

10 The present invention relates to satellite communications and more particularly to a method and apparatus for providing adaptive communication routes.

15 Prior art space-borne communication systems consist of satellite vehicles which form the space segment and terrestrial components which form the ground segment to facilitate communications from any near-earth position to any other near-earth position. In a typical communication
20 scenario, messages which can be data and/or voice are sent from the initiating near-earth user, possibly via an intervening space link, through a ground station to the space segment, then through multiple elements in the space segment, and finally back to earth via a second ground station, and ultimately routed to the terminating near-earth user. For this method to work
25 reliably, it is critical that at least one route through the space segment be operational and that the terminating space-to-ground links, facilitated by the ground station, be operational. Failure to provide at least one route through the space segment or a failure in any of the terminating space-to-ground links will result in a lack of connectivity to portions of the globe.

30 Within prior art system design, connectivity to an entire terrestrial
service area depends on the viability of the active space/ground link
supported by the ground station. Any failure within that link will result in
system outages. Additionally, prior art approaches to solving this problem
are overly complex, requiring active coordination of multiple system
35 components directed by a central control authority.

5 Within multiple satellite communication systems which employ constellations of orbiting satellites, either due to early constellation population considerations or satellite failures, "holes" can exist. When one of these holes covers a ground station area, connectivity to that area is lost.

Existing system design limits the positioning of ground stations such
10 that a limited number of ground stations may be placed within the "footprint" of a single satellite, due to the satellite's limited resources (i.e., antennae) with which to implement space-to-ground links. Also, constellation traffic into or out of a single ground station is limited by the capacity of the supported space/ground link. This forces large cost and complexity
15 increases as the traffic volume increases. Further, existing systems are limited in their ability to efficiently optimize operation for cost-per-packet considerations. These factors are not taken into account when data is transported.

Additionally, global communication does not occur in a equally
20 distributed fashion about the globe, either in space or time. Most often, the volume of traffic expected in a communication system in any part of the world is highly dependent on the time of day and the day of the week, resulting in periods of relatively low activity and other periods of intense activity. Current global system designs exhibit throughput limitations or
25 "bottlenecks" caused by this characteristic unbalanced system loading. Unfortunately, prior art satellite networks are somewhat limited in their ability to alleviate congestion situations without the invention. This forces the system designers to choose between specifying a system which is capable of handling peak loads, leaving excess network capacity un-utilized over
30 large periods of time, or designing a limited system which is unable to support peak demand.

Therefore, there is a substantial need to provide a method and
suitable apparatus for maintaining continuity of service in a global
communication system despite interruptions in the satellite-to-ground radio
35 frequency communication links.

5 There is also a substantial need to provide such a method and apparatus which can minimize the effect of substantial changes in the system network while still providing the necessary continuity of service.

Brief Description of the Drawings

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A more complete understanding of the present invention can be derived by referring to the detailed description and claims when considered in connection with the Figures, wherein like reference numbers refer to similar items throughout the Figures, and:

15 FIG. 1 shows a block diagram of a satellite-based communication system in accordance with a preferred embodiment of the present invention;

FIG. 2 shows a block diagram of a ground station which is an earth-based intelligent switch that operates within a satellite-based communication system and provides earth-based links and earth-to-space links in accordance with a preferred embodiment of the present invention;

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FIG. 3 shows a flow chart for a procedure to route signals when an uplink re-route condition exists in accordance with a preferred embodiment of the present invention; and

FIG. 4 shows a flow chart for a procedure to route signals when a downlink re-route condition exists in accordance with a preferred embodiment of the present invention.

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Detailed Description of a Preferred Embodiment

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The present invention describes a satellite-based communication system that has been adapted to provide an improved method for establishing communication links between ground stations and space-based satellite switches. "Common" earth-based termination nodes are replaced by "intelligent" switches. Alternate links are established using links between intelligent space-based switches, links between intelligent

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5 earth-based switches, and links between intelligent space-based switches and intelligent earth-based switches. The processor in the intelligent earth-based switch allows the system to automatically adapt to failure, overload, and other re-routing conditions.

10 In a preferred embodiment, the ground segment of satellite-based communication system is formed using terrestrial links and intelligent ground stations which are used as switches. In such a system, ground stations link terrestrial communications facilities to and from the space-borne backbone. In prior art systems, all communications between the system users are carried by the space-borne backbone. In a preferred
15 embodiment of the present invention, an alternative link capability is established by linking these ground station facilities together in an intelligent manner.

In the prior art, the operation of the ground station elements involves transport of data packets in two directions. Transport of data from the
20 ground segment to the space segment is referred to as packet "uplink", while data transport from the space segment to the ground is called packet "downlink".

In a preferred embodiment of the present invention, a third direction for data transport within the communication system is established using the ground
25 segment. This third direction for data transport is called packet "terrestrial crosslink". In the "terrestrial crosslink", native system packets are transported via terrestrial links from one ground station to another ground station.

In the prior art, the ground entities are responsible for not only
30 transport (uplink and downlink) of the backbone packets, but also for conversion of data to/from the system native packets from/to a format which is compatible with the existing terrestrial telephone networks.

In the prior art design, when downlink packets are received by the ground entities, any packet which is not intended for that ground entity is
35 discarded. In a preferred embodiment of the present invention, ground

5 stations accept all downlink packets bound for any destination. Ground station controllers determine which uplink data packets to route via space links and which uplink data packets to route via the terrestrial links.

Similarly, in the prior art design, all uplink packets are sent via the ground entity's packet handling component to the satellite link. No
10 consideration is given to the packet destinations or current system resource limitations, including the volume of traffic currently being handled by the target ground/space link. In a preferred embodiment of the present invention, a ground station controller is incorporated into the ground stations. This ground station controller monitors uplink packet traffic, and
15 makes a space vs. ground routing decision including (but not limited to) factors such as current traffic flow, economics, and network health status.

Additionally in prior art systems, some constellation configurations can induce an inordinate delay due to "crosslink" connectivity, or the lack thereof. This invention provides a means of minimizing the delay, or latency,
20 as seen by the system users.

FIG. 1. shows a block diagram of a satellite-based communication system 30 in accordance with a preferred embodiment of the present invention. Constellation 10 includes communication satellites 11, a system controller 13, and ground stations 14. To simplify the understanding of the
25 present invention, only two communication satellites are shown in FIG. 1, but more may be present. Also, to simplify the understanding of the present invention, only two ground stations 14 are shown in FIG. 1, but more may be present. Communication satellites 11 are in data communication with one another through data communication links 20 that are provided by
30 constellation 10. In addition, communication satellites 11 are linked to communication nodes 12 through links 22,27. Also communication satellites 11 are linked to ground stations 14 through links 23,25.

Ground stations 14 are located at various locations proximate to the surface of the earth. In a preferred implementation, all ground stations are
35 connected together via terrestrial link facilities 24, which remain active at all

5 times. These facilities may be custom implementations or may utilize existing terrestrial facilities to link the various ground station sites.

Terrestrial links 24 are treated as "additional or alternate links" for purposes of native network traffic handling. Links 24 are utilized to transport native system packets to and from other ground segment ground stations. Those
10 skilled in the art will appreciate that links 24 can be implemented as fiber optic cable, microwave network, T1 or other wireline network or the like.

Grounds stations 14 are typically connected to a terrestrial system such as a Public Switched Telephone Network (PSTN) 32 and/or a terrestrial cellular system, for example. Ground stations 14 basically
15 function as an interface between the terrestrial system users and the rest of the network.

In a preferred embodiment, system 30 also could include a system control center 13 which controls some operations of the space and/or terrestrial segments. System control center 13 connects to space segment
20 over link 26.

FIG. 2. shows a block diagram of a ground station 14 (FIG. 1) which is an earth-based intelligent switch that operates within a satellite-based communication system and provides terrestrial links 24 (FIG. 1) and earth-to-space links 23,25 (FIG. 1) in accordance with a preferred embodiment of
25 the present invention.

Uplink interface 50 is shown to depict a mechanism for establishing links 23,25 (FIG. 1) with communication satellites 11 (FIG. 1). It will be understood that while each ground station 14 is illustrated in FIG. 2 as having a single uplink interface 50 for establishing links 23,25 (FIG. 1),
30 each ground station 14 could comprise several uplink interfaces 50, so that ground station 14 can communicate with more than one satellite at a time, for example, with an approaching satellite and with a receding satellite simultaneously. Path 51 is shown to depict a means for establishing data links between uplink interfaces 50 and ground station controller 54. Data
35 packets are sent to ground station controller 54 using link 51. Also, it will be

5 understood that while each ground station 14 is illustrated in FIG. 2 as having a single path 51, each ground station 14 could comprise several paths, so that more than one of uplink interfaces 50 can communicate with ground station controller 54 at one time.

Downlink interface 52 is shown to depict a mechanism for
10 establishing links 23,25 (FIG. 1) with communication satellites 11(FIG. 1). It will be understood that while each ground station 14 is illustrated in FIG. 2 as having a single uplink interface 52 for establishing links 23,25 (FIG. 1), each ground station 14 will typically comprise several downlink interfaces 52, so that ground station 14 can communicate with more than one satellite
15 at a time, for example, with an approaching satellite and with a receding satellite simultaneously. Path 53 is shown to depict a means for establishing data links between downlink interfaces 52 and ground station controller 54. Data packets are received from ground station controller 54 using link 53. Also, it will be understood that while each ground station 14
20 is illustrated in FIG. 2 as having a single path 53, each ground station 14 will typically comprise several paths, so that more than one of downlink interfaces 52 can communicate with ground station controller 54 at one time.

Terrestrial connection interface 56 is shown to depict a mechanism
25 for establishing links 24 (FIG. 1) with other ground stations 14 (FIG. 1). It will be understood that while each ground station 14 is illustrated in FIG. 2 as having a single terrestrial connection interface 56 for establishing links 24 (FIG. 1), each ground station 14 will typically comprise several terrestrial connection interfaces 56, so that ground station 14 can communicate with
30 more than one other ground station at a time, for example, with at least two of its nearest neighboring ground stations simultaneously. Path 55 is shown to depict a means for establishing data links between terrestrial connection interfaces 56 and ground station controller 54. Data packets are sent to and received from ground station controller 54 using link 56. Also, it
35 will be understood that while each ground station 14 is illustrated in FIG. 2

5 as having a single path 55, each ground station 14 could comprise several paths, so that more than one of terrestrial connection interfaces 56 can communicate with ground station controller 54 at one time.

Ground station controller 54 is used to control ground station 14. Ground station controller 54 determines which data packets to send via
10 links 23,25. Ground station controller 54 sends outgoing data packets to uplink interface 50 via link 51. Ground station controller 54 determines which data packets should not be sent to uplink interface 50 and sends these data packets to terrestrial connection interface 56 via link 55. Ground station controller 54 also receives incoming data packets on link 53.
15 Ground station controller 54 also can receive incoming data packets from terrestrial connection interface 56 via link 55. Incoming data packets could be received, for example, when another ground station received a data packet destined for ground station 14. This might occur because some problem with the downlink to ground station 14 precluded sending the
20 packet directly to ground station 14.

FIG. 3 shows a flow chart for a procedure to route signals when an uplink re-route condition exists in accordance with a preferred embodiment of the present invention. Uplink re-route condition determining procedure 300 starts in step 302, for example, when uplink data is available. In step
25 304, an uplink communication channel between a ground station and a space-based switch is evaluated. The results of this evaluation of the uplink are recorded and these results help to determine the status of the space-to-ground link. In step 306, in a preferred embodiment of the present invention one or more of the terrestrial connections with other ground stations are
30 evaluated. This step determines the status for the ground segment. This involves determining the current status for all of the earth-based switches and the communication links between the earth-based switches. In step 308, a query is performed to determine if some re-route condition exists which warrants re-routing of one or more data packets. A re-route condition
35 could be, for example, based such factors as current traffic flow, economics,

5 and network health status. If a re-route condition exists, then the process branches to step 310 and one or more data packet are sent over a terrestrial route and procedure 300 continues with step 314. In a preferred embodiment, the data packets are sent over a "best" terrestrial route. The best terrestrial route can be determined using variables such as delay, cost,
10 and link loading. If a re-route condition does not exist, then the process branches to step 312 and the data packets are sent over the uplink and procedure 300 continues with step 314. In step 314, a query is performed to determine if additional data packets need to be sent. If more data exists then procedure 300 branches to step 308 to evaluate the re-route condition
15 again. If there is no more data to send at the present time, then procedure 300 branches to step 316 and ends.

FIG. 4 shows a flow chart for a procedure to route signals when a downlink re-route condition exists in accordance with a preferred embodiment of the present invention. Downlink re-route condition
20 determining procedure 400 starts in step 402, for example, when data arrives. In step 404, downlink data packets are received. When one ground station downlink is not functioning well, a second ground station receives data packets from the first ground station. The second ground station sends the data packet over the terrestrial link to the first ground station. In
25 step 406, in a preferred embodiment of the present invention one or more of the terrestrial connections with other ground stations are evaluated. This step determines the status for the ground segment. In step 410, a query is performed to determine if the received data packets are destined for this ground station or not. If the data packets are destined for this ground
30 station, then the process branches to step 412 and the data packets are processed. If the data packets are not destined for this ground station, then the process branches to step 414 and the data packets are stored and procedure 400 continues with step 416. In step 416, the data packets are sent to the next ground station over the terrestrial links. In step 418, a query
35 is performed to determine if additional data packets need to be received. If

5 more data exists then procedure 400 branches to step 408 to evaluate the re-route condition again. If there is no more data to receive at the present time, then procedure 400 branches to step 418 and ends.

The present invention facilitates handling of traffic via a single ground station in excess of the capacity of the space to ground link supported by the ground station. To implement this, excess uplink packet traffic is routed via
10 the terrestrial component to an alternate ground station for uplink via a link which is currently sparsely loaded. The processor which performs this routing decision may determine which packets are ultimately targeted for another ground station site and route those via terrestrial links, while routing
15 all satellite delivered traffic (e.g., traffic destined for a user unit directly communicating with a satellite entity, without an intervening ground station) via the space link, for example.

Alternatively, the controller may select terrestrial versus space links on a cost-per-packet basis, dictated by the time-of-day or other factors.
20 Downlink data destined for a ground station in excess of current link capacity may be routed to an alternate space to ground link (e.g., at another, less loaded ground station) and ultimately routed to the destination ground station via the terrestrial link to the target ground station. In this manner, a ground station can be designed for a lower link capacity, yet still support a
25 higher volume of peak traffic.

The present invention facilitates economic based facility decision as well. The ground station controller may make an uplink routing decision based upon current cost to transport a single packet using either the space link or terrestrial link, thus minimizing the cost per packet transported.

30 A key advantage of the present invention is the ability to automatically adapt to varying network conditions, including link failures and overloads. When the ground station controller detects traffic volume which is nearing (or at) capacity, alternate links can be immediately pressed into increased service. This reaction is independent of the cause of the overloading (e.g.,
35 either system component failure or simple increased demand). In this

5 manner, the system adapts to the current load in a most efficient manner. This feature allows designers to relax capacity specifications from those which are necessary to address peak traffic.

10 The present invention facilitates a power saving method in the satellite component as well. In a situation where a single satellite is supporting active links to more than one ground station, one of these ground station links may be terminated and, using the ground stations, traffic destined for the other ground station link can be rerouted to an alternate space to ground link supported by another satellite. Alternatively, this multiple link traffic could be combined (if current capacity allows) into a
15 single supported downlink, allowing the satellite to terminate the additional active links, thus saving power.

In some constellation configurations, particularly when there are constellation holes due to satellite failure or prior to a fully populated constellation, it may be much more efficient to utilize ground links for at
20 least a portion of a packet's route. In fact, there will be many situations in which a given ground station does not have connectivity to the network via the space links. But, it is imperative that the system provide continuous service. Also, in some constellations, an inter-connection condition could exist which prevents the timely packet routing between some satellites in
25 the constellation. To alleviate this condition in the prior art design, a packet must be sent to an alternate constellation satellite for delivery to its ultimate destination. This invention addresses both of these conditions by facilitating an alternate route, most likely one with far less inherent delay, for packet transport.

30 In a preferred embodiment, it is expected that the terrestrial links required by the present invention could be provided by existing telephony infrastructure or custom configured, installed and dedicated to the apparatus of the invention. The method and application of the present invention is independent of this consideration.

5 An alternative implementation of the method and apparatus of the present invention would utilize enhanced capability within the ground station to "pack/unpack" the native mode data such that it is compatible with currently existing telephony networks, and to route terrestrial data via the PSTN network to the other ground stations. Note that this method is more
10 complex, and increases resource demands within the ground station, when compared with the preferred implementation.

 The present invention improves reliability of prior art satellite-based communication networks, while increasing available capacity above what is currently supported for any ground based component. In effect, the invention
15 melds multiple ground to space links into a "virtual link". The present invention allows for ground infrastructure, and associated traffic volume capacity which exceeds the capacity of the ground station's space to ground link, utilizing a "virtual space to ground link".

 Multiple ground stations could be placed within a single satellite
20 footprint. This number is not limited by the satellite multiple-link capabilities, as is the case with the prior art system. This allows more system revenue through the marketing of additional ground stations.

 The present invention allows the creation and marketing of a "minimal" ground station configuration which would employ no
25 space/ground links. This ground station configuration would utilize the present invention to implement a virtual space/ground link. Once again, revenue can be increased. This minimal ground station can also be used to allow an operator to establish a ground station without antennas. This could result, for example, if there were problems with a license to operate
30 an RF antenna in a particular country.

 Prior art system design forces a complex implementation and methodology to react to a failure or decreased traffic carrying ability with any ground entity's space/ground link for any reason, including satellite full or partial failures or non-population of the constellation. The method and
35 apparatus of the present invention alleviates this concern without any

5 "reaction" time necessary. In fact, the method and apparatus of the present invention handles this case as a non-issue.

The present invention has been described above with reference to preferred embodiments. However, those skilled in the art will recognize that changes and modifications can be made in these preferred embodiments
10 without departing from the scope of the present invention. For example, while preferred embodiments have been described in terms of using specific procedures as shown in FIG. 3 and FIG. 4 for determining re-route conditions, other procedures or methods can also be employed. Accordingly, these and other changes and modifications which are obvious
15 to those skilled in the art are intended to be included within the scope of the present invention.



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Claims

What is claimed is:

- 10 1. A method for routing data through a communication system comprising at least one satellite and multiple ground stations which act as data switches for the communication system, the method comprising the steps of:
- a) establishing, by a first ground station, an uplink communication
- 15 channel for carrying the data between said first ground station and a satellite of said at least one satellite;
- b) establishing, by said first ground station, one or more terrestrial connections between said first ground station and at least one other ground station;
- 20 c) determining whether a re-route condition exists for which re-routing of at least some of the data carried on the uplink communication channel is desired; and
- d) when the re-route condition exists, sending said at least some of the data over the one or more terrestrial connections rather than exclusively
- 25 over said uplink communication channel.
2. The method as claimed in claim 1 further comprising the step of:
- e) when said re-route condition does not exist, sending all of the data on said uplink communication channel.

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5 3. A method for receiving data from at least one satellite of a communication system, wherein said communication system comprises at least one satellite and multiple ground stations which act as data switches for said communication system, the method comprising the steps of:

10 a) establishing, by a first ground station, a downlink communication channel for carrying the data between said first ground station and a satellite of said at least one satellite;

 b) establishing, by said first ground station, one or more terrestrial connections between said first ground station and at least one other ground station;

15 c) receiving the data carried on said downlink communication channel;

 d) evaluating a destination address within a data packet of said data to determine whether said first ground station is a destination of said data packet; and

20 e) when said first ground station is not the destination of said data packet, sending said data packet over a terrestrial connection to a second ground station.

25 4. A method as claimed in claim 1 wherein said sending step is preceded by the step of:

 storing said data packet of said data.

30 5. In a satellite communication system comprising a system control center, a plurality of satellites, and a plurality of ground stations which act as earth-based intelligent switches, certain ones of said plurality of satellites communicating with certain ones of said plurality of ground stations via radio communication links, a method for providing adaptive routing of communications to enhance service, said method comprising the following steps:



- 5 a) providing alternate terrestrial links between sets of ground stations in said plurality of ground stations; and
- b) using said alternate terrestrial links when said one of said radio communication links experiences a service issue.
- 10 6. The method as claim in claim 5, wherein said service issue is a cost problem.
7. The method as claim in claim 5, wherein said service issue is a capacity problem.
- 15 8. The method as claim in claim 5, wherein said service issue is a failed link problem.
9. The method as claim in claim 5, wherein said service issue is a
- 20 priority problem.
10. The method as claim in claim 5, wherein said service issue is a antenna licensing problem.
- 25 11. A ground station for use in a communication system comprising said ground station, at least one other ground station , and at least one satellite, said ground station comprising:
- a) a ground station controller for controlling the operation of said ground station by routing data over an uplink communication channel and
- 30 over a terrestrial channel when a problem exists with routing over the uplink communication channel;
- b) an uplink interface, coupled to said ground station controller, for establishing the uplink communication channel;
- c) a downlink interface, coupled to said ground station controller, for
- 35 establishing a downlink communication channel; and



- 5 d) a terrestrial connection interface, coupled to said ground station controller, for establishing one or more terrestrial connections between said first ground station and said at least one other ground station.

12. A ground station for use in a communication system comprising
10 said ground station, at least one other ground station , and at least one satellite, said ground station comprising:

- a) a ground station controller for controlling the operation of said ground station by routing uplink data over a terrestrial channel; and
 b) a terrestrial connection interface, coupled to said ground station
15 controller, for establishing one or more terrestrial connections between said first ground station and said at least one other ground station.

13. A communication system comprising:

- a) at least one satellite; and
20 b) multiple ground stations located proximate to a surface of an earth, wherein a ground station of said multiple ground stations is coupled to said at least one satellite and to at least one other of said multiple ground stations and said ground station sends data packets over an uplink communication channel or over a terrestrial link to another ground station
25 when a problem exists with the uplink communication channel.