GROUND NETWORK WITH ACCESS NODE CLUSTERS FOR END-TO-END BEAMFORMING

TECHNICAL FIELD

[0001] The disclosed systems, methods, and apparatuses relate to end-to-end beamforming in a system using an end-to-end relay.

BACKGROUND

[0002] Wireless communication systems, such as satellite communication systems, provide a means by which data, including audio, video, and various other sorts of data, may be communicated from one location to another. Information originates at a first station, such as a first ground-based station, and is transmitted to a wireless relay, such as a communication satellite. Information received by the wireless relay is retransmitted to a second station, such as a second ground-based station. In some wireless relay communication systems, either the first or second station (or both) are mounted on a craft, such as an aircraft, watercraft, or landcraft. Information may be transmitted in just one direction (*e.g.*, from a first ground-based station to a second ground-based station only) or may be transmitted in both directions (*e.g.*, also from the second ground-based station to the first ground-based station).

[0003] In a wireless relay communication system in which the wireless relay is a satellite, the satellite may be a geostationary satellite, in which case the satellite's orbit is synchronized to the rotation of the Earth, keeping the coverage area of the satellite essentially stationary with respect to the Earth. In other cases, the satellite is in an orbit about the Earth that causes the coverage area of the satellite to move over the surface of the Earth as the satellite traverses its orbital path.

[0004] The signals that are directed to or from a first station may be directed by using an antenna that is shaped to focus the signal into a narrow beam. Such antennas typically have a paraboloid shaped reflector to focus the beam.

[0005] In some cases, a beam may be formed electronically by adjusting the gain and phase (or time delay) of signals that are transmitted, received, or both from several elements of a phased array antenna. By properly selecting the relative phase and gain transmitted and/or received by each element of a phased array antenna, the beam may be directed. In most cases, all of the energy being transmitted from a ground-based station is intended to be received by

CLAIMS

1. A system for providing a communication service to user terminals geographically distributed over a user coverage area via an end-to-end relay comprising multiple receive/transmit signal paths, comprising:

a beam signal interface that obtains multiple forward beam signals comprising forward user data streams for transmission to the user terminals grouped by multiple forward user beam coverage areas;

a beam weight generator that generates a forward beam weight matrix for end-to-end beamforming to the multiple forward user beam coverage areas via the end-to-end relay;

a beamformer coupled with the beam signal interface and the beam weight generator, the beamformer comprising a forward matrix multiplier that obtains a plurality of access-node specific forward signals based on a matrix product of the forward beam weight matrix and a vector of the forward beam signals; and

a plurality of access node clusters, wherein each access node cluster is associated with a corresponding one of a plurality of access node areas, and wherein each of the plurality of access node clusters comprises:

a plurality of access nodes geographically distributed within the corresponding access node area, wherein each access node cluster obtains a respective set of the plurality of access node-specific forward signals, and wherein each of the plurality of access nodes of the each access node cluster comprises a transmitter that transmits a respective forward uplink signal to the end-to-end relay based on one of the respective set of the plurality of access node-specific forward signals, and wherein the respective forward uplink signals are pre-corrected to compensate for respective path delays and phase shifts introduced between the plurality of access nodes and the end-to-end relay.

2. The system of claim 1, wherein each of the plurality of access node areas is non-overlapping with other access node areas of the plurality of access node areas.

3. The system of claim 1, wherein at least one of the plurality of access node areas is non-overlapping with the user coverage area.

4. The system of claim 1, wherein a first set of forward uplink signals from a first access node cluster of the plurality of access node clusters are carried via a first set of the multiple

receive/transmit signal paths and a second set of forward uplink signals from a second access node cluster of the plurality of access node clusters are carried via a second set of the multiple receive/transmit signal paths.

5. The system of claim 4, wherein the first set of forward uplink signals and the second set of forward uplink signals both contribute to forming at least one forward user beam associated with at least one of the multiple forward user beam coverage areas.

6. The system of claim 4, wherein:

the first set of the multiple receive/transmit signal paths are coupled with a first array of cooperating user-link constituent antenna elements of a user-link antenna subsystem of the end-to-end relay, and the second set of the multiple receive/transmit signal paths are coupled with a second array of cooperating user-link constituent antenna elements of the user-link antenna subsystem;

the user coverage area comprises a first user coverage area and a second coverage area;

the first array of cooperating user-link constituent antenna elements is associated with the first user coverage area; and

the second array of cooperating user-link constituent antenna elements is associated with the second user coverage area.

7. The system of claim 1, wherein the multiple receive/transmit signal paths are selectively coupled via a first set of switches to one of a first array of cooperating feeder-link constituent antenna elements associated with a first access node cluster of the plurality of access node clusters or a second array of cooperating feeder-link constituent antenna elements associated with a second access node cluster of the plurality of access node clusters.

8. The system of claim 7, wherein the user coverage area comprises a first user coverage area and a second user coverage area, and wherein the multiple receive/transmit signal paths are selectively coupled via a second set of switches to one of a first array of cooperating user-link constituent antenna elements associated with the first user coverage area or a second array of cooperating user-link constituent antenna elements associated with the second user coverage area.

9. The system of claim 8, wherein the first user coverage area is non-overlapping with the corresponding access node area of the first access node cluster and the second user coverage area is non-overlapping with the corresponding access node area of the second access node cluster.

10. The system of claim 1, wherein:

each of the plurality of access nodes comprises a receiver that receives a respective return downlink signal from the end-to-end relay via an antenna, each of the respective return downlink signals comprising a composite of return uplink signals transmitted from a plurality of the user terminals and relayed by at least a subset of the multiple receive/transmit signal paths of the end-to-end relay to form a composite return signal;

the beam weight generator generates a return beam weight matrix for end-to-end beamforming of transmissions from multiple return user beam coverage areas to the plurality of access node clusters via the end-to-end relay; and

the beamformer comprises a return matrix multiplier that obtains respective return beam signals for the multiple return user beam coverage areas based on a matrix product of the return beam weight matrix and a vector of the respective composite return signals, wherein the respective composite return signals are corrected for timing and phase for respective path delays and phase shifts between the end-to-end relay and the plurality of access nodes.

11. A method for providing a communication service to user terminals geographically distributed over a user coverage area via an end-to-end relay comprising multiple receive/transmit signal paths, comprising:

obtaining multiple forward beam signals comprising forward user data streams for transmission to a plurality of the user terminals grouped by multiple forward user beam coverage areas;

identifying a forward beam weight matrix for end-to-end beamforming of transmissions from a set of access nodes to the multiple forward user beam coverage areas via the end-to-end relay, the set of access nodes comprising access nodes of at least one of a plurality of access node clusters, wherein each of the plurality of access node clusters comprises a plurality of access nodes at geographically distributed locations within a corresponding one of a plurality of access node areas;

generating respective access node-specific forward signals for transmission by the set of access nodes, each of the respective access node-specific forward signals comprising a composite of respective forward beam signals weighted by respective forward beamforming weights of the forward beam weight matrix; and

transmitting respective forward uplink signals from the set of access nodes based on the respective access node-specific forward signals, wherein the respective forward uplink signals are pre-corrected to compensate for respective path delays and phase shifts between the plurality of access nodes and the end-to-end relay.

12. The method of claim 11, wherein the transmitting comprises:

transmitting a first set of forward uplink signals from a first access node cluster of the plurality of access node clusters to the end-to-end relay to be carried via a first set of the multiple receive/transmit signal paths; and

transmitting a second set of forward uplink signals from a second access node cluster of the plurality of access node clusters to the end-to-end relay to be carried via a second set of the multiple receive/transmit signal paths.

13. The method of claim 12, further comprising:

forming at least one forward user beam for providing the communication service in at least one of the multiple forward user beam coverage areas using at least a subset of the first set of forward uplink signals and at least a subset of the second set of forward uplink signals.

14. The method of claim 12, wherein the user coverage area comprises a first user coverage area and a second user coverage area and further comprising forming a first set of user beams for providing the communication service in the first user coverage area from the first set of forward uplink signals and forming a second set of user beams for providing the communication service in the second user coverage area from the second set of forward uplink signals.

15. The method of claim 11, further comprising:

selectively coupling inputs of the multiple receive/transmit signal paths to a first array of cooperating feeder-link constituent antenna elements associated with a first access node cluster of the plurality of access node clusters during a first time period; and

selectively coupling inputs of the multiple receive/transmit signal paths to a second array of cooperating feeder-link constituent antenna elements associated with a second access node cluster of the plurality of access node clusters during a second time period.

16. The method of claim 15, wherein the user coverage area comprises a first user coverage area and a second user coverage area, and further comprising:

selectively coupling outputs of the multiple receive/transmit signal paths to a first array of cooperating user-link constituent antenna elements associated with the first user coverage area during the first time period; and

selectively coupling outputs of the multiple receive/transmit signal paths to a second array of cooperating user-link constituent antenna elements associated with the second user coverage area during the second time period.

17. The method of claim 11, further comprising:

receiving, by a receiver at each of the plurality of access nodes, a respective return downlink signal from the end-to-end relay, each of the respective return downlink signals comprising a composite of return uplink signals transmitted from a plurality of the user terminals and relayed by at least a subset of the multiple receive/transmit signal paths of the end-to-end relay to form a composite return signal;

generating a return beam weight matrix for end-to-end beamforming of transmissions from multiple return user beam coverage areas to the plurality of access node clusters via the end-to-end relay; and

obtaining respective return beam signals for the multiple return user beam coverage areas based on a matrix product of the return beam weight matrix and a vector of the respective composite return signals, wherein the respective composite return signals are corrected for timing and phase for respective path delays and phase shifts between the end-to-end relay and the plurality of access nodes.

18. A system for providing a communication service to user terminals geographically distributed over a user coverage area via an end-to-end relay comprising multiple receive/transmit signal paths, comprising:

a plurality of access node clusters, wherein each access node cluster is associated with a corresponding one of a plurality of access node areas, and wherein each of the plurality of access node clusters comprises:

a plurality of access nodes geographically distributed within the corresponding access node area, each of the plurality of access nodes comprising a receiver that receives a respective return downlink signal from the end-to-end relay, each of the respective return downlink signals comprising a composite of return uplink signals transmitted from a plurality of the user terminals and relayed by at least a subset of the multiple receive/transmit signal paths of the end-to-end relay to form a composite return signal;

a beam weight generator that generates a return beam weight matrix for end-to-end beamforming of transmissions from multiple return user beam coverage areas to the plurality of access node clusters via the end-to-end relay; and

a return beamformer coupled with the beam weight generator, the return beamformer comprising a matrix multiplier that obtains respective return beam signals for the multiple return user beam coverage areas based on a matrix product of the return beam weight matrix and a vector of the respective composite return signals, wherein the respective composite return signals are corrected for timing and phase for respective path delays and phase shifts between the end-to-end relay and the plurality of access nodes.

19. The system of claim 18, wherein a first access node cluster of the plurality of access node clusters receives a first set of return downlink signals corresponding to the return uplink signals carried via a first set of the multiple receive/transmit signal paths and a second access node cluster of the plurality of access node clusters receives a second set of return downlink signals corresponding to the return uplink signals carried via a second set of the multiple receive/transmit signal paths.

20. The system of claim 19, wherein the first set of return downlink signals and the second set of return downlink signals both contribute to forming at least one return user beam associated with at least one of the multiple return user beam coverage areas.

21. The system of claim 19, wherein:

inputs of the first set of the multiple receive/transmit signal paths are coupled with a first array of cooperating user-link constituent antenna elements of a user-link antenna subsystem of the end-to-end relay, and inputs of the second set of the multiple receive/transmit signal paths are coupled with a second array of cooperating user-link constituent antenna elements of the user-link antenna subsystem;

the user coverage area comprises a first user coverage area and a second coverage area;

the first array of cooperating user-link constituent antenna elements is associated with the first user coverage area; and

the second array of cooperating user-link constituent antenna elements is associated with the second user coverage area.

22. The system of claim 18, wherein the multiple receive/transmit signal paths are selectively coupled via a first set of switches to one of a first array of cooperating feeder-link constituent antenna elements for transmitting a first set of return downlink signals to a first access node cluster of the plurality of access node clusters or a second array of cooperating feeder-link constituent antenna elements for transmitting a second set of return downlink signals to a second access node cluster of the plurality of access node clusters.

23. The system of claim 22, wherein the user coverage area comprises a first user coverage area and a second user coverage area, and wherein the multiple receive/transmit signal paths are selectively coupled via a second set of switches to one of a first array of cooperating user-link constituent antenna elements associated with the first user coverage area or a second array of cooperating user-link constituent antenna elements associated with the second user coverage area.

24. The system of claim 23, wherein the first user coverage area is non-overlapping with the corresponding access node area of the first access node cluster and the second user coverage area is non-overlapping with the corresponding access node area of the second access node cluster.

25. A method for providing a communication service to user terminals geographically distributed over a user coverage area via an end-to-end relay comprising multiple receive/transmit signal paths, the method comprising:

receiving, at a set of access nodes, respective return downlink signals from the end-to-end relay, each of the respective return downlink signals comprising return user data streams transmitted from a plurality of the user terminals and relayed by the end-to-end relay, to form a composite return signal, the set of access nodes comprising access nodes of at least one of a plurality of access node clusters, wherein each of the plurality of access node clusters comprises a plurality of access nodes at geographically distributed locations within a corresponding one of a plurality of access node areas;

identifying a return beam weight matrix for end-to-end beamforming of transmissions from multiple return user beam coverage areas to the set of access nodes via the end-to-end relay;

applying, to each of the respective composite return signals, respective beamforming weights of the return beam weight matrix to obtain a respective plurality of weighted composite return signals associated with each of the multiple return user beam coverage areas; and

combining, for the each of the multiple return user beam coverage areas, the respective plurality of weighted composite return signals to obtain a return beam signal associated with the each of the multiple return user beam coverage areas, wherein the respective plurality of weighted composite return signals are corrected to compensate for respective path delays and phase shifts between the end-to-end relay and the set of access nodes prior to the combining.

26. The method of claim 25, wherein the receiving comprises:

receiving, at a first access node cluster of the plurality of access node clusters, a first set of return downlink signals corresponding to the return uplink signals carried via a first set of the multiple receive/transmit signal paths; and

receiving, at a second access node cluster of the plurality of access node clusters a second set of return downlink signals corresponding to the return uplink signals carried via a second set of the multiple receive/transmit signal paths.

27. The method of claim 26, further comprising:

forming at least one return user beam associated with at least one of the multiple return user beam coverage areas using at least a subset of the first set of return downlink signals and at least a subset of the second set of return downlink signals.

28. The method of claim 26, wherein the user coverage area comprises a first user coverage area and a second user coverage area, the method further comprising:

forming a first set of return user beams associated with the first user coverage area from the first set of return downlink signals and forming a second set of return user beams associated with the second user coverage area from the second set of return downlink signals.

29. The method of claim 25, wherein the user coverage area comprises a first user coverage area and a second user coverage area, and further comprising:

selectively coupling inputs of the multiple receive/transmit signal paths to a first array of cooperating user-link constituent antenna elements associated with the first user coverage area during a first time period; and

selectively coupling the multiple receive/transmit signal paths to a second array of cooperating user-link constituent antenna elements associated with the second user coverage area during a second time period.

30. The method of claim 29, further comprising:

selectively coupling outputs of the multiple receive/transmit signal paths to a first array of cooperating feeder-link constituent antenna elements associated with a first access node cluster of the plurality of access node clusters during the first time period; and

selectively coupling outputs of the multiple receive/transmit signal paths to a second array of cooperating feeder-link constituent antenna elements associated with a second access node cluster of the plurality of access node clusters during the second time period.