[0047] Another category of approaches to impairment compensation involves limited beamforming. As described herein, feeder beams are produced using focused antenna elements, and some embodiments of the focused antenna elements are implemented according to a multiple feed per beam (MFPB) architecture. In MFPB architectures, each antenna feed can be associated with a weighted and combined set of multiple feed signals. To form each weighted and combined set, multiple feed signals can be passed through phase shifters, summers, and/or other hardware that can adjust amplitude weights, phase, and/or other characteristics of the resulting combined feed signal according to applied coefficients. The applied coefficients can be stored in a beamforming coefficient memory on the satellite 140. The coefficients can be pre-computed and/or adaptively updated (e.g., using feedback to the satellite from the gateways), so that the resulting combined feed signals can generated statically or adaptively. Applying the coefficients effectively applies some beamforming to the feeder signals, which can be used to compensate for impairments in the feeder antenna pattern. For example, crosstalk can be predetermined (e.g., estimated or pre-computed) or measured using any of the approaches described above. Rather than using equalization or cancelation to remove the measured crosstalk, coefficients in the MFPB architecture can be used to apply limited beamforming to at least partially correct for the antenna impairments causing the crosstalk (e.g., in a predefined or adaptive manner). Some embodiments can use a hybrid of the categories of approaches. For example, equalization or cancelation can be used to remove measured crosstalk on one of the feeder uplink or downlink, and limited beamforming can be used to remove crosstalk on the other of the feeder uplink or downlink.

[0048] Effective implementation of MSSMFL can rely on proper mutual synchronization of signals among the spatially separated feeder links. A number of approaches can be used to implement such mutual synchronization, and those approaches can depend on characteristics (e.g., overlap, etc.) of the user and feeder coverage areas. For example, in the forward direction, the gateway terminals 130 transmit forward uplink signals to the satellite 140, which are received by antenna elements of the feeder antenna subsystem 230, communicated through forward-link pathways of the forward repeater subsystem 240 to the user antenna subsystem 250, and transmitted as forward downlink signals by antenna elements of the user antenna subsystem 250. To enable the transmitted forward downlink signals to spatially combine to form forward user beams, embodiments use feeder-side ground segment components to generate the feeder signals 135 as mutually synchronized, beam-weighted forward uplink signals. In general, the satellite 140 (e.g., the various components illustrated in FIG. 4) can be a means for relaying mutually phase-synchronized, beam-weighted uplink signals as phase-coherent downlink signals that spatially combine to form forward user beams. For example, the FAEs 243 can receive mutually phase-synchronized, beam-weighted uplink signals; and the signals can be passed through the forward repeater subsystem 240 and transmitted by the BAEs 247 as phase-coherent downlink signals that spatially combine to form forward user beams. To enable receipt of the forward uplink signals, embodiments include multiple, spatially separated means for communicating the mutually phase-synchronized, beam-weighted uplink signals; and means for mutually phase-synchronizing the uplink signals at the spatially separated means for communicating, so that the forward uplink signals will be received phase-synchronously by the means for relaying. For example, embodiments use ground components in conjunction with satellite signaling to mutually synchronize feeder-link signals between geographically distributed gateway terminals 130 and the satellite 140. Similarly, in the return direction, the user terminals transmit return uplink signals to the satellite 140, which are received by antenna elements of the user antenna subsystem 250, communicated through return-link pathways of the return repeater subsystem 340 to the feeder antenna subsystem 230, and transmitted as return downlink signals by antenna elements of the feeder antenna subsystem 230. Using feeder-side ground segment components to mutually synchronize and beam-weight the received return downlink signals can effectively form the return user beams from which the return uplink signals were transmitted.

a beam-weighted forward signal input in communication with the forward beamformer (210) via a distribution network (120);

a synchronization input coupled with a synchronization subsystem (125); and

a feeder uplink signal output that corresponds to a mutually synchronized version of the beam-weighted forward signal input in accordance with the synchronization input; and

the satellite of any of claims 1 – 9, wherein each forward-link FAE port is communicatively coupled with the feeder uplink signal output of a corresponding one of the gateway terminals.

11. The satellite communications system of claim 10, wherein:

each geographically distributed gateway terminal further comprises:

a return signal output in communication with a return beamformer via the distribution network; and

a feeder downlink signal input; and

each FAE of the feeder antenna subsystem further has a return-link FAE port;

each BAE of the user antenna subsystem further has a return-link BAE port; and

the satellite further comprises a return repeater subsystem (340) having a return uplink frequency range and a return downlink frequency range, wherein the return repeater subsystem comprises a plurality of return-link pathways, each coupled between one of the return-link BAE ports and one of the return-link FAE ports, and each having an input in the return uplink frequency range and an output in the return downlink frequency range,

wherein the return-link pathways are configured to generate a plurality of return downlink signals for transmission by the FAEs, the return downlink signals generable from return uplink signals received at the BAEs from at least one user terminal, thereby forming at least one return user beam for communications with the at least one user terminal.

12. The satellite communications system of claim 10, wherein:

surface distortions on the feeder reflector define feeder antenna impairment regions (1210); and

the plurality of geographically distributed gateway terminals are positioned away from the feeder antenna impairment regions.

13. The satellite communications system of claim 10, wherein:

surface distortions on the feeder reflector define feeder antenna impairment regions; and

the feeder antenna subsystem comprises a multiple feed per beam antenna to apply limited beamforming to feeder beams to compensate for the feeder antenna impairment regions.

14. The satellite communications system of claim 13, wherein:

the multiple feed per beam antenna comprises a beamforming coefficient memory having pre-computed beamforming coefficients stored therein, the pre-computed beamforming coefficients used to apply the limited beamforming.

15. The satellite communications system of claim 13, wherein:

the multiple feed per beam antenna comprises a beamforming coefficient memory having adaptively updated coefficients stored therein, the adaptively updated coefficients used to apply the limited beamforming.

16. The satellite communications system of claim 10, wherein:

the plurality of geographically distributed gateway terminals comprises M gateway terminals; and

the generating comprises converting from the return uplink frequency range to the return downlink frequency range.

38. The method of any of claims 31, 32, 35, or 36, wherein:

the receiving is by a wireless relay; and

the synchronizing comprises:

receiving a beacon signal at the gateway locations, the beacon signal transmitted from the relay;

receiving, at each gateway location, a respective loopback signal transmitted from the gateway location; and

phase-synchronizing, at each gateway location, the received respective loopback signal with the received beacon signal.

39. The method of any of claims 31 - 38, further comprising:

receiving feed input signals (1512) from the gateway locations; and

generating crosstalk-corrected feed signals (1514) as a function of the feed input signals and a stored crosstalk matrix.

40. The method of claim 39, further comprising:

sequentially coupling a loopback antenna element, over a plurality of time slots, with each of the focused feeder uplink antenna elements, thereby, in each of the time slots, transmitting a repeated loopback signal to the gateway locations in response to receiving a loopback beacon signal from the gateway location associated with the focused feeder uplink antenna element that is sequentially coupled in the time slot,

wherein, over the plurality of time slots, the feed input signals correspond to the repeated loopback signals as received at the gateway locations.

41. The method of claim 39, further comprising:

sequentially coupling a loopback antenna element, over a plurality of time slots, with each of a plurality of focused feeder downlink antenna elements, thereby, in each of the time slots, transmitting a repeated loopback signal to the gateway location associated with the focused feeder downlink antenna elements that is sequentially coupled in the time slot in response to receiving a loopback beacon signal from the gateway locations,

wherein, in each of the time slots, at least one of the feed input signals corresponds to the repeated loopback signal as received by at least one of the gateway locations in the time slot.

42. The method of any of claims 31 - 38, further comprising:

receiving at least one probe signal by at least one of the gateway locations from at least one user terminal; and

generating at least one crosstalk-corrected feed signal as a function of comparing the at least one probe signal with an expected feed signal.

43. The method of any of claims 31 - 38, further comprising:

receiving at least one probe signal by at least one user terminal from at least one of the gateway locations; and

generating at least one crosstalk-corrected feed signal as a function of comparing the at least one probe signal with an expected user signal.