

terminals is known from their GPS receivers. For small pitch and yaw angles, trigonometry is used to determine pitch and yaw, as follows and as illustrated in FIG. 7D:

$$\text{Pitch angle } \theta = t_{\text{pitch}} * v / \text{alt} \quad [1]$$

$$\text{Yaw angle } \phi = t_{\text{yaw}} * v / L \quad [2]$$

[0052] FIGs. 8A through 8C depict a method for measuring roll angle β . This technique requires a small group of user terminals **108**_i, $i = 1, n$, such as where n is equal to 6, as a practical minimum. The user terminals are arranged in a line that is essentially perpendicular to the direction of flight of satellite **106**. At one moment in time, all user terminals report a power measurement. As depicted in FIG. 7B, the power measurements can be plotted. If these points are connected, they define a curve with the characteristic hump shape. The peak of the curve can then be estimated. This plot is compared a plot of the predicted power for each user terminal at the time of measurement. The shift (left <-> right) of the actual vs. predicted power numbers correlates to the roll angle. For small roll angles, trigonometry is used to determine roll as follows and as illustrated in FIG. 8C:

$$\text{Roll angle } \beta = \text{distance} / \text{alt} \quad [3]$$

[0053] For small angular errors, the methods depicted in FIGs. 5A-5B, 6A-6C, 7A-7D, and 8A-8C are valid even if roll, pitch, and yaw errors are occurring simultaneously.

[0054] FIGs. 9A and 9B depict an alternative method for determining roll, pitch, and yaw simultaneously. As depicted in FIG. 9A, a plurality of user terminals **108**_i, $i = 1, n$, is arranged in a line across the path of satellite **106**. The user terminals can, alternatively, be randomly positioned as long as there are a sufficient number of user terminals to observe every beam **210** from satellite **106**. As depicted in FIG. 9B, each user terminal **108**_i measures received power for a period of time.

[0055] Referring again to FIG. 4, a computer model of the beam patterns can predict what power is received at any particular user terminals at all points in time. Consequently, a total power error can be computed as the sum, over all times and over all user terminals, of the square of the difference between measured power and predicted power, per expression [4]:

$$\text{PowerError} = \sum_{\text{all terminals and all times}} (\text{power}_{\text{meas}} - \text{power}_{\text{predicted}})^2 \quad [4]$$

The computer model can be manipulated to include any and all values of roll, pitch, and yaw error in its prediction. A “brute force” approach to solving the problem is to calculate the total power error for every combination of roll, pitch, and yaw error, with a granularity, for example, of 0.1 deg and then select the case with the lowest total power error. In the absence of measurement noise, this method will have an error of about +/- 0.05 deg.

[0056] To mitigate the effects of measurement noise, any number of estimation methods known to one skilled in the art can be employed. One method is to “smooth out” the total power error data by computing the average of all neighboring cases for each case and then selecting the lowest power error from the resulting operation, as per expression [5].

$$smoothedPowerError_{ijk} = (\frac{1}{27}) \sum_{i-1}^{i+1} \sum_{j-1}^{j+1} \sum_{k-1}^{k+1} PowerError_{ijk} \quad [5]$$

Where i, j, k are indices for the particular instance of roll, pitch, and yaw, respectively.

[0057] Any measurements obtained are subject to measurement error and each estimate of the timing discrepancy (e.g., due to improper satellite attitude, etc.) will be corrupted by such measurement error. The error is a random variable and, of course, its value is not known. But the variance of the error can be estimated from knowledge of receiver noise and an analysis of the method used to derive the discrepancy estimate from the received signal. Different discrepancy estimates will not be, in general, statistically independent. There are many reasons, in fact, why certain discrepancy estimates might be correlated. The methods used to calculate the variances of discrepancy estimates can also be used to estimate the mutual correlations between estimates. Estimates of variances and correlations, collectively, are referred to as the “covariance matrix.”

[0058] FIG. 10 depicts method **1000** for maintaining the signal-to-noise ratio (SNR) at the user terminals when switching between beams. Method **1000** uses the techniques discussed above for determining pointing errors (i.e., roll, pitch, and yaw).

[0059] In accordance with task **1001**, a user terminal measures received power from the satellite beam. Per task **1002**, the user terminal transmits the measurement results along with its location (e.g., GPS coordinates, etc.) to a data processing system that is typically, but not necessarily, part of the satellite system core network (see, e.g., FIG. 1). The referenced information is transmitted from the user terminal to the satellite, from the satellite to the gateway antenna, and from the gateway antenna to the data processing system. In addition to transmitting, to the gateway antenna, information received from the user terminal, the satellite also obtains, per task **1003**, and transmits its own location data

What is claimed is:

1. A method for maintaining a signal-to-noise ratio at a user terminal when the user terminal switches communications between a first beam and a second beam, wherein the first and second beam are transmitted from a non-geostationary satellite, the method comprising:

defining a mathematical relationship between at least one of pitch, roll, and yaw offsets of the satellite and a timing discrepancy that arises therefrom, wherein the timing discrepancy is a difference in an arrival time of expected peak power and measured peak power as received from the first beam and the second beam; and

adjusting a time at which the user terminal switches communications between the first and second beam based on the mathematical relationship.

2. The method of claim 1 and further comprising determining at least one of the pitch, roll, and yaw offsets by measuring, at the user terminal, power received at least one of the first beam and the second beam, as a function of time.

3. The method of claim 2 wherein determining at least one of the pitch, roll, and yaw offsets further comprises generating a curve fit of the measurements of power received as a function of time obtained by the user terminal.

4. The method of claim 3 wherein determining at least one of the pitch, roll, and yaw offsets further comprises:

comparing the curve fit to a reference profile of expected power received at the user terminal as a function of time; and

determining an offset between a peak value of the curve fit and a peak value of the reference profile.

5. The method of claim 2 and further wherein, for measuring pitch and yaw offsets together, at least two user terminals measure power received as a function of time.

6. The method of claim 2 and further wherein, for measuring roll offset, at least six user terminals measure power received as a function of time.

7. The method of claim 1 wherein pitch, roll, and yaw offsets are determined simultaneously, the method further comprising:

measuring, at a plurality of user terminals, power received from all beams transmitted from the satellite as a function of time, including the first and second beam;

generating a prediction of power received at the user terminals as a function of time;

computing a total power error as the sum, over all user terminals, of the square of the difference between measured power received and predicted power received.

8. The method of claim 1 wherein the user terminal switches communications between the first beam and the second beam when doing so results in a constant signal-to-noise ratio.

9. A method for maintaining a signal-to-noise ratio at a user terminal when the user terminal switches communications between a first beam and a second beam, wherein the first and second beam are transmitted from a non-geostationary satellite, the method comprising:

determining a pointing error of the first beam and of the second beam by defining a mathematical relationship between at least one of pitch, roll, and yaw offsets of the satellite and a timing discrepancy that arises therefrom, wherein the timing discrepancy is a difference in an arrival time of expected peak power and measured peak power as received from the first beam and the second beam; and

transmitting information pertaining to the pointing error of the first beam and the second beam to the satellite;

adjusting an attitude of the satellite to correct the pointing error of the first beam and the second beam.

10. The method of claim 9 and further comprising determining at least one of the pitch, roll, and yaw offsets by measuring, at the user terminal, power received at least one of the first beam and the second beam, as a function of time.

11. The method of claim 10 wherein determining at least one of the pitch, roll, and yaw offsets further comprises generating a curve fit of the measurements of power received as a function of time obtained by the user terminal.

12. The method of claim 11 wherein determining at least one of the pitch, roll, and yaw offsets further comprises:

comparing the curve fit to a reference profile of expected power received at the user terminal as a function of time; and

determining an offset between a peak value of the curve fit and a peak value of the reference profile.

13. The method of claim 10 and further wherein, for measuring pitch and yaw offsets together, at least two user terminals measure power received as a function of time.

14. The method of claim 10 and further wherein, for measuring roll offset, at least six user terminals measure power received as a function of time.

15. The method of claim 9 wherein pitch, roll, and yaw offsets are determined simultaneously, the method further comprising:

measuring, at a plurality of user terminals, power received from all beams transmitted from the satellite as a function of time, including the first and second beam;

generating a prediction of power received at the user terminals as a function of time;

computing a total power error as the sum, over all user terminals, of the square of the difference between measured power received and predicted power received.

16. The method of claim 9 wherein the user terminal switches communications between the first beam and the second beam when doing so results in a constant signal-to-noise ratio.

17. A method for maintaining a signal-to-noise ratio at a user terminal when the user terminal switches communications between a first beam and a second beam, wherein the first and second beam are transmitted from a non-geostationary satellite, the method comprising:

measuring, at the user terminal, power received from at least the first beam;

transmitting, from the user terminal, the measurements of power received and a location of the user terminal, to a data processing system;

transmitting, from the satellite to the data processing system, one or more locations of the satellite obtained while the measurements of power were measured by the user terminal;

generating, at the data processing system, predicted received power levels at the user terminal for all possible combinations of pointing error of the satellite;

selecting, at the data processing system, a best estimate of satellite pointing error from all possible combinations thereof; and

transmitting, from the data processing system, the best estimate of satellite pointing error to one of: (a) the satellite and (b) the user terminal, wherein:

- (i) if the best estimate is transmitted to the satellite, the method further comprises:
correcting, at the satellite, the pointing error thereof based on the best estimate thereof;
- (ii) if the best estimate is transmitted to the user terminal, the method further comprises adjusting, at the user terminal, a beam-switching schedule.