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(54) Title: HIGH ALTITUDE CELLULAR COMMUNICATION SYSTEM PLATFORM

(57) Abstract

A high altitude cellular communications system platform utilizing a multi-beam array antenna having an array of elements. A multi-beam array antenna and associated circuitry are mounted on a high altitude atmospheric/stratospheric platform positioned up to 150 kilometers high. A cellular communications processor controls setup and tear down of wireless communication links or calls with subscriber's personal communication devices. Vertical broadcasting provides sharp antenna radiation pattern boundaries between cells allowing for both high inter-cell resolution and small cell size. In an alternative embodiment, the cellular communications processor is located on the ground and communicates with the high altitude platform via a communications link. The system can operate independently or in conjunction with ground based cellular systems and Low Earth Orbit Satellite systems using common personal communication devices.

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HIGH ALTITUDE CELLULAR COMMUNICATION SYSTEM PLATFORM

FIELD AND BACKGROUND OF THE INVENTION

Today, the demand for wireless cellular communications, including personal communication services (PCS), is growing at a faster and faster rate. United States PCS usage alone is currently estimated at 31 million subscribers by the year 2003 and 150 million in the long run. The PCS international industry is expected to be worth 195 billion dollars by the end of the decade. High demand currently exists for both narrowband communications (i.e. voice, picture phone, paging and private radio) and wideband communications (i.e. video, multimedia and high bandwidth digital data). A limited frequency band, however, has been allocated to cellular communication. In the United States, the Federal Communications Commission (FCC) has recently allocated at present 3 MHz centered around 900 MHz for narrowband communications and 120 MHz centered around 2 GHz for wideband communications.

Without cellular technology, a very limited number of calls could take place simultaneously in the same region. Cellular technology greatly expands the number of calls that can simultaneously be made. Regions with high demand for cellular telephone subscriptions are broken down geographically into smaller sized cells. A large city or densely populated region may be divided into a large number of cells. Each cell has a base station and is able to support a finite number of simultaneous calls. Base stations include transmission and receiving equipment for communicating with subscriber cellular equipment, such as telephones. Each base station maintains communication links with all other cells as well as maintaining access to the standard telephone network. Both base station transmitters and cellular communication devices transmit radio signals at a reduced power level. Transmitted power is reduced in order to ensure that communications taking place in one cell do not interfere with communications in other cells. It is this feature of cellular communications that makes it possible to reuse the limited frequency spectrum available in cells that are remote enough to avoid interference and crosstalk between them.

The limitation of conventional cellular communication systems is that it is very difficult to limit the range of the base station radio transmitters and at the same time maintain a uniform level of radio transmission and reception within the cell, a necessary condition for maintaining reliable communications. Radio waves emitted from the antennas of base station transmitters decay gradually, typically at a rate of $1/R^4$, R being the distance from the base station antennas, and do not maintain a uniform level within the cell. In addition, due to destructive scattering, reflections and wave interference (especially in areas with numerous structures) the radio signal level at each point in the cell is unpredictable and is susceptible to periodic fading and statistical variation. The situation becomes worse when considering hand held personal cellular or motor vehicle cellular communications, both of which are mobile. As the cells become smaller, this problem becomes more and more acute. This is due to the larger affect of statistical variation of the communication range. This is a major obstacle for increasing the volume of cellular communication service. With present day technology, often the entire available frequency spectrum has been used. The only way to increase the service volume is by reducing the size of the cells.

The difficulty in maintaining both a uniform broadcasting level within the cell and a sharp cutoff beyond the cell boundary, results in problematic and poor quality cellular communications. Due to the lack of a sharp cutoff in the power level across cell boundaries, the reuse rate of the spectral bandwidth is reduced. Typically, the reuse rate in a hexagonal lattice cell arrangement is less than 1:7. This means that each cell, in a group of seven neighboring cells, must use different portions of the available spectrum. Spectral band reuse can only take place in the adjacent group of seven cells. Crosstalk, however, still occurs, reducing the quality of the communications.

Another disadvantage of conventional cellular technology is that due to the need to maintain a minimum power level at cell boundaries, destructive wave interference sites and areas shadowed by building structures, the power of the base station transmitter must be high. In densely populated areas high transmitted power is a common source of concern with residents residing near the base station apprehensive about radiation hazards.

In addition, in order to maintain radio communication with subscribers at any geographical point in the cell at all times, the power of the subscriber's radio transmitter must be higher than essentially required. This is due to nonuniformity within the cell of the reception sensitivity of the base station receiver. This nonuniformity is similar in nature to the transmission nonuniformity described above. Reception sensitivity nonuniformity and the consequent need to increase the power of the subscriber's radio transmitter causes personalized cellular communications devices to be heavier and more expensive than necessary, in addition to generating complaints from radiation hazard conscious subscribers.

SUMMARY OF THE INVENTION

The present invention overcomes the disadvantages and limitations of the prior art by providing a system of cellular communications employed at high altitude on a floating, flying or hovering platform that utilizes multi-beam array antenna technology. The platform consolidates many conventional base stations into one system, eliminating the need for redundant equipment.

A main advantage of utilizing a multi-beam array antenna, mounted on a high altitude platform, is that the array can be designed to have radiation lobes (i.e. beams) with sharp boundaries between cells. The ground can, therefore, be illuminated by a beam with a slowly varying distribution, greatly reducing the effects of diffractions from obstacles, multiple scattering and rapid variations and fading of the signal. This advantage is due mostly to the effects of communicating in the vertical direction, rather than in the horizonal direction. An added benefit is that in military applications, vertical communication provides better electronic intelligence (ELINT) security and better immunity to jamming and other types of electronic warfare.

In addition, the shape of each individual beam can be optimized, using aperture synthesis techniques, to increase insulation and reduce crosstalk between cells. This allows both the base station transmitter and the personal communications devices, to transmit and receive power at a reduced level resulting in lighter weight portable radio devices, longer battery life, lower cost, less health risk from radiation hazards, etc. The more efficient upwards looking antennas included in personal communication devices of such a system further reduce the required transmit power resulting in the same benefits in connection with reduced transmit power levels.

The boundaries for the entire service area can be easily changed by transporting the high altitude platform to a new location. This mobility also allows cellular service to be setup quickly to provide coverage for new service areas, on a temporary basis over disaster areas (e.g., earthquakes, floods, fires or other events leading to outage of ground based communication or requiring major evacuation), special events and for military applications.

Use of multi-beam array antenna technology allows cells to be reassigned dynamically. Cell coverage (e.g., cell size reduction and expansion) can be electronically controlled and adjusted in response to, for example, changes in communication load distribution, emergencies, etc.

In addition, reliability and stability are increased and the area of service coverage expanded by connecting, either physically or electronically, two or more floating platforms controlled by a central computer.

Hence, there is provided according to the teachings of the present invention, a high altitude platform cellular communications system comprising a cellular communications processor for controlling a plurality of wireless radio communication links between a plurality of cellular communication devices and the system, multi-beam array antenna control circuitry coupled to the cellular communications processor, the multi-beam array antenna control circuitry for controlling radio frequency transmission from and reception to the high altitude cellular communications system, multi-beam array circuitry coupled to the multi-beam array antenna control circuitry, the multi-beam array circuitry for simultaneously generating a plurality of transmission signals and for simultaneously receiving a plurality of reception signals, a multi-beam array antenna coupled to the multi-beam array circuitry, the multi-beam array antenna for simultaneously generating a plurality of independent beams for transmission and reception of radio signals to and from assigned terrestrial cells, and a high altitude platform for supporting the high altitude cellular communications system at a predetermined altitude, the high altitude platform for approximately maintaining the position of the high altitude cellular communications system at the predetermined altitude and horizontal position.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawing, wherein:

FIG. 1 is a block diagram of a preferred embodiment of the present invention illustrating an airborne based cellular communications processor; and

FIG. 2 is a block diagram of a preferred embodiment of the present invention illustrating a ground based cellular communications processor.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention is of a cellular communications system mounted on a high altitude platform and utilizing a multi-beam array antenna to broadcast a multitude of signals simultaneously to cells located on the ground.

The principles and operation of the present invention may be better understood with reference to the drawing and the accompanying description.

A block diagram of an embodiment of the present invention is shown in Figure 1. This embodiment includes an airborne based cellular communications processor **26** at the core of cellular communications system **10**. Coupled to airborne cellular processor **26** is multi-beam array (MBA) antenna control circuitry **30**. Coupled to MBA antenna control circuitry **30** is multi-beam array (MBA) radio frequency (RF) antenna circuitry **24**. Coupled to MBA RF antenna circuitry **24** is an MBA antenna **14**. MBA antenna **14** includes a plurality of array elements **16**. The entire system is mounted on a high altitude platform **12** that can either float, hover or fly over a certain area on the ground. Platform **12** may be a blimp, drone, airplane, remotely piloted vehicle (RPV), helicopter or the apparatus for supporting an unmanned airborne vehicle disclosed in U.S. Patent No. 5,074,489, issued to Gamzon, entitled Method And System For

Supporting An Airborne Vehicle In Space. A preferred embodiment includes high altitude platform **12** disclosed in U.S. Patent No. 5,074,489. System **10** maintains a connection to an external communications network **40**, which may include the standard telephone network, a video network, a fiber optic network, a computer data network and/or other types of communications networks. A ground station functions in maintaining the link between system **10** and external communications network **40**. A ground link controller located on platform **12** controls communications between platform **12** and the ground station. A satellite link controller located on platform **12** controls communications between platform **12** and one or more satellites **46**.

As previously described, conventional cellular technology works by dividing a geographical area to be covered into small sized cells. Within each cell is placed a base station transmitter and receiver. Both cellular phone transmitters and base station transmitters transmit at a reduced power level suitable for the particular cell size. This scheme allows the available frequency spectrum to be reused by distant cells. A processor controls the setup and tearing down of each call made through subscriber cellular equipment.

Instead of having a multitude of land based transmitters and receivers, spread out over a large geographic area, system **10** joins them together into one central location. MBA antenna **14**, when connected to MBA RF antenna circuitry **24**, is capable of generating many independent antenna radiation beams **20** simultaneously. MBA RF Antenna circuitry **24** is an RF beam forming network, typically including a Rotman lens or a Butler RF matrix, and an RF switching matrix. RF antenna circuitry **24** is capable of simultaneously generating all beams **20** of MBA antenna **14**. The aperture distributions across all array elements **16** for all beams are superimposed on each other, making use of the same physical aperture which is common to all beams **20**. Each beam **20** is assigned a transmit/receive port in RF antenna circuitry **24**. Each transmit/receive port is connected to a corresponding port of MBA control circuitry **30**. MBA control circuitry **30** controls MBA antenna circuitry **24** by channeling signals to and from transmit/receive ports of MBA antenna circuitry **24**. Each beam **20** covers a single cell **22**. Thus, each beam replaces one terrestrial base station. RF antenna circuitry **24** with many beams enables MBA antenna **14** to cover an area with many cells. In addition, coverage can be expanded by joining multiple platforms **12** together. Each platform **12** is able to communicate with other platforms, satellites and ground stations, forming a network.

In a preferred embodiment, shown in Figure 1, airborne cellular communications processor **26** is located on high altitude platform **12**, preferably up to 150 kilometers high. Ground station **42** communicates with a ground link controller **56** located on high altitude platform **12** via a suitable communications link such as RF, optical, microwave, etc. In addition, an optional satellite link controller **54** communicates with one or more satellites **46**. Airborne cellular communications processor **26** controls the establishment and breakdown of calls. Airborne processor **26** communicates with ground station **42**, though ground link controller **56**. Ground station **42** maintains communication links with external communications network **40**. External communications network **40** may include the standard telephone network or other types of networks such as, video, fiber and/or data.

Similarly to maintaining communication links with satellites, high altitude platform may include an auxiliary radio link for communicating with planes, ships or boats. Alternatively, MBA antenna **14** may be used to communicate with planes, ships or boats. The auxiliary radio link would be coupled to communications processor **26**.

In a preferred embodiment, shown in Figure 2, cellular communications processor **48** is ground based, communicating with airborne cellular communications processor **58** through ground link controller **52**. Optional satellite link controller **50** maintains communications with one or more satellites **46**.

The laws of diffraction can be utilized to estimate the number of cells that be can be serviced by MBA antenna **14**. The following definitions apply:

N = Number of cells

D = Cell diameter

d = Antenna array diameter

h = Platform height

F = Factor < 1

λ = Radio wavelength

$\Delta\theta$ = Angular extent of the entire service area (including N cells) from the high altitude platform

$$D = F\lambda h/d$$

$$N = (\Delta\theta d/F\lambda)^2$$

As an example, assume λ = 15 cm (for a frequency of 2 GHz), d = 5 m, F = 1 and $\Delta\theta$ = 1 rad (considering viewing angles smaller than 30° relative to the vertical direction on all cells). The number of cells, N, is approximately 1,000 (i.e. a grid of cells approximately 32 x 32).

Platform height can also be estimated given the cell diameter. The platform height is primarily limited by the cell diameter and antenna array size, as shown in the following relationship:

$$h = Dd/(F\lambda)$$

Lower heights or larger antenna arrays will be required for smaller cell sizes. If high altitude platform **12** is at a height h = 20 km, cell size **22** dimension D is calculated to be 600 m.

The example above is realistic for the following reasons. Generally, global winds are at a minimum between 17 and 22 km high, making it easier to maintain the position and orientation of high altitude platform **12**. The density of air at this altitude is low but still high enough to support a number of practical platforms **12** enumerated previously. In addition, the distance of 20 km is close enough to the earth, making it possible to energize the platform by power transmission or other means. As cell size is reduced, the uniformity of transmission/reception levels inside cells **22** and the low inter-cell interference cause the general performance of system **10** to remain high. This is in direct contrast to the negative effects of reduced cell size associated with conventional cellular technology. Note that because of practical limitations on the size of antenna array **14**, platforms that are located at heights much larger than that of the example will generate cells that are much larger than 600 meters and will not match the increasing need for lower cell sizes.

In a preferred embodiment, cellular communications system **10** is deployed together with specialized personal communication devices (i.e. personal cellular telephones or computer or video devices) distributed to subscribers. The high altitude platform **12** is positioned approximately vertical (i.e. 45° to 90° off the horizon) relative to most cells **22**. MBA antenna **14** transmits and receives using circularly polarized radiation. The personal communication devices are equipped with an upwards looking antenna which can receive circularly polarized radiation and an optional sideways looking antenna which can receive linear polarization. The ability to receive linearly polarized radiation, in addition to circularly polarized radiation, allows the personal communications devices to also be used with conventional ground base stations. The feature of an upwards looking antenna made available to subscribers of the high altitude platform cellular service allows them to be used with satellite global communications systems, such as Motorola's Iridium system or Teledesic's Global Wireless Broadband Network, thereby enhancing the services available to subscribers with the same radio communication device they already own.

In another embodiment, the number of available calls or channels can be doubled by simultaneously utilizing both clockwise and counterclockwise circular polarization. Half the personal communication devices would be outfitted with a clockwise circularly polarized antenna and the other half with a counter clockwise circularly polarized antenna. Signals having clockwise circular polarization, for example, cannot be received by phones having counter clockwise circularly polarized antennas, and vice versa.

Another application of the system **10** is as an add-on to a global satellite system. Typically, global satellite systems have very large cells in sparsely populated areas. However, they utilize personal communication devices having upwards looking antennas. Thus, high altitude platform **12**, positioned at a relatively low altitude compared to global satellite systems, can use the same phones already owned by subscribers, such as of low earth orbiting satellite systems, to provide higher resolution cell coverage in specifically chosen high traffic areas.

As stated previously, current cellular communications services cannot provide wideband services, such as video communication (e.g., traffic control of road junctions, picturephone, video on demand, etc.), computer communication, multimedia services, etc. Such wide bandwidth services would consume the available spectrum unless very small cells with high reusability of the spectrum were employed. Cellular communications system **10** can provide such wideband services due to its ability to provide small size cells having sharp beam cutoffs between cells. An advantage of this feature is that system **10** can be employed in delivering wideband communications services. These services may be integrated in present state of the art communications networks (e.g., the Internet), making it possible to provide a large number of subscribers with enhanced quality and high speed transmission of pictures, real time video and large computer data files. Such services can also be provided through other video and multimedia vendors, including cable TV, or video networks (which can provide personal movie order transmissions), picturephone networks, etc. In addition, it may be possible that the orthogonality between the polarizations of the vertically transmitting system and the standard horizontally transmitting system, may allow the reuse of the entire frequency bandwidth allocated for ground based services (including the telephone service bands). In addition, system **10** can be employed to respond quickly to the demand for new service areas.

Another application of cellular communications system **10** is as a complement to conventional existing ground based cellular networks. Ground based cellular communications systems can benefit from the flexible cell definition of system **10**. Service in congested areas is improved by the ability to better define cell boundaries and to create smaller cells. In addition, new service areas can quickly be covered by system **10**, on a temporary basis, until permanent base station equipment is installed. System **10** can also provide service to cells in which it would be difficult to locate a base station because of real estate problems or because of objections by local residents. Ground base stations that develop problems and cease to operate can be taken offline and temporarily replaced by system **10** until fixed and placed back in service.

In applications where system **10** complements conventional ground base stations, MBA antenna **14** must transmit and receive vertically polarized radiation in an almost horizontal direction. This makes it necessary to position floating platform **12** at some distance from the service area (i.e. less than 45° above the horizon) and to cause antenna array **14** transmit and receive nearly vertically polarized radiation. This allows system **10** to communicate with conventional personal communications devices. This will, however, reduce the number of available cells that can be serviced by system **10**. Alternatively, the personal communications devices may be equipped with both horizontal and vertical looking antennas and platform **12** may still be placed approximately above the service area.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

WHAT IS CLAIMED IS:

1. A high altitude platform cellular communications system comprising:

a cellular communications processor for controlling a plurality of wireless radio communication links between a plurality of cellular communication devices and the system;

multi-beam array antenna control circuitry coupled to said cellular communications processor, said multi-beam array antenna control circuitry for controlling radio frequency transmission from and reception to the high altitude cellular communications system;

multi-beam array circuitry coupled to said multi-beam array antenna control circuitry, said multi-beam array circuitry for simultaneously generating a plurality of transmission signals and for simultaneously receiving a plurality of reception signals;

a multi-beam array antenna coupled to said multi-beam array circuitry, said multi-beam array antenna for simultaneously generating a plurality of independent beams for transmission and reception of radio signals to and from previously assigned terrestrial cells; and

a high altitude platform for supporting the high altitude cellular communications system at a predetermined altitude, said high altitude platform for approximately maintaining the position of the high altitude cellular communications system at said predetermined altitude and horizontal position.

2. The cellular communications system of claim 1, wherein said transmission and reception signals include circularly polarized radiation broadcast to and from said cellular communication devices in a vertical direction.

3. The cellular communications system of claim 1, wherein said transmission and reception signals include both clockwise and counterclockwise circularly polarized radiation broadcast to and from said cellular communication devices in a vertical direction.

4. The cellular communications system of claim 1, wherein said transmission and reception signals include linearly polarized radiation broadcast to and from conventional cellular communication devices and said cellular communication devices in a nearly horizontal direction.

5. The cellular communications system of claim 1, wherein said cellular communication devices receive and transmit clockwise circularly polarized radiation broadcast to and from said multi-beam array antenna in a vertical direction.

6. The cellular communications system of claim 1, wherein said cellular communication devices receive and transmit counterclockwise circularly polarized radiation broadcast in a vertical direction.

7. The cellular communications system of claim 1, wherein said cellular communication devices receive and transmit linearly polarized radiation broadcast in a nearly horizontal direction.

8. The cellular communications system of claim 1, wherein said cellular communications devices receive and transmit circularly polarized radiation and linearly polarized radiation.

9. The cellular communications system of claim 1, wherein said high altitude platform maintains an altitude range up to 150 kilometers.

10. The cellular communications system of claim 1, wherein said high altitude platform includes a drone.

11. The cellular communications system of claim 1, wherein said high altitude platform includes an aerostat.

12. The cellular communications system of claim 1, wherein said high altitude platform includes an unmanned airborne vehicle.

13. The cellular communications system of claim 1, wherein said cellular communications processor includes an airborne cellular communications processor located on said high altitude platform.

14. The cellular communications system of claim 13, further comprising a ground station for maintaining communications with an external communications network, said ground station communicating with said airborne cellular communication processor through a ground link controller.

15. The cellular communications system of claim 1, wherein said cellular communications processor includes a ground portion and an airborne portion located on said high altitude platform, said ground portion communicating with said airborne portion through a ground link controller.

16. The cellular communications system of claim 15, further comprising a ground station for maintaining communications with an external communications network.

17. The cellular communications system of claim 1, further comprising a satellite link controller for communicating with one or more satellites.

18. The cellular communications system of claim 1, further comprising communications links with airplanes, ships and boats utilizing said MBA array antenna.

19. The cellular communications system of claim 1, further comprising an auxiliary radio link for providing communications with airplanes, ships and boats.

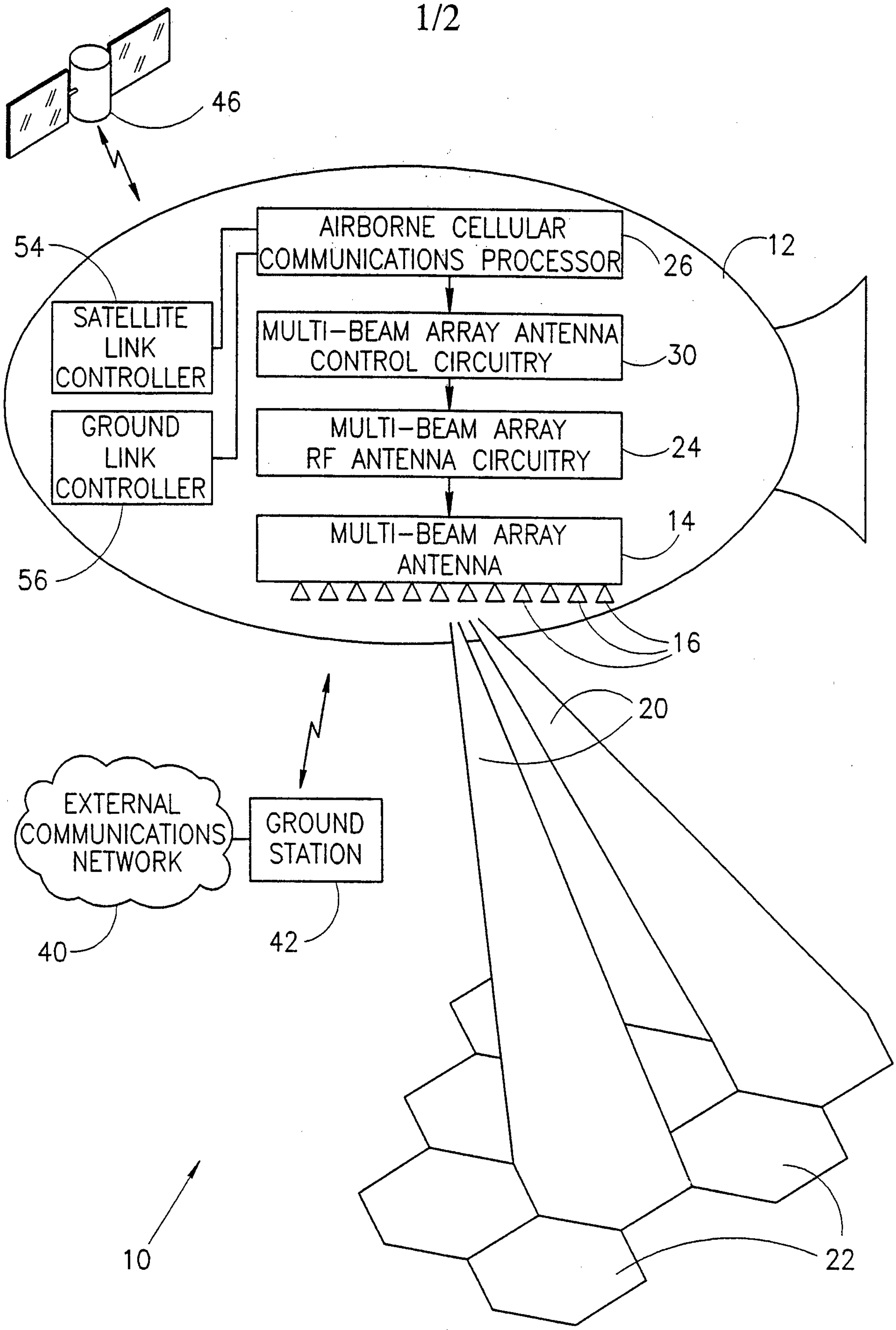
46
AIRBORNE CELLULAR COMMUNICATIONS PROCESSOR
26
12
54
SATELLITE LINK CONTROLLER
MULTI-BEAM ARRAY ANTENNA CONTROL CIRCUITRY
30
GROUND LINK CONTROLLER
MULTI-BEAM ARRAY RF ANTENNA CIRCUITRY
24
14
MULTI-BEAM ARRAY ANTENNA
56
16
20
EXTERNAL COMMUNICATIONS NETWORK
GROUND STATION
40
42
10
22

FIG.1

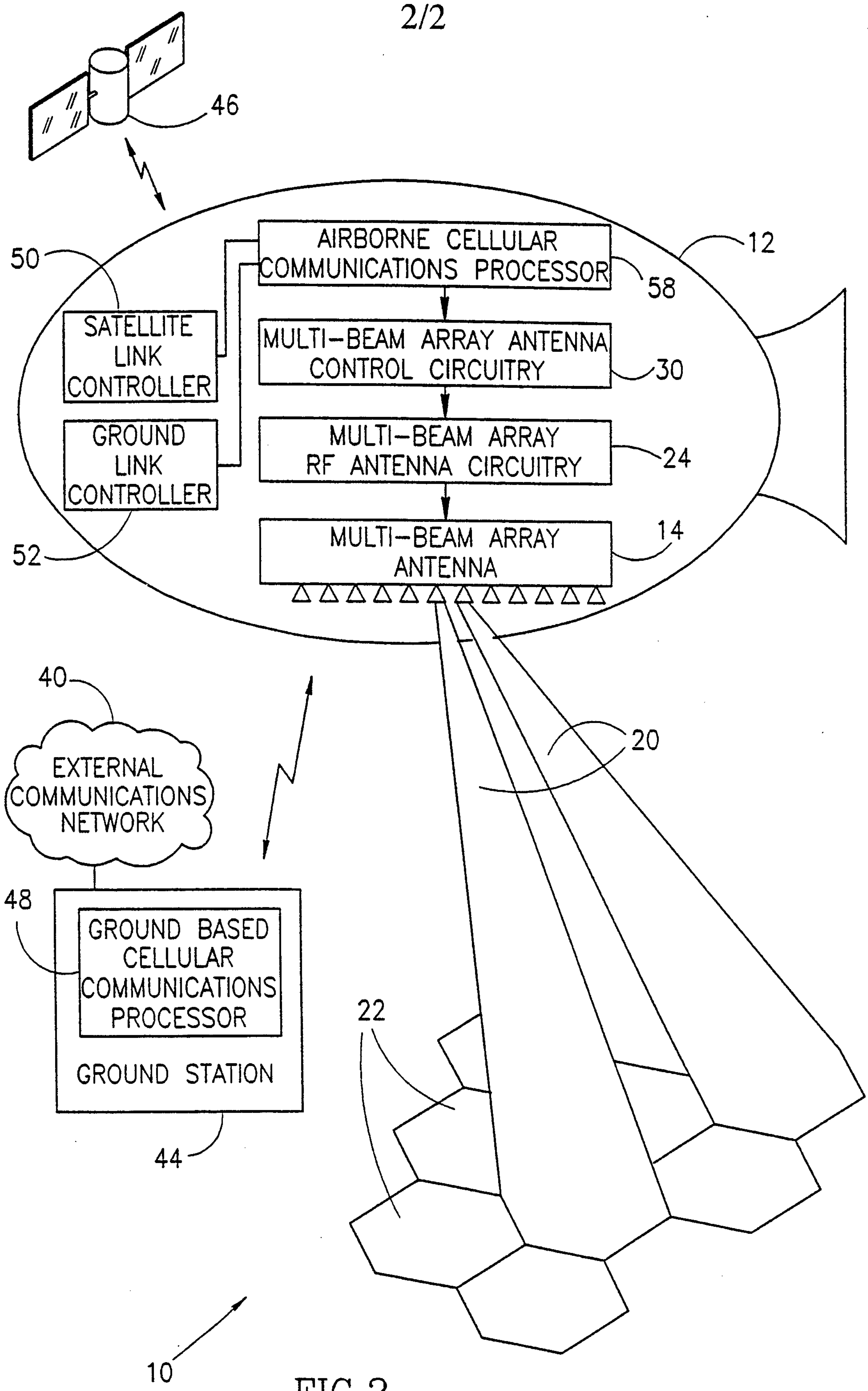
46
50
12
AIRBORNE CELLULAR COMMUNICATIONS PROCESSOR
58
SATELLITE LINK CONTROLLER
MULTI-BEAM ARRAY ANTENNA CONTROL CIRCUITRY
30
GROUND LINK CONTROLLER
MULTI-BEAM ARRAY RF ANTENNA CIRCUITRY
24
52
MULTI-BEAM ARRAY ANTENNA
14
40
EXTERNAL COMMUNICATIONS NETWORK
20
48
GROUND BASED CELLULAR COMMUNICATIONS PROCESSOR
GROUND STATION
22
44
10

FIG.2