

CLAIMS

What is claimed is:

- 1 1. A system for communications, comprising:
2 a first satellite (105) in a first orbit;
3 a plurality of second satellites (115) in second orbits that are lower than the
4 first orbit, wherein the plurality of second satellites (115) are configured to detect respective
5 signal components (125) of a signal originating from a geographic area (140) and to relay the
6 respective signal components (125) to the first satellite (105); and
7 a beamformer (155, 190) configured to form a beam associated with the
8 geographic area (140) to obtain a beam signal based at least in part on the respective signal
9 components (125) and an estimated return channel, wherein the estimated return channel
10 comprises channel components between the geographic area (140) and the plurality of second
11 satellites (115).
- 1 2. The system of claim 1, wherein the first satellite (105) comprises:
2 a plurality of transponders (175), wherein to transmit a representation of the
3 signal to a ground system (130), each transponder (175) of the plurality of transponders (175)
4 is configured to receive the respective signal components (125) relayed by the plurality of
5 second satellites (115) and to transmit a representation of the respective signal components
6 (125) to the ground system (130).
- 1 3. The system of any one of claims 1 or 2, wherein each satellite of the
2 plurality of second satellites (115) comprises:
3 at least one repeater (160), wherein to relay the respective signal components
4 (125) to the first satellite (105), repeaters (160) of the plurality of second satellites (115) are
5 configured to amplify the respective detected signal components (125) and transmit
6 respective amplified signal components (110) to the first satellite (105).
- 1 4. The system of claim 3, wherein the at least one repeater (160) is a non-
2 processing repeater.
- 1 5. The system of any one of claims 3 or 4, wherein the repeaters (160) of
2 the plurality of second satellites (115) are configured to transmit the respective amplified

3 signal components (110) at a same frequency as the respective signal components (125)
4 detected at the repeaters (160).

1 6. The system of any one of claims 3 through 5, wherein the repeaters
2 (160) of the plurality of second satellites (115) are configured to transmit the respective
3 amplified signal components (110) at a different frequency than the respective signal
4 components (125) detected at the repeaters (160).

1 7. The system of any one of claims 3 through 6, wherein each of the
2 repeaters (160) of the plurality of second satellites (115) are configured to transmit a
3 respective amplified signal component at a respective frequency of a plurality of frequencies.

1 8. The system of any one of claims 1 through 7, wherein:
2 the respective signal components (125) detected by the plurality of second
3 satellites (115) are detected via a first channel between the plurality of second satellites (115)
4 and the geographic area (140),
5 the respective signal components (125) are relayed to the first satellite (105)
6 via a second channel between the plurality of second satellites (115) and the first satellite
7 (105), and
8 the first satellite (105) is configured to transmit a representation of the
9 respective signal components (125) to a ground system (130) via a third channel between the
10 first satellite (105) and the ground system (130).

1 9. The system of any one of claims 1 through 8, wherein the beamformer
2 (155, 190) is further configured to:
3 estimate a return covariance associated with the estimated return channel;
4 determine beam coefficients of the beam based at least in part on the estimated
5 return channel and the return covariance; and
6 apply the beam coefficients to the respective signal components (125) to
7 obtain the beam signal.

1 10. The system of any one of claims 1 through 9, further comprising:
2 a ground system (130) comprising:
3 at least one gateway (135) configured to receive a representation of the
4 respective signal components (125); and

5 the beamformer (155, 190), wherein the beamformer (155, 190) is
6 coupled with the at least one gateways (135) and configured to apply beam
7 coefficients of the beam to the representation of the respective signal components
8 (125) to obtain the beam signal.

1 11. The system of any one of claims 1 through 9, wherein the first satellite
2 (105) comprises the beamformer (155, 190).

1 12. The system of any one of claims 1 through 9 or 11, wherein the first
2 satellite (105) is configured to transmit the beam signal to a ground system (130).

1 13. The system of any one of claims 1 through 12, wherein:
2 the plurality of second satellites (115) is configured to detect a plurality of
3 respective signal components (125) of a plurality of signals originating from a plurality of
4 geographic areas (140), the plurality of signals comprising the signal and the plurality of
5 geographic areas (140) comprising the geographic area (140); and
6 the beamformer (155, 190) is configured to form a plurality of beams
7 associated with the plurality of geographic areas (140) to obtain a plurality of beam signals
8 based at least in part on the plurality of respective signal components (125) and a plurality of
9 estimated return channels, the plurality of beams comprising the beam, the plurality of beam
10 signals comprising the beam signal, and the plurality of estimated return channels comprising
11 the estimated return channel.

1 14. The system of claim 13, wherein the beamformer (155, 190) is further
2 configured to:
3 estimate a return covariance associated with the plurality of geographic areas
4 (140); and
5 determine beam coefficients of the beam based at least in part on the estimated
6 return channel and the return covariance and to apply the beam coefficients to the plurality of
7 respective signal components (125) to obtain the plurality of beam signals.

1 15. The system of any one of claims 1 through 14, wherein the first
2 satellite (105) is configured to detect a direct signal component (120) of the signal.

- 1 16. The system of claim 15, wherein the beamformer (155, 190) is further
2 configured to:
3 obtain the beam signal based at least in part on the direct signal component
4 (120).
- 1 17. The system of any one of claims 1 through 16, wherein the
2 beamformer (155, 190) is further configured to:
3 estimate the estimated return channel based at least in part on other signals
4 received from one or more other geographic areas (140).
- 1 18. The system of claim 17, wherein the other signals comprise one or
2 more reference signals transmitted by transmitters in known locations.
- 1 19. The system of any one of claims 1 through 18, wherein the plurality of
2 second satellites (115) comprises:
3 a first set of satellites in a first orbital plane (405-1) of the second orbits.
- 1 20. The system of claim 19, wherein the plurality of second satellites (115)
2 further comprises:
3 a second set of satellites in a second orbital plane (405-2) of the second orbits.
- 1 21. The system of any one of claims 1 through 20, further comprising:
2 a processor (153, 187) configured to demodulate the beam signal.
- 1 22. The system of any one of claims 1 through 21, further comprising:
2 a processor (153, 187) that comprises the beamformer (155, 190).
- 1 23. The system of any one of claims 1 through 22, wherein the first orbit is
2 a geostationary orbit.
- 1 24. A method for communications, comprising:
2 obtaining beam coefficients of a beam associated with a geographic area (140)
3 based at least in part on an estimated return channel that comprises a first channel component
4 between the geographic area (140) and a plurality of second satellites (115) and a second
5 channel component between the plurality of second satellites (115) and a first satellite (105);
6 and

7 forming a beam associated with the geographic area (140) to obtain a beam
8 signal based at least in part on the beam coefficients and a plurality of signal components
9 (125) of a signal originating from the geographic area (140) and relayed by the plurality of
10 second satellites (115) to the first satellite (105).

1 25. The method of claim 24, further comprising:
2 receiving a representation of the plurality of signal components (125), wherein
3 the beam signal is obtained based at least in part on applying the beam coefficients to the
4 representation of the plurality of signal components (125).

1 26. The method of any one of claims 24 or 25, further comprising:
2 transmitting a representation of the signal to a ground system (130) based at
3 least in part on transmitting a representation of the respective signal components (125).

1 27. The method of any one of claims 24 through 26, further comprising:
2 receiving respective signal components (125) from the plurality of second
3 satellites (115), the plurality of signal components (125) comprising the respective signal
4 components (125).

1 28. The method of any one of claims 24 through 27, further comprising:
2 receiving the respective signal components (125) from the plurality of second
3 satellites (115) at a same frequency as the plurality of signal components (125) of the signal
4 detected at the plurality of second satellites (115).

1 29. The method of any one of claims 24 through 28, further comprising:
2 receiving the respective signal components (125) from the plurality of second
3 satellites (115) at one or more different frequencies than the plurality of signal components
4 (125) of the signal detected at the plurality of second satellites (115).

1 30. The method of any one of claims 24 through 29, further comprising:
2 estimating a return channel from a geographic area (140), the return channel
3 comprising a first channel component between a first satellite (105) and a plurality of second
4 satellites (115) and a second channel component between the plurality of second satellites
5 (115) and the geographic area (140).

1 31. The method of claim 30, wherein estimating the return channel of the
2 geographic area (140) comprises:
3 determining a plurality of return channels based at least in part on one or more
4 other signals received from known geographic locations; and
5 interpolating characteristics of the plurality of return channels to estimate
6 characteristics of the return channel.

1 32. The method of claim 31, wherein the one or more other signals
2 comprise one or more reference signals transmitted by transmitters in the known geographic
3 locations.

1 33. The method of any one of claims 24 through 32, further comprising:
2 obtaining a representation of the plurality of signal components (125) relayed
3 by the plurality of second satellites (115) and a representation of a direct signal component
4 (120) of the signal received at the first satellite (105) from the geographic area (140), wherein
5 the beam signal is determined based at least in part on the representation of the plurality of
6 signal components (125) and the representation of the direct signal component (120).

1 34. The method of any one of claims 24 through 33, further comprising:
2 estimating a return covariance associated with the geographic area (140) based
3 at least in part on the return channel; and
4 determining beam coefficients of the beam based at least in part on the return
5 channel and the return covariance.

1 35. The method of any one of claims 24 through 34, wherein obtaining the
2 beam signal comprises:
3 applying the beam coefficients of the beam to a representation of the plurality
4 of signal components (125) of the signal to obtain the beam signal.

5 36. The method of any one of claims 24 through 35, further comprising:
6 estimating a plurality of return channels from a plurality of geographic areas
7 (140), the plurality of return channels comprising the return channel and the plurality of
8 geographic areas (140) comprising the geographic area (140);
9 estimating a return covariance based at least in part on the plurality of return
10 channels; and

11 determining a plurality of beam coefficients of a plurality of beams based at
12 least in part on the plurality of return channels and the return covariance, the plurality of
13 beam coefficients comprising the beam coefficients and the plurality of beams comprising the
14 beam.

1 37. The method of claim 36, further comprising:
2 applying the plurality of beam coefficients of the plurality of beams to
3 representations of pluralities of signal components (125) associated with a plurality of signals
4 originating from the plurality of geographic areas (140) to obtain one or more beam signals,
5 the one or more beam signals comprising the beam signal.

1 38. A communications device (605), comprising:
2 a beamformer (155, 190) configured to:
3 obtain beam coefficients of a beam associated with a geographic area
4 (140) based at least in part on an estimated return channel that comprises a first
5 channel component between the geographic area (140) and a plurality of second
6 satellites (115) and a second channel component between the plurality of second
7 satellites (115) and a first satellite (105); and
8 form a beam associated with the geographic area (140) to obtain a
9 beam signal based at least in part on the beam coefficients and a plurality of signal
10 components (125) of a signal originating from the geographic area (140) and relayed
11 by the plurality of second satellite (115) to the first satellite (105).

1 39. The communications device (605) of claim 38, further comprising a
2 transponder (175) that is configured to:
3 receive a representation of the plurality of signal components from the
4 plurality of second satellites (115), wherein the beam signal is obtained based at least in part
5 on applying the beam coefficients to the representation of the plurality of signal components.

1 40. The communications device (605) of any one of claims 38 or 39,
2 further comprising a transponder (175) that is configured to:
3 transmit a representation of the signal to a ground system (130) based at least
4 in part on transmitting a representation of the respective signal components (125).

1 41. The communications device (605) of any one of claims 38 through 40,
2 further comprising a transponder (175) that is configured to:
3 receive respective signal components (125) from the plurality of second
4 satellites (115), the plurality of signal components (125) comprising the respective signal
5 components (125).

1 42. The communications device (605) of any one of claims 38 through 41,
2 further comprising a transponder (175) that is configured to:
3 receive the respective signal components (125) from the plurality of second
4 satellites (115) at one or more different frequencies than the plurality of signal components
5 (125) of the signal detected at the plurality of second satellites (115).

1 43. The communications device (605) of any one of claims 38 through 42,
2 further comprising:
3 a transponder (175) configured to receive the respective signal components
4 (125) from the plurality of second satellites (115) at a same frequency as the plurality of
5 signal components (125) of the signal detected at the plurality of second satellites (115).

1 44. The communications device (605) of any one of claims 38 through 43,
2 wherein the beamformer (155, 190) is further configured to:
3 estimate a return channel from a geographic area (140), the return channel
4 comprising a first channel component between a first satellite (105) and a plurality of second
5 satellites (115) and a second channel component between the plurality of second satellites
6 (115) and the geographic area (140).

1 45. The communications device (605) of claim 44, wherein, to estimate the
2 return channel, the beamformer (155, 190) is further configured to:
3 determine a plurality of return channels based at least in part on one or more
4 other signals received from known geographic locations; and
5 interpolate characteristics of the plurality of return channels to estimate
6 characteristics of the return channel.

1 46. The communications device (605) of any one of claims 38 through 45,
2 wherein the beamformer (155, 190) is further configured to:
3 obtain a representation of the plurality of signal components (125) relayed by
4 the plurality of second satellites (115) and a representation of a direct signal component (120)
5 of the signal received at the first satellite (105) from the geographic area (140), wherein the
6 beam signal is determined based at least in part on the representation of the plurality of signal
7 components (125) and the representation of the direct signal component (120).

1 47. The communications device (605) of any one of claims 38 through 46,
2 wherein the beamformer (155, 190) is further configured to:
3 estimate a return covariance associated with the geographic area (140) based
4 at least in part on the return channel; and
5 determine beam coefficients based at least in part on the return channel and
6 the return covariance.

1 48. The communications device (605) of any one of claims 38 through 47,
2 wherein the beamformer (155, 190) is further configured to:
3 apply the beam coefficients to a representation of the plurality of signal
4 components (125) of the signal to obtain the beam signal.

1 49. The communications device (605) of any one of claims 38 through 48,
2 wherein the beamformer (155, 190) is further configured to:
3 estimate a plurality of return channels from a plurality of geographic areas
4 (140), the plurality of return channels comprising the return channel and the plurality of
5 geographic areas (140) comprising the geographic area (140);
6 estimate a return covariance based at least in part on the plurality of return
7 channels; and
8 determine a plurality of beam coefficients based at least in part on the plurality
9 of return channels and the return covariance.

1 50. The communications device (605) of claim 49, wherein the
2 beamformer (155, 190) is further configured to:
3 apply the plurality of beam coefficients to representations of pluralities of
4 signal components (125) associated with a plurality of signals originating from the plurality

- 5 of geographic areas (140) to obtain one or more beam signals, the one or more beam signals
6 comprising the beam signal.