subsatellite point in reverse order as we do the UT position, that is, backward by longitude, the longitude of the satellite and then backward by the satellite latitude.

The satellite velocity component Q' is given by the cross-product of S' and S:

$$Q' = S \times S' \times S \tag{7}$$

The latitude and longitude of the satellite can be calculated using Eqs. 8–11.

$$\sin(Ls) = \frac{z_s}{\sqrt{x_s^2 + y_s^2 + z_s^2}} \tag{8}$$

$$\cos(Ls) = \frac{\sqrt{x_s^2 + y_s^2}}{\sqrt{x_s^2 + y_s^2 + z_s^2}} \tag{9}$$

$$\sin(ls) = \frac{y_s}{\sqrt{x_s^2 + y_s^2}} \tag{10}$$

$$\cos(ls) = \frac{x_s}{\sqrt{x_s^2 + y_s^2}} \tag{11}$$

To yield the angle β_0, Eq. 12 is used to rotate the satellite velocity component Q' around the y-axis, by the latitude Ls, and then around the z-axis by the longitude Is. The coordinates of the vector P_{ref} are then used to calculate cos β_0 and sin β_0 in Eqs. 13–14.

$$P_{ref} = \begin{bmatrix} \cos(Ls) & 0 & \sin(Ls) \\ 0 & 1 & 0 \\ -\sin(Ls) & 0 & \cos(Ls) \end{bmatrix} \begin{bmatrix} \cos(ls) & \sin(ls) & 0 \\ -\sin(ls) & \cos(ls) & 0 \\ 0 & 0 & 1 \end{bmatrix} Q' \tag{12}$$

$$\cos\beta_0 = \frac{y_{Pref}}{\sqrt{y_{Pref}^2 + Z_{Pref}^2}} \tag{13}$$

$$\sin\beta_0 = \frac{Z_{Pref}}{\sqrt{y_{Pref}^2 + Z_{Pref}^2}} \tag{14}$$

Equation 15 yields the coordinates (x, y, z) of the UT position P in ECEF.

$$P = \begin{bmatrix} \cos(ls) & -\sin(ls) & 0 \\ \sin(ls) & \cos(ls) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(Ls) & 0 & -\sin(Ls) \\ 0 & 1 & 0 \\ \sin(Ls) & 0 & \cos(Ls) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\beta_0) & -\sin(\beta_0) \\ 0 & \sin(\beta_0) & \cos(\beta_0) \end{bmatrix} \begin{bmatrix} \cos\alpha \\ \sin\alpha\cos\beta \\ \sin\alpha\sin\beta \end{bmatrix} R \tag{15}$$

In Eq. 15, reading from left to right, the first matrix represents a standard rotation about the z-axis by angle Is; the second matrix represents a standard rotation about the y-axis by Ls; and the third matrix represents a standard rotation about the x-axis by β_0. The final, single-column matrix represents a scaling vector. R represents the radius of the earth.

Using the coordinates given by Eq. 15, the UT's latitude can be determined using Eq. 7 or Eq. 8 by substituting the UT coordinates for the satellite coordinates. The UT's latitude can be applied to a conventional equation used to approximate the earth's ellipsoid shape. The WGS-84 (World Geodetic System-84), which is also used in the global positioning system (GPS), specifies the earth's radius at a point with geocentric latitude L as:

$$R(L) = R_e\sqrt{1 - e_1^2\sin^2(L)} \tag{16}$$

where R_e is earth equatorial radius, R_e=6378.137 Km, and e_1^2 is the first eccentricity of earth ($\approx 6.69438\times10^{-3}$), and R(L) is the earth's radius at latitude L. The geocentric latitude L of the UT is shown in FIG. **5**. Equation 16 represents the first term in a series expansion approximating the earth's ellipsoid shape. The earth is actually an oblate spheroid or ellipsoid, i.e., it is nearly circular in any cross-section that is parallel to the equator, but is close to an ellipse in a cross-section that is perpendicular to the equator.

Using the adjusted radius, the UT position is re-estimated using the spherical approximation (step **46**). The re-estimation is accomplished by substituting the updated value of the earth's radius in Eq. 1, and then determining updated values of α, β using Eqs. 1–6.

Next, a check is made in step **48** to determine whether the updated UT position determined in step **46** has converged to the prior estimate of the UT position. If the difference between two successive estimations is below a predetermined threshold, the position determination is considered to have converged and the procedure terminates. However, if the threshold is exceeded the procedure returns to step **44**, where the earth's radius is again adjusted using the refined approximation of the earth's shape. Steps **44**–**48** repeat-until convergence is achieved.

Alternatively, steps **44** and **46** can be repeated a predetermined number of times, without comparing successive estimations, to determine whether convergence has occurred.

The method **40** can be implemented in software using a repeat-until loop structure. The repeat-until loop can take the following form:

L=Initial estimate of UT latitude (Eqs. 1–15)
REPEAT
R(L)=local radius of ellipsoid earth at latitude L (Eq. 16)
P (α,β)=POS_Det(delay, Doppler, satellite position and velocity, R(L)) (Eq. 1–6)
L=latitude at P (α, β) (Eqs. 7–15)
UNTIL (P converges).

In the above loop, P in each iteration is an approximation of the UT position. Even though the loop is expressed in a repeat-until structure, two iterations can be used to attain a level of accuracy that is acceptable in many mobile communications systems. Therefore, the loop can be made deterministic by using a "For K=1 To 2 Step **1**" loop instead of a repeat-until loop structure.

It should be appreciated that a wide range of changes and modifications may be made to the embodiments of the invention as described herein. Thus, it is intended that the foregoing detailed description be regarded as illustrative rather than limiting and that the following claims, including all equivalents, are intended to define the scope of the invention.

What is claimed is:

1. A method of determining a user terminal location on the surface of the earth by referencing a satellite rotating the earth, comprising:

estimating the user terminal location using a spherical approximation of the shape of the earth; and

adjusting the estimated user terminal location using a refined approximation of the shape of the earth.