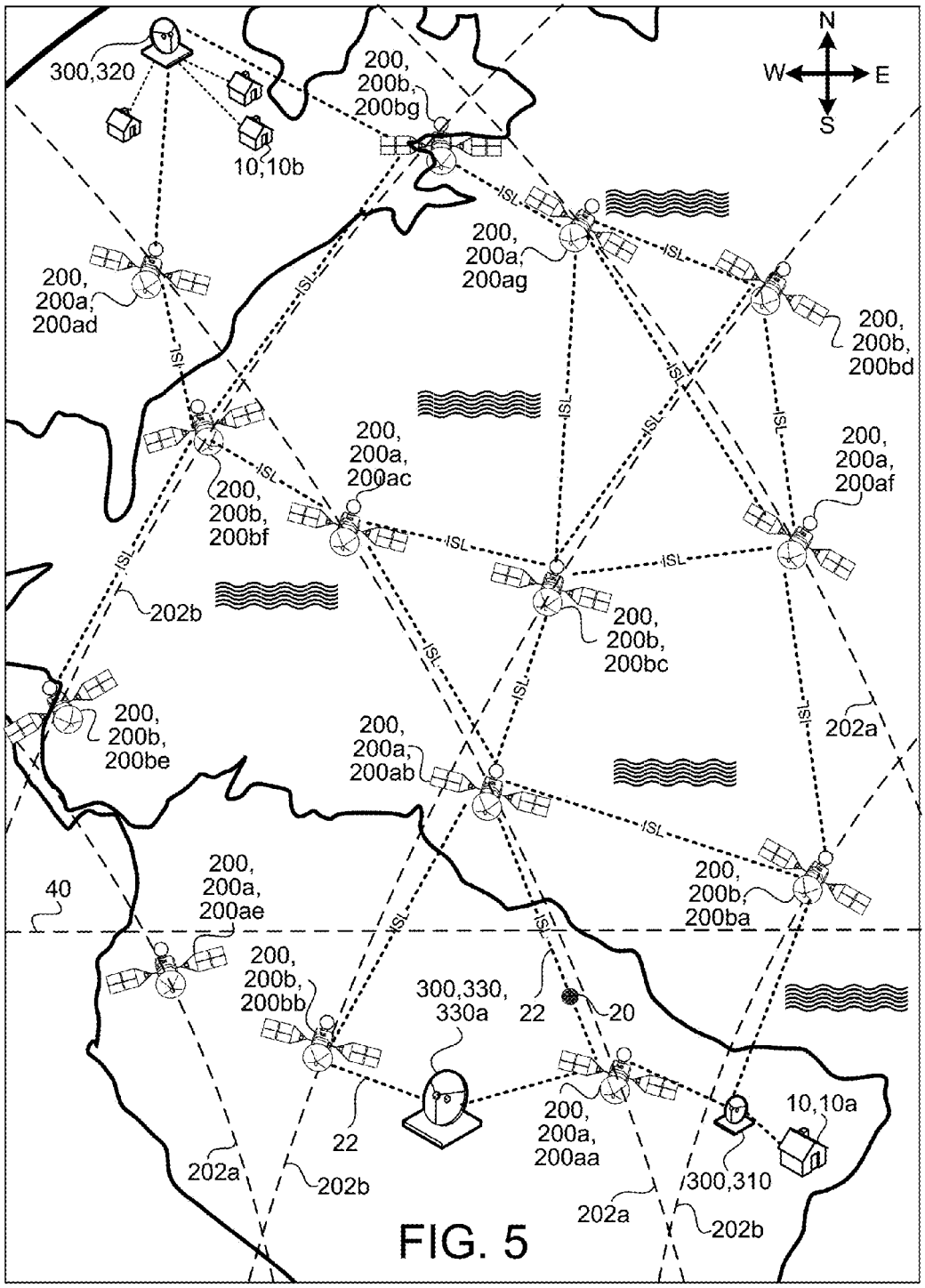

N
W
E
S
300,320
10,10b
200, 200b, 200bg
200, 200a, 200ag
200, 200a, 200ad
200, 200b, 200bd
200, 200b, 200bf
200, 200a, 200ac
200, 200a, 200af
202b
200, 200b, 200bc
200, 200b, 200be
200, 200a, 200ab
202a
40
200, 200a, 200ae
200, 200b, 200ba
200, 200b, 200bb
300,330, 330a
22
20
200, 200a, 200aa
10,10a
300,310
ISL

FIG. 5

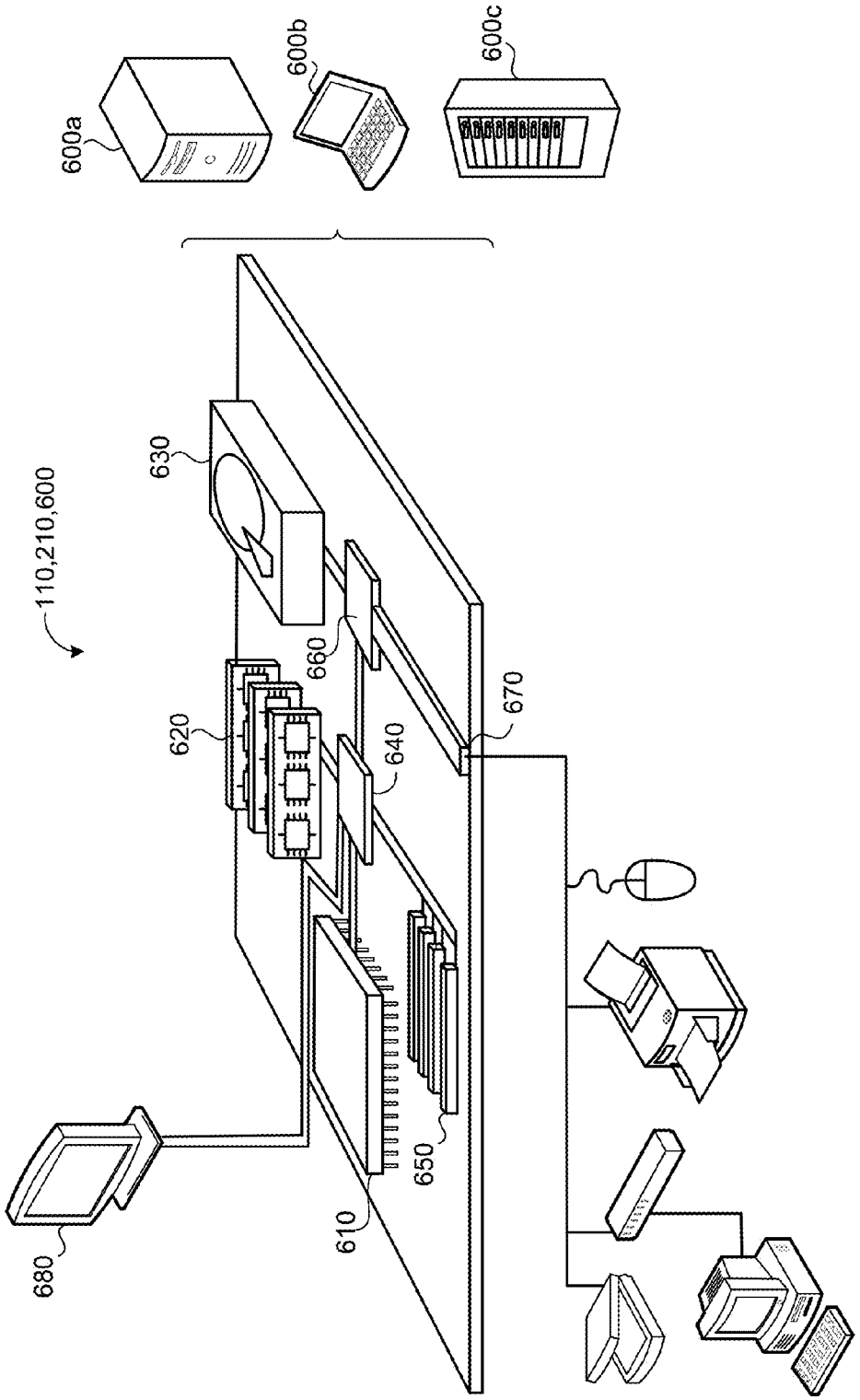


FIG. 6

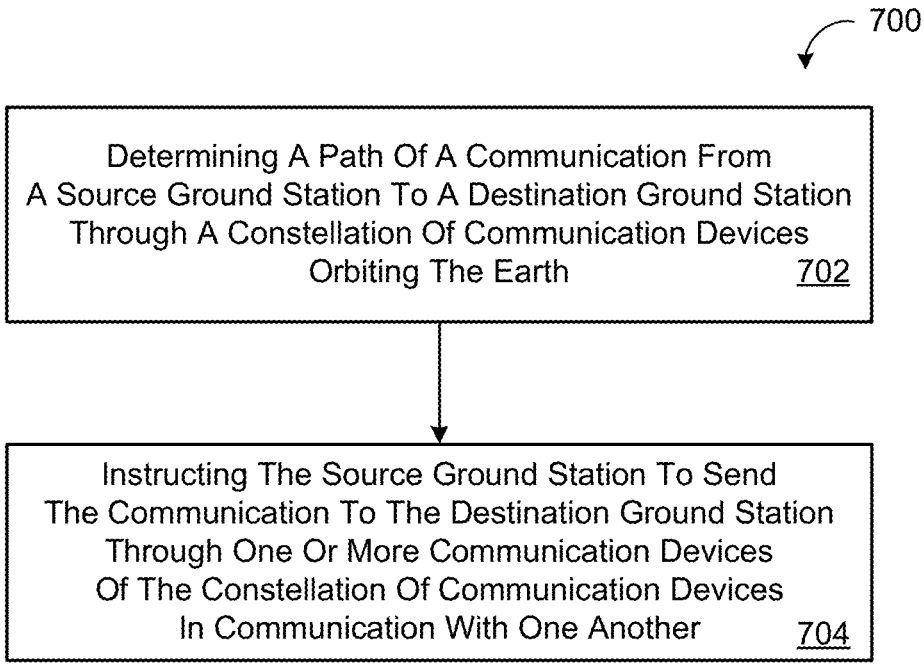

700
Determining A Path Of A Communication From A Source Ground Station To A Destination Ground Station Through A Constellation Of Communication Devices Orbiting The Earth
702
Instructing The Source Ground Station To Send The Communication To The Destination Ground Station Through One Or More Communication Devices Of The Constellation Of Communication Devices In Communication With One Another
704

FIG. 7

SATELLITE CONSTELLATION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This U.S. patent application is a continuation of, and claims priority under 35 U.S.C. §120 from, U.S. patent application Ser. No. 14/501,859, filed on Sep. 30, 2014, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to a satellite constellation having satellites orbiting the earth.

BACKGROUND

[0003] A communication network is a large distributed system for receiving information (signal) and transmitting the information to a destination. Over the past few decades the demand for communication access has dramatically increased. Although conventional wire and fiber landlines, cellular networks, and geostationary satellite systems have continuously been increasing to accommodate the growth in demand, the existing communication infrastructure is still not large enough to accommodate the increase in demand. In addition, some areas of the world are not connected to a communication network and therefore cannot be part of the global community where everything is connected to the internet.

[0004] Satellites can provide communication services to areas where wired cables cannot reach. Satellites may be geostationary or non-geostationary. Geostationary satellites remain permanently in the same area of the sky as viewed from a specific location on earth, because the satellites are orbiting the equator with an orbital period of exactly one day. Non-geostationary satellites typically operate in low- or mid-earth orbit, and do not remain stationary relative to a fixed point on earth. The orbital path of a satellite can be described in part by the plane intersecting the center of the earth and containing the orbit. Each satellite may be equipped with communication devices called inter-satellite links (or, more generally, inter-device links) to communicate with other satellites in the same plane or in other planes. The communication devices allow the satellites to communicate with other satellites. In addition, the communication devices significantly increase the cost of building, launching and operating each satellite and increase the weight of the satellite. They also greatly complicate the design and development of the satellite communication system and associated antennas and mechanisms to allow each satellite to acquire and track other satellites whose relative position is changing. Each antenna has a mechanical or electronic steering mechanism, which adds weight, cost, vibration, and complexity to the satellite, and increases risk of failure.

SUMMARY

[0005] One aspect of the disclosure provides a communication system including a constellation of communication devices (e.g., satellites) orbiting the earth. Each communication device has a corresponding orbital path or trajectory with an inclination angle of less than 90 degrees and greater than zero degrees with respect to the equator of the earth. The constellation further includes a first group of communication devices orbiting at a first altitude from the earth and at a first inclination angle and a second group of communication devices orbiting at a second altitude from the earth lower than the first altitude and at a second inclination angle different from the first inclination angle.

[0006] Implementations of the disclosure may include one or more of the following optional features. Groups of communication devices may provide overlapping coverage of portions of the earth.

[0007] In some examples, one group of communication devices orbits the earth at an inclination angle equal to about 60 degrees. Additionally or alternatively, the communication devices within an orbital path or trajectory may be separated by equal distances. The system may further include a source ground station in communication with a communication device of at least one group of communication devices and a destination ground station in communication with a communication device of at least one group of communication devices.

[0008] A current communication device having possession of a communication may be in communication with a forward communication device and a rearward communication device. The forward communication device and the rearward communication device may be within the same orbital path or trajectory as the current communication device.

[0009] The communication system may further include a data processing device in communication with the source ground station, the constellation of communication devices and the destination ground station. The data processing device may determine a routing path of a communication from a source in communication with the source ground station to a destination in communication with the destination ground station. Additionally or alternatively, the data processing device may determine the routing path based on at least one of a border gateway protocol, an interior gateway protocol, maximum flow algorithm, or shortest path algorithm. In some implementations, the data processing device determines the routing path based on a scoring function of one or more of a distance between the source and the destination, a capacity of an inter-satellite link between two devices, an operational status of a communication device, and a signal strength of a communication device. The operational status of a communication device may include an active status or an inactive status of the communication device as a whole or one or more individual components of the communication device.

[0010] The first group of communication devices and the second group of communication devices may be arranged to provide at least 75% coverage of the earth at any given time. Moreover, one or more communication devices may have a rectangular or hexagonal coverage footprint of the earth.

[0011] Another aspect of the disclosure provides a method of communication. The method includes determining, at a data processing device, a routing path of a communication from a source ground station to a destination ground station through a constellation of communication devices orbiting the earth. Each communication device has a corresponding orbital path or trajectory with an inclination angle of less than 90 degrees and greater than zero degrees with respect to the equator of the earth. The constellation includes a first group of communication devices orbiting at a first altitude from the earth and at a first inclination angle and a second group of communication devices orbiting at a second altitude from the earth lower than the first altitude and at a second inclination angle different from the first inclination

angle. The method further includes instructing, using the data processing device, the source ground station to send the communication to the destination ground station through one or more communication devices of the constellation of communication devices in communication with one another.

[0012] In some implementations, the method includes instructing the source ground station to send the communication to a first communication device in the first group of communication devices. The method further includes instructing the first communication device in the first group of communication devices to send the communication to a second communication device in the first group of communication devices or a third communication device in the second group of communication devices.

[0013] The first group of communication devices and the second group of communication devices may be arranged to provide at least 75% coverage of the earth at any given time. Moreover, one or more communication devices may have a rectangular or hexagonal coverage footprint of the earth.

[0014] The details of one or more implementations of the disclosure are set forth in the accompanying drawings and the description below. Other aspects, features, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0015] FIG. **1**A is schematic view of an exemplary global-scale communication system with satellites.

[0016] FIG. **1**B is schematic view of exemplary orbital paths or trajectories of the satellites of FIG. **1**A.

[0017] FIG. **2**A is a schematic view of an exemplary first groups of satellites of the global-scale communication system.

[0018] FIG. **2**B is a schematic view of an exemplary second groups of satellites of the global-scale communication system.

[0019] FIG. **2**C is a schematic view of the exemplary first and second groups of satellites of the global-scale communication system of FIGS. **2**A and **2**B.

[0020] FIG. **3**A is a schematic view of an exemplary path between satellites of different groups where each group is at a different altitude.

[0021] FIG. **3**B is a schematic view of an exemplary earth coverage between satellites of different groups where each group is at a different altitude.

[0022] FIG. **4** is a perspective view of a satellite used in the exemplary global-scale communication system of satellites.

[0023] FIG. **5** is a schematic view of an exemplary path between satellites for sending a communication between a first user and a second user in a global-scale communication system cupboard

[0024] FIG. **6** is a schematic view of an exemplary computing device for implementing the path of a communication between a first and second user.

[0025] FIG. **7** is a schematic view of an exemplary arrangement of operations for communicating between two users.

[0026] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0027] Referring to FIGS. **1**A-**1**B, in some implementations, a global-scale communication system **100** includes satellites **200**, gateways **300** (including source ground stations **310**, destination ground stations **320**, and optionally linking-gateways **330**), and a system data processing device **110**. In some examples, the source ground stations **310** and/or the destination ground stations **320** are user terminals or gateways **300** connected to one or more user terminals. A satellite **200** may orbit the earth **30** in Low Earth Orbit (LEO) or Medium Earth Orbit (MEO) or High Earth Orbit (HEO), including Geosynchronous Earth Orbit (GEO). The satellite **200** includes an antenna **207** that receives a communication **20** from a source ground station **310** and reroutes the communication signal to a destination ground station **320**. The satellite **200** also includes a data processing device **210** that processes the received communication **20** and determines a path of the communication **20** to arrive at the destination ground station **320**. Additionally, the global-scale communication system **100** includes multiple ground stations **300**, such as a source ground station **310**, a destination ground station **320**, and optionally a linking-gateway **330**. The source ground station **310** is in communication with a first user **10***a* through a cabled, a fiber optic, or a wireless radio-frequency connection **12***a*, and the destination ground station **320** is in communication with the second user **10***b* through a cabled, a fiber optic, or a wireless radio-frequency connection **12***b*. In some examples, the communication **20** between the source ground station **310** and the first user **10***a* or the communication **20** between the destination ground station **320** and the second user **10***b* is a wireless communication **20** (either radio-frequency or free-space optical).

[0028] A satellite **200** is an object placed into orbit around the earth **30** and may serve different purposes, such as military or civilian observation satellites, communication satellites, navigations satellites, weather satellites, and research satellites. The orbit of the satellite **200** varies depending in part on the purpose that the satellite **200** is being used for. Satellite orbits **202** may be classified based on their altitude from the surface of the earth **30** as Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and High Earth Orbit (HEO). LEO is a geocentric orbit (i.e., orbiting around the earth **30**) that ranges in altitude from 0 to 1,240 miles. MEO is also a geocentric orbit that ranges in altitude from 1,200 mile to 22,236 miles. HEO is also a geocentric orbit and has an altitude above 22,236 miles. Geosynchronous Earth Orbit (GEO) is a special case of HEO. Geostationary Earth Orbit (GSO, although sometimes also called GEO) is a special case of Geosynchronous Earth Orbit.

[0029] Due to the size of the earth **30**, a large number of satellites **200** are utilized to provide signal coverage to the populated world. Satellites **200** may have an orbital path or trajectory **204** at about a 90 degree inclination angle with respect to the equator of the earth **30**, but at a 90 degree inclination angle, the satellites **200** provide coverage to non-populated areas, such as the north and south poles. It is desirable to provide a communication system that increases the satellite signal coverage of the populated world, reduces satellite collision between satellites **200** as they orbit the earth **30**, reduce the number of satellites **200** in the global-scale communication system **100**, and provide overlapping coverage to maintain satellite coverage of a portion of the

earth **30** when one of the satellites **200** covering the same portion is experiencing a malfunction.

[0030] Multiple satellites **200** working in concert form a satellite constellation. The satellites **200** within the satellite constellation may be coordinated to operate together and overlap in ground coverage to avoid communication downtime when a satellite **200** is experiencing problems (e.g., mechanical, electrical, or communication). Two common types of constellations are the polar constellation and the Walker constellation, both designed to provide maximum earth coverage while using a minimum number of satellites **200***b*. The polar constellation includes satellites **200** arranged in a polar constellation that covers the entire earth **30** and orbits the poles (e.g., the North and South poles), while the Walker constellation includes satellites **200** that cover areas below certain latitudes, which provides a larger number of satellites **200** simultaneously in view of a user **10** on the ground (leading to higher availability, fewer dropped connections).

[0031] As shown in FIGS, **1**A and **1**B, a first user **10***a* may communicate with the second user **10***b* or a third user **10***c*. Since each user **10** is in a different location separated by an ocean or large distances, a communication **20** is transmitted from the first user **10***a* through the global-scale communication system **100** to reach its final destination, i.e., the second or third users **10***b*, **10***c*. Therefore, it is desirable to have a global-scale communication system **100** capable of routing communication signal traffic over long distances, where one user location is in a location far from a source or destination ground station **310**, **320** (e.g., ocean). It is also desirable to provide reduced latency of the system **100** and enhanced security due to the use of the satellites **200**, as compared to fiber or cable-based communications. Moreover, it is desirable to have a cost effective system. As will be discussed later, a global-scale communication system **100** capable of being readily connected and provide connectivity of satellites **200** with fewer and simpler inter-satellite links per satellite **200** is also desirable. Lastly, it is desirable to have a global-communication system **100** capable of reducing the number of satellites **200** of the global communication system **100** while providing overlapping coverage of the populated areas (to compensate for any satellite **200** undergoing problems).

[0032] Referring to FIGS. **2**A-**3**B, the satellites **200** of the global-scale communication system **100** are divided into one or more groups **202**, each group **202** includes one or more satellites **200**. In some examples, each group **202** includes one or more orbital paths or trajectories **204** where each orbital path or trajectory **204** includes multiple satellites **200** spaced from one another. The satellites **200** within an orbit **204** may be separated from one another by an equal distance D**1**, D**2**. In some examples, the global-scale communication system **100** includes a first group **202***a* of satellites **200** and a second group **202***b* of satellites **200**. The first group **202***a* of satellites **200** orbit the earth **30** at a first altitude A_1; while the second group **202***b* of satellites **200** orbit the earth **30** at a second altitude A_2. The first altitude $A_1$is greater than the second altitude A_2. In some examples, where the global-scale communication system **100** includes three or more groups **202** of satellites **200**, a third group has a third altitude less than the second altitude, a fourth group has a fourth altitude less than the third altitude, and so forth. The satellites **200** may be orbiting the earth **30** within the LEO orbit, i.e., below 2,000 km (e.g., 1,300 km).

[0033] Launching the first group **202***a* of satellites **200***a* at a higher first altitude A_1 allows the global-scale communication system **100** to have fewer satellites **200** at the first altitude A_1 since the higher a satellite **200** is, the larger coverage area the satellite **200** covers. Following the first group **202***a* of satellites **200***a* launched at the first altitude A_1, the second group **202***b* of satellites **200***b* is launched and includes a larger number of satellites **200***b*, providing a bigger system bandwidth and supporting an increase number of users using the global scale communication system **100**. Referring to FIG. **3**B, the coverage area C_1 of a first satellite **200***aa* of the first group **202***a* of satellites **200***a* is greater that the coverage area C_2 of a second satellite **200***bc* of a second group **202***b* of satellites **200***b*. The first coverage area C_1 is greater than the second coverage area C_2 because of the higher altitude of the first satellite **200***aa*.

[0034] In some examples, an inclination angle of the first group **202***a* of satellites **200***a* is different than an inclination angle of the second group **200***b* of satellites **200***b*. The second group **202***b* of satellites **200***b* provides an overlapping coverage to the coverage provided by the first group of satellites **200**. The orbits **204** within a group **202** of satellites **200** may have an equal number of satellites **200** or an unequal number of satellites **200**. In some examples, the inclination angle (e.g., 60 degree angle) prevents the satellite **200** from undergoing any pitch maneuvers to increase its coverage area.

[0035] The overlapping coverage caused by the satellites **200***a* of the first group **202***a* and the satellites **200***b* of the second group **202***b*, as shown in FIG. **3**B, (e.g., shown by a first satellite **200***aa* of the first group **200***a* and two other satellites **200***ba*, **200***bb* of the second group **202***b*) allows the satellites **200** to share power across the constellation **100**, thus reducing the battery power needed for each satellite **200**. Moreover, maintaining a constant inclination angle eliminates the need for an inter-satellite gimbal. A gimbal is a pivoted support that allows the rotation of an object about a single axis, and is usually used to keep an object upright with respect to another when the object is pitching and rolling.

[0036] Power flux density (PDF) is a measure of the power that is spread evenly across a sphere having a radius from an antenna **207** (of a satellite **200**), per unit area of that sphere. The PDF depends on a total transmitted power of the signal. Therefore, due to an overlapping coverage of the earth **30**, the PDF per satellite **200** is decreased due to sharing of power between the satellites **200**.

[0037] In some implementations, the system **100** includes coverage gaps for a short duration, such as transitory coverage gaps, which may reduce the quality of service (QOS) of the signals, but also reduces the total number of satellites **200** covering the populated earth **30**.

[0038] Squint is the angle that the transmission of the satellite **200** is offset from the normal of the plane of the antenna **207** of the satellite **200**. In some examples, the squint angle of the satellites **200** is 45 degrees or less, e.g., 37 degrees.

[0039] The system data processing device **110** may be any one of the data processing devices **210** of the satellites **200**, the data processing device **110** of any of the gateways **300**, another data processing device in communication with the satellites **200** and gateways, or a combination thereof.

[0040] The first group **202***a* of satellites **200***a* and the second group **202***b* of satellites **200***b* may be arranged to

provide at least 75% coverage of the earth at any given time. Moreover, one or more satellites **200** may have a rectangular or hexagonal coverage footprint of the earth. The hexagonal coverage footprint may allow for the fewest satellites **200**. For example, 29 satellites **200** in 29 planes/orbits **204** results in a total of 841 satellites **200** for a 45 degree squint at an altitude of 925 kilometers. A higher altitude reduces the squint and satellite count. For example, at an altitude of 1300 kilometers, the communication system **100** may include 32×32 (32 satellites **200** in 32 planes/orbits **204**), resulting in a total of 1024 satellites **200** for a 35 degree squint. In some examples, the communication system **100** employs rectangular coverage pattern and may include 29×42 (29 satellites **200** in 42 planes/orbits **204**), resulting in a total of 1218 satellites **200** for a 45 degree squint. This arrangement is insensitive to true anomaly phasing, by being flexible for inserting spare satellites **200** and allowing control of conjunction misses.

[0041] The ubiquitous double coverage of the earth caused by the satellites **200***a* of the first group **202***a* and the satellites **200***b* of the second group **202***b* allows for outages of satellites **200** (individual spacecraft failures), power sharing throughout the constellation of satellites **200**, and multiple LOS opportunities for every ground-space link, offering an ability to de-conflict from "keep away" lines of sight (e.g., to Geosynchronous Satellites). The double coverage of satellites **200** also allows maximum utilization of the individual spacecraft's' footprints, with enhanced (more) overlap over populous areas, synchrony throughout the constellation, for predictable and safe conjunction miss distances at the orbit intersections, and low spacecraft count without recourse to polar inclinations that unnecessarily provide coverage of unpopulated arctic regions.

[0042] Referring to FIG. **4**, a satellite **200** includes a satellite body **206** having a data processing device **210**. The data processing device **210** executes algorithms to determine where the satellite **200** is heading. The satellite **200** also includes an antenna **207** for receiving and transmitting a communication **20**. The satellite **200** includes solar panels **208** mounted on the satellite body **206**. The solar panels **208** provide power to the satellite **200**. In some examples, the satellite **200** includes rechargeable batteries used when sunlight is not reaching and charging the solar panels **208**.

[0043] Communication security can be a major concern when building a communication network that allows different users **10** to communicate over long distances and especially continents. A communication signal being transmitted via a cable may be intercepted and the information being communicated may be retrieved. In some examples, fiber optics cables can be tapped for interception of communications using special tapping equipment. Interception of an optical fiber allows for the retrieval of all voice and data communications transmitted through the fiber cable, which in most instances may not be detected. The fiber may also be deliberately or accidentally cut or damaged, interrupting communications. Therefore, to avoid or minimize data interception or interruption, the global-scale communication system **100** limits or in some cases eliminates the use of fiber cables, providing a more secure signal trafficking. For example, the use of fiber optic cables is limited to relatively short distances from the source and destination ground stations **310**, **320** to the user **10**. The global-communication network **100** provides overlapping coverage of portions of the earth **30** to avoid situations where one satellite **200**, providing coverage to a first area, is experiencing problems that prevents the satellite **200** from receiving or transferring a communication to a user **10** located in that first area (as shown and described with respect to FIG. **3**B). Therefore, another satellite **200** covering the same area is capable of transmitting the communication **20** to the user **10**, without having to route the communication **20** so that it is transferred via cables, if available.

[0044] Referring back to FIGS. **1**-**3**B, when constructing a global-scale communications system **100** from multiple satellites **200**, it is sometimes desirable to route traffic over long distances through the system **100** by linking one satellite **200** to another. For example, two satellites **200** may communicate via inter-satellite links. Such inter-satellite linking (ISL) is useful to provide communication services to areas far from source and destination ground stations **310**, **320** and may also reduce latency and enhance security (fiber optic cables **12** may be intercepted and data going through the cable may be retrieved). This type of inter-satellite communication is different than the "bent-pipe" model, in which all the signal traffic goes from a ground-base gateway **310**, **320** to a satellite **200***b*, and then directly down to a user **10** on earth **30** or vice versa. The "bent-pipe" model does not include any inter-device communications; instead, the satellite **200***b* acts as a repeater. In some examples of "bent-pipe" models, the signal received by the satellite **200***b* is amplified before it is re-transmitted; however, no signal processing occurs. In other examples of the "bent-pipe" model, part or all of the signal may be processed and decoded to allow for one or more of routing to different beams, error correction, or quality-of-service control; however no inter-satellite communication occurs.

[0045] In some implementations, satellites **200** within the same plane **204** maintain the same position relative to their intra-plane satellite **200** neighbors. However, the position of a satellite **200** relative to neighbors in an adjacent plane **202** (within the same group **202** or a different group) varies over time. For example, referring back to FIG. **1**B, the large-scale satellite constellation **100** includes a first group **202***a* of satellites **200***a* positioned about one or more orbital paths **204***a* and a second group **202***b* of satellites **200***b* positioned about one or more orbital paths **204***b*. A satellite distance D_1 between a first satellite **200***aa* of a first orbital path **204***aa* and a second satellite **200***ab* of the same orbital path **204***aa* is the same as the distance D_i between the second satellite **200***ab* of the first orbital path **204***aa* and a third satellite **200***ac* of the first orbital path **204***aa*. The same applies for the distances between the satellites **200***b* of any orbital path (e.g., a second distance D_2 between satellites **200***b* of an orbital path **204***b* within the second group **204***b* of satellites **200***b*). Thus, satellites **200** within the same plane **204** (which corresponds roughly to a specific latitude, at a given point in time) maintain a roughly constant position relative to their intra-plane neighbors (i.e., a forward and a rearward satellite **200**), but their position relative to neighbors in an adjacent plane varies over time.

[0046] Inter-satellite link (ISL) eliminates or reduces the number of satellite **200** to gateway hops, which decreases the latency and increases the overall network capabilities. Inter-satellite links allow for communication traffic from one satellite **200** covering a particular region to be seamlessly handed over to another satellite **200** covering the same region, where a first satellite **200** is leaving the first area and a second satellite **200** is entering the area.

[0047] In some implementations, a satellite constellation includes satellites **200** having enough inter-satellite links to make the constellation fully-connected, where each satellite **200** is equipped with communication equipment and additional antennas **207** to track the location of other satellites **200** in the same plane **202** or in other adjacent planes **202** in order to communicate with the other satellites **200***b*.

[0048] In some examples, an additional antenna **207** of a current satellite **200** is capable of tracking any other satellite **200** within the view of the current satellite **200**. Thus the additional antenna **207** tracks other satellites **200** in a different orbit and/or group of satellites **200**. This increases the cost of the satellite **200**, since it adds additional hardware (e.g., the additional antennas) and computations for the satellite **200** to track satellites **200** in other planes **202** whose position is constantly changing.

[0049] In other examples, and to maintain the simplicity and low cost of design, construction, and launch of the system **100**, the system **100** includes a satellite **200** that only tracks a first satellite **200** in front or forward of it and another satellite **200** behind it or rearward of it and uses linking-gateways **330** to link a communication **20** from one plane **204** to another. In this case, and to achieve a fully-connected system **100**, the system **100** includes linking-gateways **330** that receive a communication **20** from a satellite **200** and send the communication **20** to another satellite **200** in a different plane **204**.

[0050] As shown in FIGS. **3**A and **3**B, a linking-gateway **330** may connect two satellites **200**, each being in a different group **202***a*, **202***b*. The linking-gateway **330** receives the communication **20** from the first group **202***a* of satellites **200** and sends the communication **20** to the second group **202***b* of satellites **200**. Moreover, the linking-gateway **330** may receive a communication **20** from a satellite **200** within a group **202***a*, **202***b* and send the communication **20** to another satellite **200** within the same group **202***a*, **202***b*.

[0051] In some examples, a first satellite **200***a* orbiting a plane **204***a* of the first group **202***a* receives a communication **20** from a source ground station **310** and sends the communication **20** to a second satellite **200***b* orbiting a plane **204***b* of the second group **202***b* which in turn sends the communication to a destination ground station **320**. This set-up provides a fully-connected satellite constellation at a lower price and with less complexity than the current satellites **200** that have complex algorithms to track multiple other satellites **200**, which means a signal from one satellite **200** can be sent to any other satellite **200** within the constellation. For example, within a plane **204**, each satellite **200** can link with a forward satellite **200** located in front of the current satellite **200**, and a backward satellite **200** located rearward the current satellite **200**. This reduces the number of links of each satellite **200** to other satellites **200**, thus reducing the cost of additional equipment needed for tracking more than one satellite **200**.

[0052] As shown, in some implementations, to increase coverage of the populated earth **30**, each plane **204** has an inclination with respect to the equator **40** of the earth of greater than 0 and less or equal to 60 degrees. Additionally, all the orbits **204** within a group **202** may have an equal inclination. For example, if a first orbit **204***aa* of a first group **202***a* has a first inclination of 60 degrees with respect to the equator **40**, then any other orbit **204***a* within the same group **202***a* has an inclination of 60 degrees with respect to the equator **40** of the earth **30**. Therefore, the lower inclination of the orbits **204** (as opposed to polar orbits) decreases the number of satellites **200** to about half (e.g., as compared to a polar constellation) since the constellation is only covering the populated portion of the world and avoiding wasted coverage of the non-populated areas, such as the north and south poles. Moreover, due to the decrease of the number of satellites **200**, which is a cost savings, an additional cost savings is a reduction in the cost of launching the satellites **200**.

[0053] A ground station **300** is usually used as a connector between satellites **200** and the internet, or between satellites **200** and user terminals **10**. However, the system **100** utilizes the gateways **300** as linking-gateways **330** for relaying a communication **20** from one satellite **200** to another satellite **200**, where each satellite is in a different group **202** or plane **204**. Each linking-gateway **330** receives a communication **20** from an orbiting satellite **200**, processes the communication **20** and switches the communication **20** to another satellite **200** in a different group **202** or plane **204**. Therefore, the combination of the satellite **200** and the linking-gateways **330** provide a fully-connected system **100** when using the linking-gateways **330** to fill the gap reducing the number of antennas of each satellite **200**, which track other satellite devices that are within another group **202** or plane **204** of the current satellite **200**.

[0054] FIG. **5** provides an example of communication paths **22** from a first user **10***a* to a second user **10***b*. In some examples, a first user **10***a* in Brazil wants to communicate with a second user **10***b* in the U.S.A. The first user **10***a* sends a communication **20** to the second user **10***b*. The global-scale communication system **100** receives the communication **20** at a source ground station **310** and determines (using the system data processor **110**) a path **22** leading to the destination ground station **320**. In some examples, the source ground station **310** receives the communication **20** from the first user **10***a* through a cabled or fiber optic connection **12**. In other examples, the source ground station **310** receives the communication **20** through a wireless radio-frequency communication. Similarly, the destination ground station **320** may transmit the communication **20** to the second user **10***b* through cables or fiber optic connection **12**, or through a wireless radio-frequency communication. Other examples are possible as well, such as free-space optical communications or combinations of free-space optical, cabled, wireless radio-frequency, and fiber optic communications between users **10** and gateways **300** (e.g., source and destination ground stations **310**, **320**). Moreover, a user **10** may be in a house, a residential building, a commercial building, a data center, a computing facility, or a service provider. In some examples, the source ground station **310** and/or the destination ground station **320** connects to one or more users **10**. Moreover, a user **10** may be a source ground station **310** or a destination ground station **320**.

[0055] When the system **100** receives the communication **20**, the system data processing device **110**, **210** determines the routing path **22** of the communication **20** based on one or more criterions. In some implementations, the system data processing device **110**, **210** considers, but is not limited to, border gateway protocol (which includes routing algorithms), interior gateway protocol, maximum flow problem, and/or shortest path problem.

[0056] The border gateway protocol (BGP) is an exterior gateway protocol used to exchange routing and reachability

information between autonomous systems on the internet. The protocol is classified as either a path vector protocol or a distance vector routing protocol. The path routing protocol is a computer routing protocol for maintaining the path information (of a communication **20**) that gets updated dynamically. The path routing protocol is different from the distance vector routing protocol in that each entry in its routing table includes a destination network (e.g., destination ground station **320** or end user **10***b*), the next router (e.g., the next satellite **200**), and the path **22** to reach the destination ground station **320**. The distance vector routing protocol requires that a router (e.g., satellite **200** or linking-gateway **330**) informs its neighbors (e.g., HA satellite CD **200** or linking-gateway **330**) of topology changes periodically. When the system **100** uses the distance vector routing protocol, the system **100** considers the direction in which each communication **20** should be forwarded, and the distance from its destination (current position). The system data processing device **110** calculates the direction and the distance to any other satellite **200** in the system **100**. Direction is the measure of the cost to reach the next destination; therefore, the shortest distance between two nodes (e.g., satellites **200**, gateways **300**) is the minimum distance. The routing table of the distance vector protocol of a current device (e.g., satellite **200** or gateway **300**) is periodically updated and may be sent to neighboring devices. BGP does not utilize Interior Gateway Protocol (IGP).

[0057] Interior gateway protocol (IGP) may be used for exchanging routing information between gateways (e.g., satellites **200** or linking-gateways **330**) within an autonomous system (e.g., the system **100**). This routing information can then be used to route network-level protocols like Internet Protocol (IP). By contrast, exterior gateway protocols are used to exchange routing information between autonomous systems and rely on IGPs to resolve routes within an autonomous system. IGP can be divided into two categories: distance-vector routing protocols and link-state routing protocols.

[0058] Specific examples of IGP protocols include Open Shortest Path First (OSPF), Routing Information Protocol (RIP) and Intermediate System to Intermediate System (IS-IS).

[0059] The maximum flow problem and associated algorithm includes finding a feasible flow from a single source to a single destination through a network that is maximal, where the source and the destination are separated by other devices (e.g. satellites **200**, gateways **300**). The maximum flow problem considers the upper bound capacity between the satellites **200** or gateways **300** to determine the maximum flow. The shortest path problem includes finding a shortest path **22** between the satellites or gateways **300**, where the shortest path **22** includes the smallest cost. Shortest path may be defined in terms of physical distance, or in terms of some other quantity or composite score or weight, which is desirable to minimize. Other algorithms may also be used to determine the path **22** of a communication **20**.

[0060] The algorithms used to determine the path **22** of a communication **20** may include a scoring function for assigning a score or weight value to each link (communication between the satellites **200** or between the satellites **200** and the gateways **300**). These scores are considered in the algorithms used. For example, the algorithm may try to minimize the cumulative weight of the path **22** (i.e., sum of the weights of all the links that make up the path **22**). In some implementations, the system data processor **110** considers the physical distance (and, closely related, latency) between the satellite **200** or gateway **300**, the current link load compared to the capacity of the link between the satellite **200** or gateway **300**, the health of the satellite **200** or gateway **300**, or its operational status (active or inactive, where active indicates that the device is operational and healthy and inactive where the device is not operational); the battery of the satellite **200** or gateway **300** (e.g., how long will the device have power); and the signal strength at the user terminal (for user terminal-to-satellite link).

[0061] Referring back to FIG. **5**, the system data processing device **110**, **210** may determine multiple paths **22** of the communication **20** as shown, but select one of the paths **22** based on differing factors. For example, the source ground station **310** receives the communication **20** and sends it to the nearest satellite **200***aa* in a first group **202***a*, which in turn sends it to a linking-gateway **330***a*. In other examples, the source ground station **310** sends the communication **20** to a further satellite **200***ba* within the second group **202***b* of satellites **200***b*. Each satellite **200** receiving a communication **20** sends the communication **20** (based on the discussed criteria) to another satellite **200** or linking gateway **330** until the communication reaches its final destination, the end user **10***b*. As described, the communication **20** hops planes **204** by using the linking-gateway **330**.

[0062] FIG. **6** is schematic view of an example computing device **600** that may be used to implement the systems and methods described in this document. The computing device **600** is intended to represent various forms of digital computers, such as laptops, desktops, workstations, personal digital assistants, servers, blade servers, mainframes, and other appropriate computers. The components shown here, their connections and relationships, and their functions, are meant to be exemplary only, and are not meant to limit implementations of the inventions described and/or claimed in this document.

[0063] The computing device **600** includes a processor **610**, memory **620**, a storage device **630**, a high-speed interface/controller **640** connecting to the memory **620** and high-speed expansion ports **650**, and a low speed interface **660** connecting to a low speed bus **670** and a storage device **630**. Each of the components **610**, **620**, **630**, **640**, **650**, and **660**, are interconnected using various busses, and may be mounted on a common motherboard or in other manners as appropriate. The processor **610** can process instructions for execution within the computing device **600**, including instructions stored in the memory **620** or on the storage device **630** to display graphical information for a graphical user interface (GUI) on an external input/output device, such as a display **680** coupled to high speed interface **640**. In other implementations, multiple processors and/or multiple buses may be used, as appropriate, along with multiple memories and types of memory. Also, multiple computing devices **600** may be connected, with each device providing portions of the necessary operations (e.g., as a server bank, a group of blade servers, or a multi-processor system).

[0064] The memory **620** stores information non-transitorily within the computing device **600**. The memory **620** may be a computer-readable medium, a volatile memory unit(s), or non-volatile memory unit(s). The non-transitory memory **620** may be physical devices used to store programs (e.g., sequences of instructions) or data (e.g., program state information) on a temporary or permanent basis for use by the

computing device **600**. Examples of non-volatile memory include, but are not limited to, flash memory and read-only memory (ROM)/programmable read-only memory (PROM)/erasable programmable read-only memory (EPROM)/electronically erasable programmable read-only memory (EEPROM) (e.g., typically used for firmware, such as boot programs). Examples of volatile memory include, but are not limited to, random access memory (RAM), dynamic random access memory (DRAM), static random access memory (SRAM), phase change memory (PCM) as well as disks or tapes.

[0065] The storage device **630** is capable of providing mass storage for the computing device **600**. In some implementations, the storage device **630** is a computer-readable medium. In various different implementations, the storage device **630** may be a floppy disk device, a hard disk device, an optical disk device, or a tape device, a flash memory or other similar solid state memory device, or an array of devices, including devices in a storage area network or other configurations. In additional implementations, a computer program product is tangibly embodied in an information carrier. The computer program product contains instructions that, when executed, perform one or more methods, such as those described above. The information carrier is a computer- or machine-readable medium, such as the memory **620**, the storage device **630**, or memory on processor **610**.

[0066] The high speed controller **640** manages bandwidth-intensive operations for the computing device **600**, while the low speed controller **660** manages lower bandwidth-intensive operations. Such allocation of duties is exemplary only. In some implementations, the high-speed controller **640** is coupled to the memory **620**, the display **680** (e.g., through a graphics processor or accelerator), and to the high-speed expansion ports **650**, which may accept various expansion cards (not shown). In some implementations, the low-speed controller **660** is coupled to the storage device **630** and low-speed expansion port **670**. The low-speed expansion port **670**, which may include various communication ports (e.g., USB, Bluetooth, Ethernet, wireless Ethernet), may be coupled to one or more input/output devices, such as a keyboard, a pointing device, a scanner, or a networking device, such as a switch or router, e.g., through a network adapter.

[0067] The computing device **600** may be implemented in a number of different forms, as shown in FIG. **6**. For example, it may be implemented as a standard server **600***a* or multiple times in a group of such servers **600***a*, as a laptop computer **600***b*, or as part of a rack server system **600***c*.

[0068] FIG. **7** illustrates a method **700** of communication. The method **700** includes determining **702**, at a data processing device **110**, **210**, a routing path **22** of a communication **20** from a source ground station **310** to a destination ground station **320** through a constellation of communication devices orbiting the earth **30**. Each communication device **200** (e.g., satellite) has a corresponding orbital path or trajectory **204** with an inclination angle of less than 90 degrees and greater than zero degrees with respect to the equator **40** of the earth **30**. The constellation includes a first group **202***a* of communication devices orbiting at a first altitude A_1 from the earth **30** and at a first inclination angle. A second group **202***b* of communication devices **200** orbits at a second altitude A_2 from the earth **30** lower than the first altitude A_1 and at a second inclination angle different from the first inclination angle. The method **700** also includes instructing **704**, using the data processing device **110**, **210**, the source ground station **310** to send the communication **20** to the destination ground station **320** through one or more communication devices **200** of the constellation of communication devices **200** in communication with one another.

[0069] In some examples, the method **700** includes instructing the source ground station **310** to send the communication to a first communication device in the first group **202***a* of communication devices and instructing the first communication device in the first group **202***a* of communication devices to send the communication **20** to a second communication device in the first group **202***a* of communication devices or a third communication device in the second group **202***b* of communication devices. In some examples, the communication device includes a satellite **200**. The groups **202** of communication devices may provide overlapping coverage of portions of the earth **30**.

[0070] In some implementations, one group of communication devices **202** orbits the earth **30** at an inclination angle equal to about 60 degrees. Each group **202** of communication devices **200** may include multiple orbital paths or trajectories **204**, with each orbital path **204** having multiple communication devices **200** spaced form one another. The communication devices **200** within an orbital path or trajectory **204** may be separated by equal distances D_1, D_2.

[0071] In some examples, the method **700** further includes instructing a current communication device **200** having possession of a communication **20** to send the communication **20** to a forward or rearward communication device within the orbital path or trajectory **204** of the current communication device **200**. Determining the routing path **22** of a communication **20** from the source ground station **310** to the destination ground station **320** may include determining the routing path **22** based on at least one of a border gateway protocol, an interior gateway protocol, maximum flow algorithm, or shortest path algorithm. Alternatively, determining the routing path **22** of a communication **20** from the source ground station **310** to the destination ground station **320** may include determining based on a scoring function of one or more of a distance between the source and the destination ground stations **310**, **320**, a capacity of an inter-satellite link between two devices, and operational status of a communication device, and a signal strength of a communication device.

[0072] Various implementations of the systems and techniques described here can be realized in digital electronic and/or optical circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive data and instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.

[0073] These computer programs (also known as programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms "machine-readable medium" and "computer-readable medium" refer to any

computer program product, non-transitory computer readable medium, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term "machine-readable signal" refers to any signal used to provide machine instructions and/or data to a programmable processor.

[0074] Implementations of the subject matter and the functional operations described in this specification can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Moreover, subject matter described in this specification can be implemented as one or more computer program products, i.e., one or more modules of computer program instructions encoded on a computer readable medium for execution by, or to control the operation of, data processing apparatus. The computer readable medium can be a machine-readable storage device, a machine-readable storage substrate, a memory device, a composition of matter effecting a machine-readable propagated signal, or a combination of one or more of them. The terms "data processing apparatus", "computing device" and "computing processor" encompass all apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. The apparatus can include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them. A propagated signal is an artificially generated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus.

[0075] A computer program (also known as an application, program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[0076] The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

[0077] Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for performing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. However, a computer need not have such devices. Moreover, a computer can be embedded in another device, e.g., a mobile telephone, a personal digital assistant (PDA), a mobile audio player, a Global Positioning System (GPS) receiver, to name just a few. Computer readable media suitable for storing computer program instructions and data include all forms of non-volatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto optical disks; and CD ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0078] One or more aspects of the disclosure can be implemented in a computing system that includes a backend component, e.g., as a data server, or that includes a middleware component, e.g., an application server, or that includes a frontend component, e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the subject matter described in this specification, or any combination of one or more such backend, middleware, or frontend components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network ("LAN") and a wide area network ("WAN"), an internetwork (e.g., the Internet), and peer-to-peer networks (e.g., ad hoc peer-to-peer networks).

[0079] The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other. In some implementations, a server transmits data (e.g., an HTML page) to a client device (e.g., for purposes of displaying data to and receiving user input from a user interacting with the client device). Data generated at the client device (e.g., a result of the user interaction) can be received from the client device at the server.

[0080] While this specification contains many specifics, these should not be construed as limitations on the scope of the disclosure or of what may be claimed, but rather as descriptions of features specific to particular implementations of the disclosure. Certain features that are described in this specification in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any

suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[0081] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multi-tasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0082] A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the disclosure. For example, this disclosure may be applied to high altitude pseudo-satellites (HAPSs) and/or unmanned aerial vehicles (UAVs) orbiting or moving around the earth in conjunction with or in place of satellites. Accordingly, other implementations are within the scope of the following claims. For example, the actions recited in the claims can be performed in a different order and still achieve desirable results.

What is claimed is:

1. A communication system comprising:

a constellation of communication devices orbiting earth, each communication device having a corresponding orbital path and an inclination angle with respect to the equator of the earth, the constellation comprising:

a first group of communication devices having orbital paths at a first altitude from the earth and at a first inclination angle, each orbital path of the first group of communication devices having multiple communication devices spaced apart from one another; and

a second group of communication devices having orbital paths at a second altitude from the earth lower than the first altitude and at a second inclination angle different from the first inclination angle, each orbital path of the second group of communication devices having multiple communication devices spaced apart from one another; and

at least one linking device separate from and in communication with the constellation of communication devices, the at least one linking device relaying communications between two communication devices that are in a different groups of communication devices and/or in different orbital paths,

wherein the first group of communication devices communicates with the second group of communication devices only by way of the at least one linking device.

2. The communication system of claim **1**, wherein a first communication device having a first orbital path communicates with a second communication device having a second orbital path only by way of the at least one linking device.

3. The communication system of claim **2**, wherein the first communication device and the second communication device reside in the same group of communication devices or in different groups of communication devices.

4. The communication system of claim **1**, wherein the inclination angle of each communication device is less than 90 degrees and greater than zero degrees with respect to the equator of the earth.

5. The communication system of claim **4**, wherein the inclination angle of the communication devices of one of the groups of communication devices is about 60 degrees.

6. The communication system of claim **1**, wherein the groups of communication devices provide overlapping coverage of portions of the earth.

7. The communication system of claim **1**, wherein the communication devices within each orbital path are separated by equal distances.

8. The communication system of claim **1**, wherein a current communication device having possession of a communication is in communication with a forward communication device and a rearward communication device, the forward communication device and the rearward communication device within the same orbital path as the current communication device.

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

a source ground station in communication with the constellation of communication devices;

a destination ground station in communication with the constellation of communication devices; and

a data processing device in communication with the source ground station, the constellation of communication devices, and the destination ground station, the data processing device determining a routing path of a communication from the source ground station to the destination ground station.

10. The communication system of claim **9**, wherein the data processing device determines the routing path based on a scoring function of one or more of a distance between the source and the destination, a capacity of an inter-satellite link between two devices, an operational status of a communication device, or a signal strength of a communication device, wherein the operational status of a communication device comprises an active status or an inactive status of the communication device as a whole or one or more individual components of the communication device.

11. A method comprising:

determining, at data processing hardware, a routing path of a communication from a source ground station to a destination ground station through a constellation of communication devices orbiting earth, each communication device having a corresponding orbital path and an inclination angle with respect to the equator of the earth, the constellation comprising:

a first group of communication devices having orbital paths at a first altitude from the earth and at a first inclination angle, each orbital path of the first group of communication devices having multiple communication devices spaced apart from one another; and

a second group of communication devices having orbital paths at a second altitude from the earth lower than the first altitude and at a second inclination angle different from the first inclination angle, each orbital path of the second group of communication devices having multiple communication devices spaced apart from one another; and

instructing, by the data processing hardware, the source ground station to send the communication to the destination ground station along the determined routing path through the constellation of communication devices,

wherein at least one linking device separate from and in communication with the constellation of communication devices relays communications between two communication devices that are in a different groups of communication devices and/or in different orbital paths, and

wherein the first group of communication devices communicates with the second group of communication devices only by way of the at least one linking device.

12. The method of claim **11**, wherein a first communication device having a first orbital path communicates with a second communication device having a second orbital path only by way of the at least one linking device.

13. The method of claim **12**, wherein the first communication device and the second communication device reside in the same group of communication devices or in different groups of communication devices.

14. The method of claim **11**, wherein the inclination angle of each communication device is less than 90 degrees and greater than zero degrees with respect to the equator of the earth.

15. The method of claim **14**, wherein the inclination angle of the communication devices of one of the groups of communication devices is about 60 degrees.

16. The method of claim **11**, wherein the groups of communication devices provide overlapping coverage of portions of the earth.

17. The method of claim **11**, wherein the communication devices within each orbital path are separated by equal distances.

18. The method of claim **11**, further comprising:

instructing, by the data processing hardware, the source ground station to send the communication to a first communication device in the first group of communication devices; and

instructing, by the data processing hardware, the first communication device in the first group of communication devices to send the communication to:

a second communication device in the first group of communication devices; or

a third communication device in the second group of communication devices.

19. The method of claim **11**, further comprising instructing, by the data processing hardware, a current communication device having possession of a communication to send the communication to a forward communication device or a rearward communication device within the same orbital path of the current communication device.

20. The method of claim **11**, wherein determining the routing path of the communication from the source ground station to the destination ground station is based on a scoring function of one or more of a distance between the source ground station and the destination ground station, a capacity of an inter-satellite link between two devices, an operational status of a communication device, or a signal strength of a communication device, wherein the operational status of a communication device comprises an active status or an inactive status of the communication device as a whole or one or more individual components of the communication device.

* * * * *