

CLOSED LOOP POWER CONTROL FOR LOW EARTH ORBIT SATELLITE
COMMUNICATIONS SYSTEM

5

FIELD OF THE INVENTION:

10 This invention relates in general to repeater-based communication systems and, in particular, to satellite-based communications systems having bidirectional communication signal links between one or more satellites and at least one ground station.

15 BACKGROUND OF THE INVENTION:

Satellite-based communications systems are well are represented in the prior art. By example, reference is made to U.S. Patent No. 5,303,286, which issued on April 12, 20 1994 to one of the inventors of this patent application, and which is entitled "Wireless Telephone/Satellite Roaming System". Reference is also made to the numerous U.S. Patents, foreign patents, and other publications that are of record in U.S. Patent 5, 303,286.

25

Low earth orbit satellite systems have been proposed for worldwide for mobile, cellular-like communications. These systems provide an ability to use low cost, hand-held communication devices, or user terminals, for communicating 30 via satellite to parties in remote, rural, suburban and other environments.

As one example, user links to and from one or more satellites may operate on a relatively low frequency, such 35 as UHF signal. The user links are connected by the one or more satellites to ground station-originated feeder links

that operate at a higher frequency, e.g., 3 GHz to 40 GHz or more. The feeder links are connected to a terrestrial gateway which allows the user to gain access to the public switched telephone network (PSTN), a private network, or
5 some other terrestrial communications facility.

In general, if the feeder link frequency is below 7 GHz there is small potential for signal impairment. However, for frequencies above 7 GHz the effect of rain on the links
10 to and from a satellite becomes increasingly significant. Research by NASA and others quantified this rain effect and have found the impairment to be more severe in what are termed 'rain cells' that are distributed around the site of a satellite uplink transmitter operating
15 above 7 GHz.

A further consideration in a wireless communication system is the control of transmission power. By example, individual user links may be power controlled by a central
20 site, such as a base station, after link impairment information between the user terminal and the base station is exchanged. This technique is generally referred to as user terminal power control. A function of this power control is to mitigate fading caused by trees, buildings
25 and other RF-impairing factors within the user link. These impairments have the characteristic of reducing the signal power level to a lower level. To compensate for the reduction in signal level, the user terminal can be commanded to increase its transmitted power.
30 Correspondingly, the user terminal may be able to request that the central station transmit at a higher power level.

However, and in a satellite-based communication system that uses satellites as repeaters, an increase in transmitted
35 power from the user terminal or from a ground station, such as a gateway, can result in increased power being required for the satellite repeater. In that satellite power is a

primary resource to be provided to and partitioned between many users, any increase in the power consumption of the satellite is undesirable. Furthermore, and for battery-powered user terminals, an increase in transmission power
5 can have a detrimental impact on the number and duration of calls that can be made before the battery is required to be recharged.

This problem is compounded if the feeder link itself
10 becomes impaired, in that the effect will be a reduction in signal power in all associated user links. To compensate for the reduction in signal power, all user terminals may request the ground station to increase its output power, thereby significantly increasing the satellite power
15 consumption.

It is therefore desirable to provide a power control function for a satellite-based communications system that overcomes these and other problems.

20

SUMMARY OF THE INVENTION

This invention is directed to a satellite communication system, and a method executed by same, for providing
25 adaptive closed loop power control. In accordance with a method of this invention for operating a satellite communication system having at least one satellite and at least one ground station, the following steps are executed. A first step transmits an uplink reference signal with a
30 first frequency from the ground station to the satellite. The uplink reference signal experiences an attenuation between the ground station and the satellite due to, by example, a rain cell. A next step receives the reference signal with the satellite and repeats the reference signal
35 with a second frequency as a downlink reference signal that is transmitted from the satellite. The second frequency is less than the first frequency and is not significantly

impaired or attenuated by the rain cell. The downlink reference signal is transmitted with a power that is a function of the power of the received uplink reference signal. A next step receives the downlink reference signal and determines from the received downlink reference signal an amount of attenuation that was experienced at least by the uplink reference signal between the ground station and the satellite. A next step adjusts a transmitted power of the uplink reference signal in accordance with the determined amount of attenuation so as to substantially compensate for the attenuation.

In a further aspect this invention teaches methods and apparatus using a spread spectrum downlink power monitor to mitigate rain loss in a low earth orbiting satellite communication system.

Further in accordance with this invention there is provided a satellite communication system that includes at least one satellite communication signal repeater; at least one ground station for transmitting a feeder link comprised of a plurality of communication signals to the at least one satellite communication signal repeater; and a plurality of user terminals each receiving one of the communication signals over a user link from the at least one satellite communication signal repeater. In accordance with this invention the satellite communication system further includes a closed loop power control system comprising a plurality of inner loops, individual ones of which operate to compensate one of the user links for communication signal impairments occurring at least between the user terminal and the at least one satellite communication repeater, and an outer loop which operates to compensate all of the user links for feeder link impairments occurring between the at least one ground station and the at least one satellite communication signal repeater.

BRIEF DESCRIPTION OF THE DRAWINGS

The above set forth and other features of the invention are made more apparent in the ensuing Detailed Description of the Invention when read in conjunction with the attached Drawings, wherein:

Fig. 1 is block diagram of a satellite communication system that is constructed and operated in accordance with a presently preferred embodiment of this invention;

Fig. 2 is a block diagram of one of the gateways of Fig. 1;

Fig. 3A is a block diagram of the communications payload of one of the satellites of Fig. 1;

Fig. 3B illustrates a portion of the beam pattern that is transmitted from one of the satellites of Fig. 1;

Fig. 4 is a block diagram that depicts the ground equipment support of satellite telemetry and control functions;

Fig. 5 is block diagram of the CDMA sub-system of Fig. 2;

Fig. 6 is a block diagram illustrating the satellite communication system having an adaptive power control function in accordance with this invention;

Fig. 7 is a block diagram that illustrates in greater detail the components of the adaptive power control function;

Fig. 8 is a logic flow diagram that illustrates a power control method of this invention; and

Fig. 9 depicts a two-level adaptive power control loop of this invention having an outer, global feeder link power

control loop to compensate for bulk power impairments and a plurality of inner, user link power control loops to compensate for individual user link power impairments.

5

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 illustrates a presently preferred embodiment of a satellite communication system 10 that is suitable for use with the presently preferred embodiment of the adaptive power control function of this invention. Before describing this invention in detail, a description will first be made of the communication system 10 so that a more complete understanding may be had of the power control function.

15 The communications system 10 may be conceptually subdivided into a plurality of segments 1, 2, 3 and 4. Segment 1 is referred to herein as a space segment, segment 2 as a user segment, segment 3 as a ground (terrestrial) segment, and segment 4 as a telephone system infrastructure segment.

20

In the presently preferred embodiment of this invention there are a total of 48 satellites in, by example, a 1414 km Low Earth Orbit (LEO). The satellites 12 are distributed in eight orbital planes with six equally-spaced satellites per plane (Walker constellation). The orbital planes are inclined at 52 degrees with respect to the equator and each satellite completes an orbit once every 114 minutes. This approach provides approximately full-earth coverage with, preferably, at least two satellites in view at any given time from a particular user location between about 70 degree south latitude and about 70 degree north latitude. As such, a user is enabled to communicate to or from nearly any point on the earth's surface within a gateway (GW) 18 coverage area to or from other points on the earth's surface (by way of the PSTN), via one or more gateways 18 and one or more of the satellites 12, possibly also using a portion of the telephone infrastructure segment 4.

35

It is noted at this point that the foregoing and ensuing description of the system 10 represents but one suitable embodiment of a communication system within which the teaching of this invention may find use. That is, the specific details of the communication system are not to be read or construed in a limiting sense upon the practice of this invention.

Continuing now with a description of the system 10, a soft transfer (handoff) process between satellites 12, and also between individual ones of 16 spot beams transmitted by each satellite (Fig. 3B), provides unbroken communications via a spread spectrum (SS), code division multiple access (CDMA) technique. The presently preferred SS-CDMA technique is similar to the TIA/EIA Interim Standard, "Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System" TIA/EIA/IS-95, July 1993, although other spread spectrum and CDMA techniques and protocols can be employed.

The low earth orbits permit low-powered fixed or mobile user terminals 13 to communicate via the satellites 12, each of which functions, in a presently preferred embodiment of this invention, solely as a "bent pipe" repeater to receive a communications traffic signal (such as speech and/or data) from a user terminal 13 or from a gateway 18, convert the received communications traffic signal to another frequency band, and to then re-transmit the converted signal. That is, no on-board signal processing of a received communications traffic signal occurs, and the satellite 12 does not become aware of any intelligence that a received or transmitted communications traffic signal may be conveying.

Furthermore, there need be no direct communication link or links between the satellites 12. That is, each of the satellites 12 receives a signal only from a transmitter

located in the user segment 2 or from a transmitter located in the ground segment 3, and transmits a signal only to a receiver located in the user segment 2 or to a receiver located in the ground segment 3.

5

The user segment 2 may include a plurality of types of user terminals 13 that are adapted for communication with the satellites 12. The user terminals 13 include, by example, a plurality of different types of fixed and mobile user terminals including, but not limited to, handheld mobile radio-telephones 14, vehicle mounted mobile radio-telephones 15, paging/messaging-type devices 16, and fixed radio-telephones 14a. The user terminals 13 are preferably provided with omnidirectional antennas 13a for bidirectional communication via one or more of the satellites 12.

It is noted that the fixed radio-telephones 14a may employ a directional antenna. This is advantageous in that it enables a reduction in interference with a consequent increase in the number of users that can be simultaneously serviced with one or more of the satellites 12.

It is further noted that the user terminals 13 may be dual use devices that include circuitry for also communicating in a conventional manner with a terrestrial cellular system.

Referring also to Fig. 3A, the user terminals 13 may be capable of operating in a full duplex mode and communicate via, by example, L-band RF links (uplink or return link 17b) and S-band RF links (downlink or forward link 17a) through return and forward satellite transponders 12a and 12b, respectively. The return L band RF links 17b may operate within a frequency range of 1.61 GHz to 1.625 GHz, a bandwidth of 16.5 MHz, and are modulated with packetized digital voice signals and/or data signals in accordance

with the preferred spread spectrum technique. The forward S band RF links 17a may operate within a frequency range of 2.485 GHz to 2.5 GHz, a bandwidth of 16.5 MHz. The forward RF links 17a are also modulated at a gateway 18 with
5 packetized digital voice signals and/or data signals in accordance with the spread spectrum technique.

The 16.5 MHz bandwidth of the forward link is partitioned into 13 channels with up to, by example, 128 users being
10 assigned per channel. The return link may have various bandwidths, and a given user terminal 13 may or may not be assigned a different channel than the channel assigned on the forward link. However, when operating in the diversity reception mode on the return link (receiving from two or
15 more satellites 12), the user is assigned the same forward and return link RF channel for each of the satellites.

The ground segment 3 includes at least one but generally a plurality of the gateways 18 that communicate with the
20 satellites 12 via, by example, a full duplex C band RF link 19 (forward link 19a (to the satellite), return link 19b (from the satellite)) that operates within a range of frequencies generally above 3 GHz and preferably in the C-band. The C-band RF links bi-directionally convey the
25 communication feeder links, and also convey satellite commands to the satellites and telemetry information from the satellites. The forward feeder link 19a may operate in the band of 5 GHz to 5.25 GHz, while the return feeder link 19b may operate in the band of 6.875 GHz to 7.075 GHz.

30

The satellite feeder link antennas 12g and 12h are preferably wide coverage antennas that subtend a maximum earth coverage area as seen from the LEO satellite 12. In the presently preferred embodiment of the communication
35 system 10 the angle subtended from a given LEO satellite 12 (assuming 10° elevation angles from the earth's surface) is approximately 110°. This yields a coverage zone that is

approximately 3600 miles in diameter.

The L-band and the S-band antennas are multiple beam antennas that provide coverage within an associated terrestrial service region. The L-band and S-band antennas 12d and 12c, respectively, are preferably congruent with one another, as depicted in Fig. 3B. That is, the transmit and receive beams from the spacecraft cover the same area on the earth's surface, although this feature is not critical to the operation of the system 10.

As an example, several thousand full duplex communications may occur through a given one of the satellites 12. In accordance with a feature of the system 10, two or more satellites 12 may each convey the same communication between a given user terminal 13 and one of the gateways 18. This mode of operation, as described in detail below, thus provides for diversity combining at the respective receivers, leading to an increased resistance to fading and facilitating the implementation of a soft handoff procedure.

It is pointed out that all of the frequencies, bandwidths and the like that are described herein are representative of but one particular system. Other frequencies and bands of frequencies may be used with no change in the principles being discussed. As but one example, the feeder links between the gateways and the satellites may use frequencies in a band other than the C-band (approximately 3 GHz to approximately 7 GHz), for example the Ku band (approximately 10 GHz to approximately 15 GHz) or the Ka band (above approximately 15 GHz). When using one of these latter two frequency bands the teaching of this invention becomes especially useful.

The gateways 18 function to couple the communications payload or transponders 12a and 12b (Fig. 3A) of the

satellites 12 to the telephone infrastructure segment 4. The transponders 12a and 12b include an L-band receive antenna 12c, S-band transmit antenna 12d, C-band power amplifier 12e, C-band low noise amplifier 12f, C-band antennas 12g and 12h, L band to C band frequency conversion section 12i, and C band to S band frequency conversion section 12j. The satellite 12 also includes a master frequency generator 12k and command and telemetry equipment 12l.

Reference in this regard may also be had to U.S. Patent No. _____, by E. Hirshfield and C.A. Tsao, entitled "Mobile Communications Satellite Payload" (USSN 08/060,207).

The telephone infrastructure segment 4 is comprised of existing telephone systems and includes Public Land Mobile Network (PLMN) gateways 20, local telephone exchanges such as regional public telephone networks (RPTN) 22 or other local telephone service providers, domestic long distance networks 24, international networks 26, private networks 28 and other RPTNs 30. The communication system 10 operates to provide bidirectional voice and/or data communication between the user segment 2 and Public Switched Telephone Network (PSTN) telephones 32 and non-PSTN telephones 32 of the telephone infrastructure segment 4, or other user terminals of various types, which may be private networks.

Also shown in Fig. 1 (and also in Fig. 4), as a portion of the ground segment 3, is a Satellite Operations Control Center (SOCC) 36, and a Ground Operations Control Center (GOCC) 38. A communication path, which includes a Ground Data Network (GDN) 39 (see Fig. 2), is provided for interconnecting the gateways 18 and TCUs 18a, SOCC 36 and GOCC 38 of the ground segment 3. This portion of the communications system 10 provides overall system control functions.

Fig. 2 shows one of the gateways 18 in greater detail. Each gateway 18 includes up to four dual polarization RF C-band sub-systems each comprising a dish antenna 40, antenna driver 42 and pedestal 42a, low noise receivers 44, and high power amplifiers 46. All of these components may be located within a radome structure to provide environmental protection.

The gateway 18 further includes down converters 48 and up converters 50 for processing the received and transmitted RF carrier signals, respectively. The down converters 48 and the up converters 50 are connected to a CDMA sub-system 52 which, in turn, is coupled to the Public Switched Telephone Network (PSTN) through a PSTN interface 54. As an option, the PSTN could be bypassed by using satellite-to-satellite links.

The CDMA sub-system 52 includes a signal summer/switch unit 52a, a Gateway Transceiver Subsystem (GTS) 52b, a GTS Controller 52c, a CDMA Interconnect Subsystem (CIS) 52d, and a Selector Bank Subsystem (SBS) 52e. The CDMA sub-system 52 is controlled by a Base Station Manager (BSM) 52f and functions in a manner similar to a CDMA-compatible (for example, an IS-95 compatible) base station. The CDMA sub-system 52 also includes the required frequency synthesizer 52g and a Global Positioning System (GPS) receiver 52h.

The PSTN interface 54 includes a PSTN Service Switch Point (SSP) 54a, a Call Control Processor (CCP) 54b, a Visitor Location Register (VLR) 54c, and a protocol interface 54d to a Home Location Register (HLR). The HLR may be located in the cellular gateway 20 (Fig. 1) or, optionally, in the PSTN interface 54.

The gateway 18 is connected to telecommunication networks through a standard interface made through the SSP 54a. The gateway 18 provides an interface, and connects to the PSTN

Primary Rate Interface (PRI). The gateway 18 is further capable of providing a direct connection to a Mobile Switching Center (MSC).

5 The gateway 18 provides SS-7 ISDN fixed signalling to the CCP 54b. On the gateway-side of this interface, the CCP 54b interfaces with the CIS 52d and hence to the CDMA sub-system 52. The CCP 54b provides protocol translation functions for the system Air Interface (AI), which may be
10 similar to the IS-95 Interim Standard for CDMA communications.

Blocks 54c and 54d generally provide an interface between the gateway 18 and an external cellular telephone network
15 that is compatible, for example, with the IS-41 (North American Standard, AMPS) or the GSM (European Standard, MAP) cellular systems and, in particular, to the specified methods for handling roamers, that is, users who place calls outside of their home system. The gateway 18 supports
20 user terminal authentication for system 10/AMPS phones and for system 10/GSM phones. In service areas where there is no existing telecommunications infrastructure, an HLR can be added to the gateway 18 and interfaced with the SS-7 signalling interface.

25 A user making a call out of the user's normal service area (a roamer) is accommodated by the system 10 if authorized. In that a roamer may be found in any environment, a user may employ the same terminal equipment to make a call from
30 anywhere in the world, and the necessary protocol conversions are made transparently by the gateway 18. The protocol interface 54d is bypassed when not required to convert, by example, GSM to AMPS.

35 It is within the scope of the teaching of this invention to provide a dedicated, universal interface to the cellular gateways 20, in addition to or in place of the conventional

"A" interface specified for GSM mobile switching centers and vendor-proprietary interfaces to IS-41 mobile switching centers. It is further within the scope of this invention to provide an interface directly to the PSTN, as indicated
5 in Fig. 1 as the signal path designated PSTN-INT.

Overall gateway control is provided by the gateway controller 56 which includes an interface 56a to the above-mentioned Ground Data Network (GDN) 39 and an interface 56b
10 to a Service Provider Control Center (SPCC) 60. The gateway controller 56 is generally interconnected to the gateway 18 through the BSM 52f and through RF controllers 43 associated with each of the antennas 40. The gateway controller 56 is further coupled to a database 62, such as
15 a database of users, satellite ephemeris data, etc., and to an I/O unit 64 that enables service personnel to gain access to the gateway controller 56. The GDN 39 is also bidirectionally interfaced to a Telemetry and Command (T&C) unit 66 (Figs. 1 and 4).

20 Referring to Fig. 4, the function of the GOCC 38 is to plan and control satellite utilization by the gateways 18, and to coordinate this utilization with the SOCC 36. In general, the GOCC 38 analyses trends, generates traffic
25 plans, allocates satellite 12 and system resources (such as, but not limited to, power and channel allocations), monitors the performance of the overall system 10, and issues utilization instructions, via the GDN 39, to the gateways 18 in real time or in advance.

30 The SOCC 36 operates to maintain and monitor orbits, to relay satellite usage information to the gateway for input to the GOCC 38 via the GDN 39, to monitor the overall functioning of each satellite 12, including the state of
35 the satellite batteries, to set the gain for the RF signal paths within the satellite 12, to ensure optimum satellite orientation with respect to the surface of the earth, in

addition to other functions.

As described above, each gateway 18 functions to connect a given user to the PSTN for both signalling, voice and/or data communications and also to generate data, via database 62 (Fig. 2), for billing purposes. Selected gateways 18 include a Telemetry and Command Unit (TCU) 18a for receiving telemetry data that is transmitted by the satellites 12 over the return link 19b and for transmitting commands up to the satellites 12 via the forward link 19a. The GDN 39 operates to interconnect the gateways 18, GOCC 38 and the SOCC 36.

In general, each satellite 12 of the LEO constellation operates to relay information from the gateways 18 to the users (C band forward link 19a to S band forward link 17a), and to relay information from the users to the gateways 18 (L band return link 17b to C band return link 19b). This information includes SS-CDMA synchronization and paging channels, in addition to power control signals. Various CDMA pilot channels may also be used to monitor interference on the forward link. Satellite ephemeris update data is also communicated to each of the user terminals 13, from the gateway 18, via the satellites 12. The satellites 12 also function to relay signalling information from the user terminals 13 to the gateway 18, including access requests, power change requests, and registration requests. The satellites 12 also relay communication signals between the users and the gateways 18, and may apply security to mitigate unauthorized use.

In operation, the satellites 12 transmit spacecraft telemetry data that includes measurements of satellite operational status. The telemetry stream from the satellites, the commands from the SOCC 36, and the communications feeder links 19 all share the C band antennas 12g and 12h. For those gateways 18 that include a

TCU 18a the received satellite telemetry data may be forwarded immediately to the SOCC 36, or the telemetry data may be stored and subsequently forwarded to the SOCC 36 at a later time, typically upon SOCC request. The telemetry data, whether transmitted immediately or stored and subsequently forwarded, is sent over the GDN 39 as packet messages, each packet message containing a single minor telemetry frame. Should more than one SOCC 36 be providing satellite support, the telemetry data is routed to all of the SOCCs.

The SOCC 36 has several interface functions with the GOCC 38. One interface function is orbit position information, wherein the SOCC 36 provides orbital information to the GOCC 38 such that each gateway 18 can accurately track up to four satellites that may be in view of the gateway. This data includes data tables that are sufficient to allow the gateways 18 to develop their own satellite contact lists, using known algorithms. The SOCC 36 is not required to known the gateway tracking schedules. The TCU 18a searches the downlink telemetry band and uniquely identifies the satellite being tracked by each antenna prior to the propagation of commands.

Another interface function is satellite status information that is reported from the SOCC 36 to the GOCC 38. The satellite status information includes both satellite/transponder availability, battery status and orbital information and incorporates, in general, any satellite-related limitations that would preclude the use of all or a portion of a satellite 12 for communications purposes.

An important aspect of the system 10 is the use of SS-CDMA in conjunction with diversity combining at the gateway receivers and at the user terminal receivers. Diversity combining is employed to mitigate the effects of fading as

signals arrive at the user terminals 13 or the gateway 18 from multiple satellites over multiple and different path lengths. Rake receivers in the user terminals 13 and the gateways 18 are employed to receive and combine the signals from multiple sources. As an example, a user terminal 13 or the gateway 18 provides diversity combining for the forward link signals or the return link signals that are simultaneously received from and transmitted through the multiple beams of the satellites 12.

10

In this regard the disclosure of U.S. Patent No. 5,233,626, issued August 3, 1993 to Stephen A. Ames and entitled "Repeater Diversity Spread Spectrum Communication System", is incorporated by reference herein in its entirety.

15

The performance in the continuous diversity reception mode is superior to that of receiving one signal through one satellite repeater, and furthermore there is no break in communications should one link be lost due to shadowing or blockage from trees or other obstructions that have an adverse impact on the received signal.

20

The multiple, directional, antennas 40 of a given one of the gateways 18 are capable of transmitting the forward link signal (gateway to user terminal) through different beams of one or more satellites 12 to support diversity combining in the user terminals 13. The omnidirectional antennas 13a of the user terminals 13 transmit through all satellite beams that can be "seen" from the user terminal 13.

30

Each gateway 18 supports a transmitter power control function to address slow fades, and also supports block interleaving to address medium to fast fades. Power control is implemented on both the forward and reverse links. The response time of the power control function is adjusted to accommodate for a worst case 30 msec satellite round trip

35

delay.

The block interleavers (53d, 53e, 53f, Fig. 5) operate over a block length that is related to vocoder 53g packet frames. An optimum interleaver length trades off a longer length, and hence improved error correction, at the expense of increasing the overall end-to-end delay. A preferred maximum end-to-end delay is 150 msec or less. This delay includes all delays including those due to the received signal alignment performed by the diversity combiners, vocoder 53g processing delays, block interleaver 53d-53f delays, and the delays of the Viterbi decoders (not shown) that form a portion of the CDMA sub-system 52.

Fig. 5 is a block diagram of the forward link modulation portion of the CDMA sub-system 52 of Fig. 2. An output of a summer block 53a feeds a frequency agile up-converter 53b which in turn feeds the summer and switch block 52a. The telemetry and control (T&C) information is also input to the block 52a.

An unmodulated direct sequence SS pilot channel generates an all zeros Walsh Code at a desired bit rate. This data stream is combined with a short PN code that is used to separate signals from different gateways 18 and different satellites 12. If used, the pilot channel is modulo 2 added to the short code and is then QPSK or BPSK spread across the CDMA FD RF channel bandwidth. The following different pseudonoise (PN) code offsets are provided: (a) a PN code offset to allow a user terminal 13 to uniquely identify a gateway 18; (b) a PN code offset to allow the user terminal 13 to uniquely identify a satellite 12; and (c) a PN code offset to allow the user terminal 13 to uniquely identify a given one of the 16 beams that is transmitted from the satellite 12. Pilot PN codes from different ones of the satellites 12 are assigned different time/phase offsets from the same pilot seed PN code.

If used, each pilot channel that is transmitted by the gateway 18 may be transmitted at a higher or lower power level than the other signals. A pilot channel enables a user terminal 13 to acquire the timing of the forward CDMA channel, provides a phase reference for coherent demodulation, and provides a mechanism to perform signal strength comparisons to determine when to initiate handoff. The use of the pilot channel is not, however, mandatory, and other techniques can be employed for this purpose.

10

The Sync channel generates a data stream that includes the following information: (a) time of day; (b) transmitting gateway identification; (c) satellite ephemeris; and (d) assigned paging channel. The Sync data is applied to a convolution encoder 53h where the data is convolutionally encoded and subsequently block interleaved to combat fast fades. The resulting data stream is modulo two added to the synchronous Walsh code and QPSK or BPSK spread across the CDMA FD RF channel bandwidth.

20

The Paging channel is applied to a convolutional encoder 53i where it is convolutionally encoded and is then block interleaved. The resulting data stream is combined with the output of a long code generator 53j. The long PN code is used to separate different user terminal 13 bands. The paging channel and the long code are modulo two added and provided to a symbol cover where the resulting signal is modulo two added to the Walsh Code. The result is then QPSK or BPSK spread across the CDMA FD RF channel bandwidth.

30

In general, the paging channel conveys several message types which include: (a) a system parameter message; (b) an access parameter message; and (c) a CDMA channel list message.

35

The system parameter message includes the configuration of

the paging channel, registration parameters, and parameters to aid in acquisition. The access parameters message includes the configuration of the access channel and the access channel data rate. The CDMA channel list message
5 conveys, if used, an associated pilot identification and Walsh code assignment.

The vocoder 53k encodes the voice into a PCM forward traffic data stream. The forward traffic data stream is
10 applied to a convolutional encoder 53l where it is convolutionally encoded and then block interleaved in block 53f. The resulting data stream is combined with the output of a user long code block 53k. The user long code is employed to separate different subscriber channels. The
15 resulting data stream is then power controlled in multiplexer (MUX) 53m, modulo two added to the Walsh code, and then QPSK or BPSK spread across the CDMA FD RF communication channel bandwidth.

20 The gateway 18 operates to demodulate the CDMA return link(s). There are two different codes for the return link: (a) the zero offset code; and (b) the long code. These are used by the two different types of return link CDMA Channels, namely the access channel and the return traffic
25 channel.

For the access channel the gateway 18 receives and decodes a burst on the access channel that requests access. The access channel message is embodied in a long preamble
30 followed by a relatively small amount of data. The preamble is the user terminal's long PN code. Each user terminal 13 has a unique long PN code generated by a unique time offset into the common PN generator polynomial.

35 After receiving the access request, the gateway 18 sends a message on the forward link paging channel (blocks 53e, 53i, 53j) acknowledging receipt of the access request and

assigning a Walsh code to the user terminal 13 to establish a traffic channel. The gateway 18 also assigns a frequency channel to the user terminal 13. Both the user terminal 13 and the gateway 18 switch to the assigned channel element and begin duplex communications using the assigned Walsh (spreading) code(s).

The return traffic channel is generated in the user terminal 13 by convolutionally encoding the digital data from the local data source or the user terminal vocoder. The data is then block interleaved at predetermined intervals and is applied to a 128-Ary modulator and a data burst randomizer to reduce clashing. The data is then added to the zero offset PN code and transmitted through one or more of the satellites 12 to the gateway 18.

The gateway 18 processes the return link by using, by example, a Fast Hadamard Transform (FHT) to demodulate the 128-Ary Walsh Code and provide the demodulated information to the diversity combiner.

The foregoing has been a description of a presently preferred embodiment of the communication system 10. A description is now made of presently preferred embodiments of the forward link power control system of this invention.

The forward link is considered as the link from the gateway 18 to the user terminals 13 via at least one satellite 12. The feeder link 19 is considered to be that portion of the forward link which connects the satellite 12 to and from the gateway 18, while the user links 17 are considered to be that portion of the forward link from which connects the satellite 12 to and from the user terminals 13.

Referring to Fig. 6, the feeder link to one or more satellites 12 from the gateway 18 provides the drive power for the user links. The user links consume a considerable

amount of power on the satellite 12. If there is no impairment on the feeder link, as between the gateway 18 and the satellite 12', the power of the satellite is maximized to its associated user links, thereby maximizing the efficiency and capacity of the total system.

However, if the feeder link itself is impaired, as by a rain cell located between the gateway 18 and the satellite 12'', the user link power control loop described previously will be activated whether or not a particular user terminal 13 finds itself impaired. That is, a user terminal 13 detecting a decrease in the signal power received from the satellite 12'' will send a message over the reverse link requesting that the power of the forward link be increased. It can be appreciated that due to the attenuation in the feeder link signal due to a rain cell that all user terminals 13 receiving communication signals from the satellite 12'' will simultaneously experience a decrease in received power, and will simultaneously request that the feeder link power be increased. The resulting sudden surge in feeder link power translates to a significant corresponding increase in power consumption in the satellite 12'', which operates to repeat the feeder link signals to the user terminals 13 with a power that corresponds in a substantially linear fashion to the received feeder link power.

That is, low earth orbit satellite systems, and other satellite systems generally, track a satellite as it passes over the ground station, in this case the gateway 18. This results in the gateway 18 antenna 40 being steered such that it may be transmitting the feeder link signal F1 through the rain cell. As a result, the signal level of feeder link portion F2 will be reduced compared to F1. The feeder link portion F2 experiences additional path loss until it reaches the satellite 12''. As a result of these losses all user terminals 13 will demand more satellite

prime power.

In accordance with this invention an outer power control loop is provided in the feeder link(s) at the gateway 18.

5 The outer power control loop operates to increase the transmitted power from the gateway 18 antenna 40 in proportion to the attenuation caused by a feeder link impairment, in this case a rain cell. This outer power control loop thus maintains the power flux density received

10 by the satellite 12'' at a nearly constant level and, as a result, the user terminals 13 do not experience a significant decrease in received power from the satellite 12''.

15 In accordance with this invention the outer power control loop includes a reference signal receiver 70 and a reference signal tracking processor 72, as shown in Figs. 6 and 7. The reference signal receiver 70 and the reference signal tracking processor 72 operate in conjunction with

20 the RF system controllers 43 and feeder link RF systems 46, 50 (as shown in the gateway 18 block diagram of Fig. 2). The reference signal receiver 70 monitors a downlink reference (R) signal from the satellites 12 at a specified frequency. This frequency is selected to be low enough so

25 that it is not significantly impaired by the rain cell (for example a frequency in the S-band), and thus remains at essentially the same level at portion R2 as at portion R1. The reference signal receiver 70 demodulates the received SS-CDMA signal and outputs as a data stream 70a a reference

30 signal received signal power indication to the reference signal tracking processor 72 in the gateway 18. The reference signal tracking processor 72 processes the data stream 70a and issues error signals or commands to the one or more RF system controllers 43, which in turn control the

35 gain of the feeder link RF system(s) 46, 50 on link 1 to link N of the gateway 18. In this manner the transmitted feeder link power is increased in proportion to the amount

of attenuation experienced by the feeder link between the gateway 18 and a satellite 12.

In greater detail, and referring also to the logic flow diagram of Fig. 8, at Block A the feeder link spread spectrum reference signal receiver 70 receives and demodulates each of the down link reference signals R. Since the reference signal downlink frequency is significantly less than the uplink feeder link frequency, the majority of the rain loss (if any) is incurred by the uplink feeder link signal. Consequently, at Block B the received signal power indication signal is compared to a predetermined reference by the reference signal tracking processor 72, and at Block C an error signal (E) proportional to the feeder link loss caused by a channel impairment, such as rain, is derived and output to the RF system controllers 43. That is, an error signal (E_1 to E_N) is derived for each of the feeder links 1-N. The error signal in turn is used by each RF system controller 43 to control, at Block D, the power of the composite feeder link that is comprised of the reference signal R, and all of the individual user terminal 13 communication signals, to compensate for the rain loss.

That is, the reference signal R is transmitted on the uplink feeder link with a predetermined PN code and a first frequency from gateway 18, is attenuated by RF impairments, such as a rain cell, between the satellite 12'' and the gateway 18, is received and repeated by the satellite 12'' at a second, lower frequency on the downlink, and is received, despread, demodulated and processed by the reference signal receiver 70 and the reference signal tracking processor 72. An error signal is next developed that indicates an amount of RF impairment that is occurring on the uplink feeder link, it being remembered that the uplink frequency band causes the feeder link to be more susceptible to RF impairments, such as rain, than the

downlink signal from the satellite 12''. The error signal is then employed to vary the uplink feeder link transmission power so as to cause the power level of each of the signals received by each of the user terminals 13 to remain substantially the same.

It should be realized that an error signal can be provided to each of the RF system controllers 43, from which each RF system controller 43 derives a change in its associated feeder link power; or a change in feeder link power can be derived in the reference signal tracking processor 72 from the error signal, for each RF system controller 43, and transmitted as a suitable power control command to the RF system controllers.

Because of the ability of a spread spectrum receiver to separate multiple overlapping reference signals from a plurality of satellites by using a unique PN code for each reference signal, a single reference signal receiver 70 may be utilized to independently control the feeder link uplink powers to each of the satellites 12 within view of a particular gateway 18. That is, a distinct PN code is assigned to each reference signal. In this regard, the reference signal receiver 70 may employ a well-known RAKE receiver having a plurality of fingers for simultaneously despread and tracking a plurality of the reference signals. Alternately the reference signal receiver 70 may instead employ a single finger that is time multiplexed between the reference signals repeated by a plurality of satellites 12 that are in view of the reference signal receiver 70. In either case the uplink feeder link power is increased only as necessary, allowing more efficient use of the satellite capacity and minimizing coordination difficulties with other satellites 12 in similar orbits and which share the same band of frequencies. This technique also minimizes the effect of higher feeder link power for terrestrial coordination.

For systems employing multiple downlink beams a plurality of reference signal receivers 70 (designated 70' in Fig. 7) may be placed at suitable points over the gateway coverage area, and the reference signal data stream is conveyed to
5 the reference signal tracking processor 72 over terrestrial data lines, or as a data stream via the satellites 12. In this latter case the data stream can also be received by the reference signal receiver 70 at the gateway 18 and then input to the reference signal tracking processor 72.

10

As employed herein a received signal power or quality indication that is reported back to the gateway 18 in the data stream 70a may be, by example, a received signal strength indicator (RSSI) measurement, or a signal quality
15 measurement (e.g., bit error rate (BER) measurement), or a frame error rate measurement derived from Viterbi decoder metrics. The signal power or quality indication is compared by the reference signal tracking processor 72 to a predetermined value, such as a reference signal strength or
20 signal quality value, and the error signal is developed so as to represent a deviation between the two compared values. A goal of the outer power control loop is to minimize the feeder link power in a manner that is consistent with the desired link quality. Minimizing the
25 feeder link power, while simultaneously providing satisfactory user communications, thus conserves satellite prime power.

The reference value to which the received signal power indication is compared is determined in accordance with a
30 desired power level at which the user terminals 13 are to receive the communication signals that are repeated by the satellites 12 from the feeder link. The reference value need not be a fixed value, but can be varied depending
35 upon, by example, total user load or demand, time of day, a total desired RF flux level at the ground within a given satellite spot beam (e.g., approximately 154 dBW/m²/4 kHz,

as a function of elevation angle), etc.

For the case where a plurality of reference signal receivers 70 are located within the area served by the gateway 18, the gateway 18 may process the inputs from the plurality of reference signal receivers 70 and 70' by combining them in a predetermined manner, such as by an averaging or a weighted averaging technique. For the latter case reference signal power indications received from those reference signal receivers 70' that are associated with a region having a high user density (i.e., urban areas) may be weighted more heavily than signal power indications received from regions with a lower user density.

The power control technique of this invention thus compensates for impairments in the feeder links (e.g., rain attenuation for Ka or Ku band feeder links, impairments due to a low elevation angle satellite receiving a C-band feeder link, impairments due to signals received from impaired beams, etc.), and may also compensate for a degradation in satellite operational capacity over time.

Referring to Fig. 9, the closed loop power control technique of this invention may be viewed as a two-level adaptive power control loop 80 with an outer, global feeder link power control loop 82 to compensate for bulk power impairments (e.g., those due to rain cells) and a plurality of inner, user link power control loops 84 to compensate for individual user link impairments (such as those resulting from foliage). A time constant of the outer feeder link power control loop 82 is preferably longer (for example, 5 to 10 times longer) than that of the inner user link power control loops 84.

As an example of the closed loop power control technique of this invention; if it is assumed that the user terminal dynamic power control range is 10 dB, and if a rain cell

- introduces an 8 dB loss to the S-band forward links received by the user terminals from a satellite 12, then a 6 dB impairment in a user link caused by a fade may not be correctable. If, instead, the gateway 18 compensates all
- 5 user links for the 8 dB rain cell loss by increasing the feeder link power proportionately, then the dynamic range of the user terminal power control function is not adversely affected by the rain cell-induced loss.
- 10 While the invention has been particularly shown and described with respect to preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and details may be made therein without departing from the scope and spirit of the invention.

CLAIMS

What is claimed is:

1. A method for operating a satellite communication system having at least one satellite and at least one ground station, the satellite communication system further having a plurality of ground receivers, comprising the steps of:

transmitting a plurality of uplink signals from the ground station, at least one of the uplink signals being designated as an uplink reference signal, said plurality of uplink signals being transmitted with a first frequency from the ground station to the satellite and experiencing a first amount of attenuation between the ground station and the satellite;

receiving the plurality of uplink signals with the satellite and repeating the plurality of uplink signals with a second frequency as a plurality of downlink signals that are transmitted from the satellite to the plurality of ground receivers, the second frequency being less than the first frequency such that the plurality of downlink signals experience a second amount of attenuation between the satellite and the plurality of ground receivers, the second amount of attenuation being less than the first amount of attenuation, the plurality of downlink signals being transmitted with a power that is a function of the power of the received plurality of uplink signals;

receiving at least the reference signal from the plurality of downlink signals with at least one of the ground receivers, the received reference signal being designated as a received downlink reference signal, and determining from the received downlink reference



signal the first amount of attenuation that was experienced at least by the uplink reference signal between the ground station and the satellite; and

adjusting a transmitted power of the plurality of uplink signals from the ground station in accordance with the determined amount of attenuation so as to substantially compensate for the first amount of attenuation.

2. A method as set forth in claim 1 wherein at least some of the plurality of ground receivers are a plurality of user terminals, and where the step of transmitting the plurality of uplink signals includes a step of transmitting an uplink feeder link from the ground station to the satellite, the uplink feeder link comprising a plurality of communication signals for the plurality of user terminals; and wherein the steps of receiving the plurality of uplink signals with the satellite and repeating the plurality of uplink signals include the steps of receiving the uplink feeder link with the satellite and repeating the uplink feeder link by transmitting the plurality of communication signals from the satellite to the plurality of user terminals.

3. A method as set forth in claim 2 wherein the step of adjusting a transmitted power of the plurality of uplink signals includes a step of adjusting a transmitted power of the uplink feeder link so as to substantially compensate for the attenuation in communications signals received from the satellite at the plurality of user terminals.

4. A method as set forth in claim 1 wherein the step of transmitting a plurality of uplink signals includes a step of transmitting at least the uplink reference signal with a predetermined pseudonoise code.

5. A method as set forth in claim 1 wherein the step



of receiving the downlink reference signal receives the downlink reference signal with a single receiver.

6. A method as set forth in claim 5 wherein the step of transmitting a plurality of uplink signals includes a step of transmitting at least the uplink reference signal with a predetermined pseudonoise spreading code, and wherein the single receiver is responsive to the predetermined pseudonoise spreading code for despreading same after receiving the downlink reference signal.

7. A method as set forth in claim 1 wherein the step of receiving the downlink reference signal receives the downlink reference signal with a plurality of receivers that are disposed within a ground station coverage area.

8. A method as set forth in claim 7 wherein the step of transmitting a plurality of uplink signals includes a step of transmitting at least the uplink reference signal with a predetermined pseudonoise spreading code, and wherein each of the plurality of receivers is responsive to the predetermined pseudonoise spreading code for despreading same after receiving the downlink reference signal.

9. A method for operating a satellite communication system having at least one satellite and at least one ground station, comprising the steps of:

transmitting an uplink reference signal with a first frequency from the ground station to the satellite, the uplink reference signal experiencing an attenuation between the ground station and the satellite;

receiving the reference signal with the satellite and repeating the reference signal with a second frequency as a downlink reference signal that is transmitted



from the satellite, the second frequency being less than the first frequency, the downlink reference signal being transmitted with a power that is a function of the power of the received uplink reference signal;

receiving the downlink reference signal and determining from the received downlink reference signal an amount of attenuation that was experienced at least by the uplink reference signal between the ground station and the satellite; and

adjusting a transmitted power of the uplink reference signal in accordance with the determined amount of attenuation so as to substantially compensate for the attenuation;

wherein the step of receiving the downlink reference signal receives the downlink reference signal with a plurality of receivers that are disposed within a ground station coverage area;

wherein the step of transmitting an uplink reference signal includes a step of transmitting the uplink reference signal with a predetermined pseudonoise spreading code, and wherein each of the plurality of receivers is responsive to the predetermined pseudonoise spreading code for despread same; and

wherein the step of adjusting includes a step of combining output signals from each of the plurality of receivers.

10. A satellite communication system comprised of at least one satellite, at least one ground station, and at least one ground receiver, said satellite communication system further comprising:



means for transmitting at least one uplink reference signal in conjunction with a plurality of uplink user communication signals, the uplink reference signal and the plurality of uplink user communication signals being transmitted with a first frequency from said ground station to said satellite, the uplink reference signal experiencing an attenuation between said ground station and said satellite;

said satellite comprising a receiver for receiving the uplink reference signal and the plurality of uplink user communication signals, and further comprising a transmitter for transmitting the received uplink reference signal and the plurality of received uplink user communication signals with a second frequency as a repeated downlink reference signal and as a plurality of repeated downlink user communication signals, the second frequency being less than the first frequency, the repeated downlink reference signal and the plurality of repeated downlink user communication signals being transmitted with a power that is a function of the power of the received uplink signals;

at least one reference signal receiver comprising an input for receiving the downlink reference signal and further comprising an output for outputting the received downlink reference signal;

means, having an input coupled to said output of said at least one reference signal receiver, for determining from the received downlink reference signal an amount of attenuation that was experienced at least by the uplink reference signal between said ground station and said satellite; and

means for adjusting a transmitted power of the uplink reference signal and the plurality of uplink



communication signals in accordance with the determined amount of attenuation so as to substantially compensate for the attenuation.

11. A satellite communication system as set forth in claim 10 wherein said ground station includes means for transmitting an uplink feeder link to said satellite, the uplink feeder link comprising said plurality of uplink user communication signals for a plurality of user terminals; and wherein said satellite includes means for receiving the uplink feeder link and for repeating the uplink feeder link by transmitting the plurality of user communication signals from said satellite to said plurality of user terminals.

12. A satellite communication system as set forth in claim 11 wherein said adjusting means adjusts a transmitted power of the uplink feeder link so as to substantially compensate for the determined amount of attenuation in the user communications signals that are received at said plurality of user terminals.

13. A satellite communication system as set forth in claim 10 wherein the at least the uplink reference signal is transmitted with a predetermined pseudonoise code.

14. A satellite communication system as set forth in claim 10 wherein there are a plurality of said reference signal receivers disposed within a region served by said ground station.

15. A satellite communication system comprised of at least one satellite and at least one ground station, said satellite communication system further comprising:

means for transmitting an uplink reference signal with a first frequency from said ground station to said satellite, the uplink reference signal experiencing an attenuation between said ground station and said



satellite;

said satellite comprising a receiver for receiving the reference signal and further comprising a transmitter for transmitting the reference signal with a second frequency as a repeated downlink reference signal, the second frequency being less than the first frequency, the downlink reference signal being transmitted with a power that is a function of the power of the received uplink reference signal;

at least one reference signal receiver comprising an input for receiving the downlink reference signal and further comprising an output for outputting the received downlink reference signal;

means, having an input coupled to said output of said at least one reference signal receiver, for determining from the received downlink reference signal an amount of attenuation that was experienced at least by the uplink reference signal between said ground station and said satellite; and

means for adjusting a transmitted power of the uplink reference signal in accordance with the determined amount of attenuation so as to substantially compensate for the attenuation;

wherein there are a plurality of said reference signal receivers disposed within a region served by said ground station; and

wherein said determining means combines the output signals from each of said plurality of reference signal receivers.

16. A satellite communication system comprised of at least one low earth orbiting satellite and at least one



ground station, said satellite communication system further comprising:

a plurality of terrestrial user terminals;

means for bidirectionally coupling said at least one ground station to a terrestrial communications network;

means for transmitting an uplink feeder link with a first frequency from said at least one ground station to said satellite, said first frequency being within one of a Ka band, a Ku band, and a C band, the uplink feeder link comprising a plurality of spread spectrum communications signals for said plurality of user terminals and further comprising at least one uplink reference signal, the uplink feeder link experiencing an attenuation between said ground station and said satellite;

said satellite comprising a receiver for receiving the uplink feeder link and further comprising a transmitter for transmitting the plurality of spread spectrum communications signals as a plurality of downlink spread spectrum communications signals to said plurality of user terminals and for also transmitting the at least one reference signal as at least one downlink reference signal, the downlink spread spectrum communication signals and the at least one downlink reference signal being transmitted with a second frequency that is less than the first frequency, the downlink spread spectrum communication signals and the at least one downlink reference signal being transmitted with a power that is a function of the power of the received uplink feeder link;

at least one reference signal receiver comprised of an input for receiving the at least one downlink



reference signal and further comprising an output for outputting the received downlink reference signal;

means, having an input coupled to said output of said at least one reference signal receiver, for determining from the received downlink reference signal an amount of attenuation that was experienced at least by the uplink feeder link between said ground station and said satellite; and

means for adjusting a transmitted power of the uplink feeder link in accordance with the determined amount of attenuation such that a received signal power at said plurality of user terminals is not substantially decreased due to an attenuation of the uplink feeder link.

17. A satellite communication system comprising:

at least one satellite communication signal repeater;

at least one ground station for transmitting a feeder link comprised of a plurality of communication signals to said at least one satellite communication signal repeater;

a plurality of user terminals each receiving one of said communication signals over a user link from said at least one satellite communication signal repeater; and

closed loop power control means comprising a plurality of inner loops individual ones of which operate to compensate one of said user links for communication signal impairments occurring at least between said user terminal and said at least one satellite communication repeater, said closed loop power control means further comprising an outer loop which operates



to compensate all of said user links for feeder link impairments occurring between said at least one ground station and said at least one satellite communication signal repeater.

18. A satellite communication system as set forth in claim 17 wherein said at least one ground station comprises means for transmitting said feeder link with a first frequency, the feeder link comprising a plurality of spread spectrum communications signals for said plurality of user terminals and further comprising at least one spread spectrum reference signal.

19. A satellite communication system as set forth in claim 18 wherein said at least one satellite communication signal repeater is comprised of a receiver for receiving the feeder link and a transmitter for transmitting the plurality of spread spectrum communications signals as a plurality of user link spread spectrum communications signals to said plurality of user terminals, said at least one satellite communication signal repeater further transmitting the spread spectrum reference signal as a downlink spread spectrum reference signal, the user link spread spectrum communication signals and the downlink spread spectrum reference signal being transmitted with a second frequency that is less than the first frequency, the user link spread spectrum communication signals and the downlink spread spectrum reference signal being transmitted with a power that is a function of the power of the received uplink feeder link; and wherein said outer loop of said closed loop power control means is comprised of:

at least one reference signal receiver comprised of an input for receiving and despreading the downlink spread spectrum reference signal and further comprising an output for outputting the received and despread downlink spread spectrum reference signal;



means, having an input coupled to said output of said at least one reference signal receiver, for determining from the received and despread downlink spread spectrum reference signal an amount of attenuation that was experienced at least by the feeder link between said ground station and said satellite; and

means for adjusting a transmitted power of the feeder link in accordance with the determined amount of attenuation such that a received signal power at said plurality of user terminals is not substantially decreased due to an attenuation of the uplink feeder link.

20. A satellite communications system operative with at least one terrestrial communication system, comprising:

at least one satellite in earth orbit, said at least one satellite projecting a pattern on the surface of the earth, the pattern being comprised of a plurality of beams;

at least one terrestrial gateway that is bidirectionally coupled to said at least one terrestrial communications system, said at least one terrestrial gateway further being bidirectionally coupled through first RF links to said at least one satellite for transmitting communications traffic to, and for receiving communications traffic from, said at least one satellite;

a plurality of transceivers associated with users of said satellite communications system, each of said plurality of transceivers being bidirectionally coupled through second RF links to said at least one satellite for transmitting communications traffic to, and for receiving communications traffic from, said at



least one satellite, each of said plurality of transceivers being located in at least one of said plurality of beams;

wherein said first RF links use frequencies within a first band of radio frequencies, and wherein said second RF links use frequencies within a second band of radio frequencies that differs from said first band of radio frequencies and experience substantially less fading than frequencies in said first band of radio frequencies;

at least one reference receiver located in at least one of said beams for receiving a reference signal from one of said second RF links;

means for receiving an output from said at least one reference receiver and for determining an amount of fading experienced by said first RF links between said at least one terrestrial gateway and said at least one satellite; and

means for adjusting a transmitted power of uplinked ones of said first RF links for compensating downlinked ones of said second RF links, at said plurality of transceivers, for the determined amount of fading.

21. A satellite communication system as set forth in claim 20 wherein said at least one terrestrial gateway is located within a first beam, and wherein said at least one reference receiver is located within a second beam.

22. A satellite communications system as set forth in claim 20 wherein said at least one satellite is one of a plurality of satellites forming a constellation of non-geosynchronous earth orbit satellites.



23. A satellite communications system as set forth in claim 20 wherein said communications traffic is conveyed over said first RF links and said second RF links using a spread spectrum, code division multiple access technique.

24. A satellite communications system as set forth in claim 20 wherein said at least one satellite is comprised of a bent pipe repeater communications payload.

25. A satellite communications system as set forth in claim 20 wherein said first band of radio frequencies is greater than approximately 10 GHz, and wherein said second band of radio frequencies is less than approximately 3 GHz.

26. A satellite communications system as set forth in claim 20 wherein there are a plurality of said reference receivers disposed at different terrestrial locations, and wherein said determining means combines output signals from at least two of said reference receivers.

27. A satellite communications systems of a type that includes at least one satellite in earth orbit, at least one groundstation that is coupled through an uplink feederlink to said at least one satellite for transmitting user communications signals to said at least one satellite, and a plurality of receivers associated with users of said satellite communications system, each of said plurality of receivers being coupled to a downlink signal transmitted by said at least one satellite, wherein said uplink feederlink employs a frequency within a first band of radio frequencies, and wherein said downlink signal employs a frequency within a second band of radio frequencies that differs from said first band of radio frequencies and that experiences substantially less fading than said first band of radio frequencies, said system further comprising at least one fade compensation receiver located within a coverage area of said at least one groundstation for receiving a signal from said at least one satellite, said



signal being originally transmitted on said uplink feederlink by said at least one groundstation, said system further comprising uplink feederlink transmit power control means having an input for receiving an output from said at least one fade compensation receiver and for determining an amount of fading experienced by said uplink feederlink between said groundstation and said at least one satellite, said uplink feederlink power control means further having an output coupled to a groundstation feederlink transmitter for controlling the transmitted power of the uplink feederlink so as to compensate for the determined amount of fading.

28. A satellite communications system as set forth in claim 27 wherein said first band of radio frequencies is greater than approximately 10 GHz, and wherein said second band of radio frequencies is less than approximately 3 GHz.

29. A satellite communications system as set forth in claim 27 wherein there are a plurality of said fade compensation receivers disposed at different locations within said coverage area of said groundstation, and wherein said uplink feederlink transmit power control means combines output signals from at least two of said fade compensation receivers.