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Prediction of Communication Outage Period between Satellite and Earth station Due to Sun Interference

Yongjun Song[1], Kap-Sung Kim[2†], Ho Jin[2], and Byoung-Sun Lee[3]
[1]Solar Physics Lab., Dept. of Astronomy and Space Science, Kyung Hee University, Yongin 446-701, Korea
[2]School of Space Research, Kyung Hee University, Yongin 446-701, Korea
[3]Satellite Control and Navigation Research Team, ETRI, Daejeon 305-700, Korea
E-mail: stelle9@khu.ac.kr

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Abstract

We developed a computer program to predict solar interference period. To calculate Sun's position, we used DE406 ephemerides and Earth ellipsoid model. The Sun's position error is smaller than 10arcsec. For the verification of the calculation, we used TU media ground station on Seongsu-dong, and MBSAT geostationary communication satellite. We analysis errors, due to satellite perturbation and antenna align. The time error due to antenna align has -35 to +16 seconds at $0.1°$, and -27 to +41 seconds at $0.25°$. The time errors derived by satellite perturbation has 30 to 60 seconds.

Keywords: solar interference, ephemeris, DE406, geostationary satellite

1. Introduction

Geostationary satellites are located at an altitude of approximately 35,786km above the equator, and revolve in the same angular velocity as earth. Geostationary satellites can therefore, communicate with a ground earth station at all times. However, geostationary satellites also experience communication failure time, twice a year, closely one upon the other in spring and autumn quarters. The communication errors occur when ground station-satellite-the Sun are aligned closely, which occurs during spring and fall equinoxes. At such times, thermal noise emitted from the Sun's surface hits the rear side of the satellite and flows directly into the earth station antenna. This is called solar interference. Studies on duration calculation methods and prediction results of a solar interference phenomenon were implemented by many scientists (Vuong & Forsey 1983, Mohamadi & Lyon 1988, Lin & Yang 1989) abroad, and also by Lee et al. (1991) in Korea. To calculate the time of solar interference, information on precise position of the Sun and earth station antenna systems is necessary. Previous researches used the formula of Van Flandern (Van Flandern & Pulkkinen 1979) when calculating the Sun's position, but it has position error of about 1 arcmin. Using the precise ephemeris DE406, which published by NASA/JPL and the earth ellipsoid model, the study calculated the precise positioning of the Sun as causing error within 10 arcsec. For the verification of the calculation, we used TU media ground station located in Seongsu-dong and the MBSAT satellite operated by TU media.

†corresponding author

2. Calculation method for coordinates of the Sun

2.1. DE406

In order to obtain the coordinates of celestial bodies belong to the solar system, the equation of motion of the entire solar system should be solved, and relative equations of motion of solar system bodies used in DE406 is shown in formula (1). (Standish et al. 1992)

$$\begin{aligned}\ddot{\mathbf{r}}_{i_{\text{point mass}}} \quad = \quad & \sum_{j\neq i}\frac{\mu(\mathbf{r_j}-\mathbf{r_i})}{r_{ij}^3}\left\{1-\frac{2(\beta+\gamma)}{c^2}\sum_{k\neq i}\frac{\mu_k}{r_{jk}}-\frac{(2\beta-1)}{c^2}\sum_{k\neq j}\frac{\mu_k}{r_{jk}}+\gamma\left(\frac{v_i}{c}\right)^2\right.\\ & \left.+(1+\gamma)\left(\frac{v_j}{c}\right)^2-\frac{2(1+\gamma)}{c^2}\dot{\mathbf{r}}_\mathbf{i}\cdot\dot{\mathbf{r}}_\mathbf{j}-\frac{\mathbf{3}}{\mathbf{2c^2}}\left[\frac{(\mathbf{r_i}-\mathbf{r_j})\cdot\dot{\mathbf{r}}_\mathbf{j}}{\mathbf{r_{ij}}}\right]^{\mathbf{2}}+\frac{\mathbf{1}}{\mathbf{2c^2}}(\mathbf{r_j}-\mathbf{r_i})\cdot\ddot{\mathbf{r}}_\mathbf{j}\right\}\\ & +\frac{1}{c^2}\sum_{j\neq i}\frac{\mu_i}{r_{ij}^3}\{[\mathbf{r_i}-\mathbf{r_j}]\cdot[(\mathbf{2}+\mathbf{2}\gamma)\dot{\mathbf{r}}_\mathbf{i}-(\mathbf{1}+\mathbf{2}\gamma)\dot{\mathbf{r}}_\mathbf{j}]\}(\dot{\mathbf{r}}_\mathbf{i}-\dot{\mathbf{r}}_\mathbf{j})\\ & +\frac{3+4\gamma}{2c^2}\sum_{j\neq i}\frac{\mu_j\ddot{\mathbf{r}}_\mathbf{j}}{r_{ij}}+\sum_{m=1}^{5}\frac{\mu_m(\mathbf{r_m}-\mathbf{r_i})}{r_{im}^3}\end{aligned} \tag{1}$$

Here, $\mathbf{r_i}$, $\dot{\mathbf{r}}_\mathbf{i}$ and $\ddot{\mathbf{r}}_\mathbf{i}$ represent location, speed and acceleration of the celestial body i in the solar-system barycentric coordinate. $\mu_j = Gm_j$, where G is gravitational constant, m_j is mass of celestial body j. Moreover, β, γ are PPN (Parameterized Post-Newtonian) parameters and $\gamma = \beta = 1$.

DE406 solves Formula (1) numerically; obtained the computed value by fitting, using Chebyshev polynomial (Newhall 1989), and saved the coefficients in 64 days interval.

The recursion formula of Chebyshev polynomial can be displayed as shown in formula (2).

$$T_n(t) = 2tT_{n-1}(t) - T_{n-2}(t) \tag{2}$$

Here, n refers to the number of Chebyshev coefficients of the respective celestial body saved in DE406; 12 of them are for the Sun, and 9 for earth. Using such coefficients and formula (2), we can obtain $f(t)$ - the value of function from specific time t - as shown in formula (3) below (Press et al. 2002).

$$f(t) = \sum_{n=0}^{N} a_n T_n(t) : -1 \leq t \leq 1 \tag{3}$$

a_n shown in formula (3) is the Chebyshev coefficient saved in DE406, and $f(t)$, calculated from here, and is the position coordinate of the celestial body displayed in BCRS (Barycentric Celestial Reference System). Suppose we put geocentric-heliocentric position vectors to r in BCRS, which is calculated through DE406, to demonstrate the coordinates of the Sun viewed from a geocentric position, the vectors should be conversed to GCRS -Geocentric Celestial Reference System- using the Bias Matrix $\mathbf{B}$ and Precession Matrix $\mathbf{P}$, which are similar to formulas (4) and (5) as follows. At this time, the position vector of the Sun viewed from geocentric is placed to $\mathbf{r}'$. The Bias Matrix carries out a role to change BCRS to J2000.0 coordinate system, while the Precession Matrix calibrates celestial bodies of the current time in accordance with precession. The Bias Matrix and Precession Matrix can be obtained through Astronomical Almanac 2008 (USNO & HMNAO 2008).

$$\mathbf{B} = \begin{pmatrix} 0.9999999999999942 & -0.0000000707827974 & 0.0000000805621715 \\ 0.0000000707827948 & 0.9999999999999969 & 0.0000000330604145 \\ -0.0000000805621738 & -0.0000000330604088 & 0.9999999999999962 \end{pmatrix} \tag{4}$$

$$\mathbf{P} = \begin{pmatrix} \cos\zeta_A\cos\theta_A\cos z_A - \sin\zeta_A\sin z_A & -\sin\zeta_A\cos\theta_A\cos z_A - \cos\zeta_A\sin z_A & -\sin\theta_A\cos z_A \\ \cos\zeta_A\cos\theta_A\sin z_A + \sin\zeta_A\cos z_A & -\sin\zeta_A\cos\theta_A\sin z_A + \cos\zeta_A\cos z_A & -\sin\theta_A\sin z_A \\ \cos\zeta_A\sin\theta_A & -\sin\zeta_A\sin\theta_A & \cos\theta_A \end{pmatrix} \tag{5}$$

$$\begin{aligned} \zeta_A =& + 2''.5976176 + 2306''.0809506T + 0''.3019015T^2 + 0''.0179663T^3 \\ & - 32''.7 \times 10^{-6}T^4 - 0''.2 \times 10^{-6}T^5 && (6) \\ z_A =& - 2''.5976176 + 2306''.0803226T + 1''.0947790T^2 + 0''.0182273T^3 \\ & + 47''.0 \times 10^{-6}T^4 - 0''.3 \times 10^{-6}T^5 && (7) \\ \theta_A =& + 2004''.1917476T - 0''.4269353T^2 - 0''.0418251T^3 - 60''.1 \times 10^{-6}T^4 \\ & - 0''.1 \times 10^{-6}T^5 && (8) \\ T =& (JD_{TT} - 2451545.0)/365.25 : \text{Julian Century} && (9) \end{aligned}$$

where, ζ_A, z_A, θ_A demonstrate precession angle (Lieske et al. 1977). JD_{TT} is JD (Julian Date), calculated through TT (Terrestrial Time). The distance between center of the Earth and the Sun, $\mathbf{r}'$ calculated finally from GCRS is shown in formula (10).

$$\mathbf{r}' = \mathbf{PBr} \tag{10}$$

Since the vector is shown as three-dimensional Cartesian coordinate, semi diameter of the actual Sun as viewed from the earth can be calculated using formula (11) (Meeus 1998).

$$\alpha_s = \frac{s_0}{\Delta} \tag{11}$$

where, s_0 is semidiameter of the Sun from the distance 1 AU apart, set to $959''.63$, and Δ is actual distance between the Earth and the Sun, same to $|\mathbf{r}'|$.

2.2 Earth Ellipsoid Model

Suppose we are to display the position $\mathbf{Re}$ of observers positioned at geographical coordinate (le, ϕ), altitude above the sea level h, and local sidereal time H using a geocentric coordinate system, we can illustrate as follows via an earth ellipsoid model as shown in Figure 1 (Kim 2005).

$$\tan L = (1 - e^2)^{-1/2}\frac{v}{u} \ : \ \text{Circle} - \text{Ellipse Relations} \tag{12}$$

$$\tan\phi = -\frac{du}{dv} \ : \ \text{Relation between normal line and Geoid latitude} \tag{13}$$

$$du/dv = -(1 - e^2)^{-1}(v/u) \ : \ \text{Elliptic differentiation} \tag{14}$$

where, L is the latitude measured in the geocentric assuming earth is perfect round, ϕ is the Geoid latitude, representing observer latitude from earth ellipsoid. u, v is the coordinate of equatorial in the observer position and the coordinate to pole-ward located at the earth ellipsoid deemed the Geoids latitude ϕ. Using formula (12)∼(14), we can obtain formula (15) as follows.

$$\tan L = (1 - e^2)^{1/2}\tan\phi = \frac{(1 - e^2)^{1/2}\sin\phi}{\cos\phi} \tag{15}$$

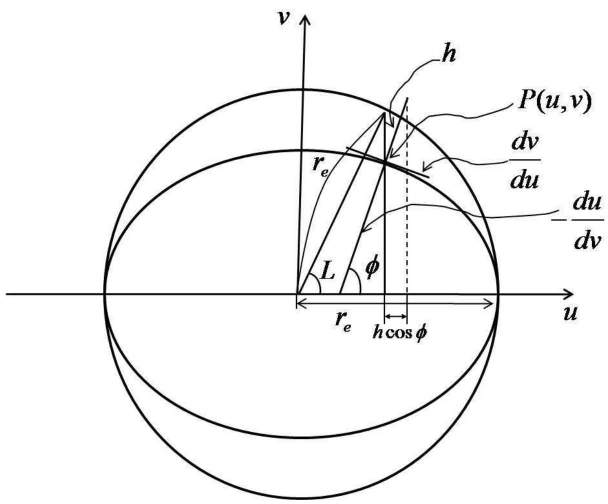

Figure 1. The observer position of geodetic latitude ϕ and altitude above sea level h, which is illustrated in an earth ellipsoid model.

Formula (16) is obtained when cos L and sin L is calculated using the Pythagorean Theorem and formula (15).

$$\cos L = \frac{\cos\phi}{(1-e^2\sin^2\phi)^{1/2}}$$
$$\sin L = \frac{(1-e^2)^{1/2}\sin\phi}{(1-e^2\sin^2\phi)} \tag{16}$$

Therefore, using formula (16), the observer position of altitude above sea level h,

$$u = r_e\cos L + h\cos\phi = \left[\frac{r_e}{(1-e^2\sin^2\phi)^{1/2}} + h\right]\cos\phi \tag{17}$$

$$v = (1-e^2)^{1/2} r_e \sin L + h\sin\phi = \left[\frac{r_e(1-e^2)}{(1-e^2\sin^2\phi)^{1/2}} + h\right]\sin\phi \tag{18}$$

where, r_e is the length of earth radius assuming earth is a complete sphere, and the length is the same as the equatorial radius of actual earth. The position vector $\mathbf{Re}$, which successes observers located at altitude above sea level h and in the center of the earth ellipsoid of which eccentricity is e, can be displayed as formula (19) as follows.

$$\mathbf{Re} = \mathbf{u}\cos\mathbf{H}\mathbf{i} + \mathbf{u}\sin\mathbf{H}\mathbf{j} + \mathbf{v}\mathbf{k} \tag{19}$$

As shown in Figure 2, we can illustrate formula (20) suppose we calculate the position vector ρ from observation place to the Sun, using the vector $\mathbf{r}'$, which is the distance between the Sun and center of the earth, and observer postion vector $\mathbf{Re}$.

$$\rho = \mathbf{r}' - \mathbf{Re} = (\mathbf{r}'_\mathbf{x} - \mathbf{u}\cos\mathbf{H})\mathbf{i} + (\mathbf{r}'_\mathbf{y} - \mathbf{u}\sin\mathbf{H})\mathbf{j} + (\mathbf{r}'_\mathbf{z} - \mathbf{v})\mathbf{k} = \rho_\mathbf{i}\mathbf{i} + \rho_\mathbf{j}\mathbf{j} + \rho_\mathbf{k}\mathbf{k} \tag{20}$$

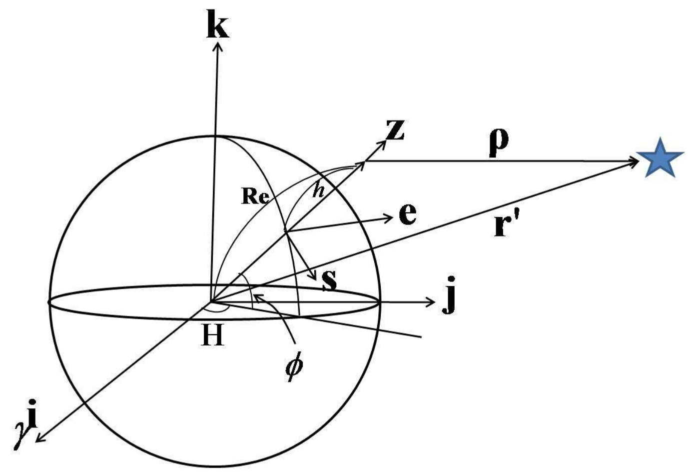

Figure 2. Observer-centric horizon coordinate system and the Earth-centric equatorial coordinate system.

As the vector ρ displayed in three-dimensional geocentric Cartesian coordination, coordinate conversion is required for the 3-axis H and 2-axis ($\pi/2 - \phi$) direction. This can be illustrated in coordinate transformation matrix as shown in formula (14).

$$\begin{pmatrix} \rho_s \\ \rho_e \\ \rho_z \end{pmatrix} = \begin{pmatrix} \cos(\pi/2-\phi) & 0 & -\sin(\pi/2-\phi) \\ 0 & 1 & 0 \\ \sin(\pi/2-\phi) & 0 & \cos(\pi/2-\phi) \end{pmatrix} \begin{pmatrix} \cos H & \sin H & 0 \\ -\sin H & \cos H & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \rho_i \\ \rho_j \\ \rho_k \end{pmatrix}$$

$$= \begin{pmatrix} \rho_i \cos H \cos(\pi/2-\phi) + \rho_j \sin H \cos(\pi/2-\phi) + \rho_k(-\sin(\pi/2-\phi)) \\ \rho_i(-\sin H) + \rho_j \cos H \\ \rho_i \cos H \sin(\pi/2-\phi) + \rho_j \sin H \sin(\pi/2-\phi) + \rho_k \cos(\pi/2-\phi) \end{pmatrix} \tag{21}$$

If the vector ρ is conversed to spherical coordinate, we can obtain the azimuth angle and the altitude of the Sun from an observation place. In addition, we calculate an off-axis angle (θ_0) between the position of a satellite and the current position of the Sun as formula (22), it is feasible via cosine law of spherical triangle (Lee et al. 1991).

$$\theta_0 = \arccos[\cos(El_{sun})\cos(El_{ant})\cos(Az_{sun} - Az_{ant}) + \sin(El_{sun})\sin(El_{ant})] \tag{22}$$

where, El_{sun} is elevation angle of the Sun, Az_{sun} is azimuth angle of the Sun, El_{ant} is elevation angle of the antenna pointing, and Az_{ant} is azimuth angle of the antenna pointing.

3. Solar Interference Calculation

Antenna noise temperature is proportionate to the ratio of which apparent solar temperature and the Sun is included in the antenna beam. Therefore, to calculate antenna noise temperature, gain pattern of earth station antenna, showing the antenna beam and apparent solar temperature, should be defined.

As the gained pattern changes depending on the characteristic of each earth station antenna, calculation should be obtained through directive measurement. However, obtaining characteristics by measuring each antenna would be practically impossible, thus, the study was conducted based on the WARC-79 gain pattern (CCIR 1982), employed by ITU. The WARC-79 gain pattern has a parameter in accordance with the radio frequency transmitted to antennas and the diameter of antennas.

T_{sun} - the off-season sun's noise temperature- can be obtained via formula (23) (Shimabukuro & Stacey 1968, Vuong & Forsey 1983).

$$T_{sun} = 120000 f^{-0.75} \tag{23}$$

where, f is frequency of solar noise and a GHz unit. The solar noise radiation will be extinct while passing through the atmosphere of earth, and the extinction efficiency has a different value according to frequency as shown in formula (24) (Johannsen & Titus 1986)

$$\begin{aligned} atten &= 0.036/\sin\left(El_{sun}\right) \quad : \quad \text{C-band[dB]} \\ atten &= 0.072/\sin\left(El_{sun}\right) \quad : \quad \text{Ku-band[dB]} \end{aligned} \tag{24}$$

Hence, the solar noise temperature observed from actual earth station antennas is as shown in formula (25).

$$T'_{sun} = T_{sun} \times 10^{-atten/10} \tag{25}$$

Moreover, as the increase of noise temperature in accordance with solar is proportionate depending upon how much solar disc comes into the range of the antenna, thus, it can be integral as formula (26) (Mohamadi & Lyon 1988).

$$\Delta T_{ant} = p \frac{T'_{sun}}{4\pi} \iint_{\text{sun's disk}} G(\theta, \phi) \sin(\theta) d\theta d\phi \tag{26}$$

where, p is the single polarization attenuation factor, its value is 0.5, and $G(\theta, \phi)$ is WARC-79 gain pattern.

Formula (26) above can integrate simple solar disc, such as on ϕ direction, hence, it can be converted to an integration method as shown in formula (27) for θ direction (Lin & Yang 1989).

$$\Delta T_{ant} = p \frac{T'_{sun}}{4\pi} \int_{\theta=\theta_0-\alpha_s \text{ or } 0}^{\theta_0+\alpha_s} G(\theta, \phi) \sin(\theta) 2(\phi_i) d\theta \tag{27}$$

where, α_s is 'semidiameter of the Sun', obtained from formula (7), θ_0 is 'off-axis angle' obtained from formula (15), and ϕ_i is as follows formula.

$$\phi_i = \left[\begin{array}{l} \pi : \text{for } \theta_0 - \alpha_s \leq 0 \text{ and } \theta \leq \alpha_s - \theta_0 \\ \arccos\left(\frac{\cos\alpha_s - \cos\theta\cos\theta_0}{\sin\theta\sin\theta_0}\right) : otherwise \end{array} \right. \tag{28}$$

While the integration method above can perform integration through numerical integration, it can create a problem on both ends of integral interval when using general Romberg integration, thus, the Gaussian quadrature method should be used (Lee et al. 1991). Moreover, integral interval should be started from 0 if $\theta_0 - \alpha_s \leq 0$.

To compare the calculated antenna noise temperature with actual observed value, a barometer enabling quantitative comparison is required, thus, Δ(C/N) is defined as a barometer as follows (Vuong & Forsey 1983, Lin & Yang 1989).

$$\Delta(C/N) = 10 \log[(T_{sys} + T_{ant})/T_{sys}] \tag{29}$$

Table 1. TU Media Ground Station Information.

Items	Value
Earth Station Longitude (Deg)	E127.034
Earth Station Latitude (Deg)	N37.546
Antenna Azimuth Angle (Deg)	153.416
Antenna Elevation Angle (Deg)	43.0
Antenna Diameter (m)	9.2
Satellite Longitude (Deg)	E144.0

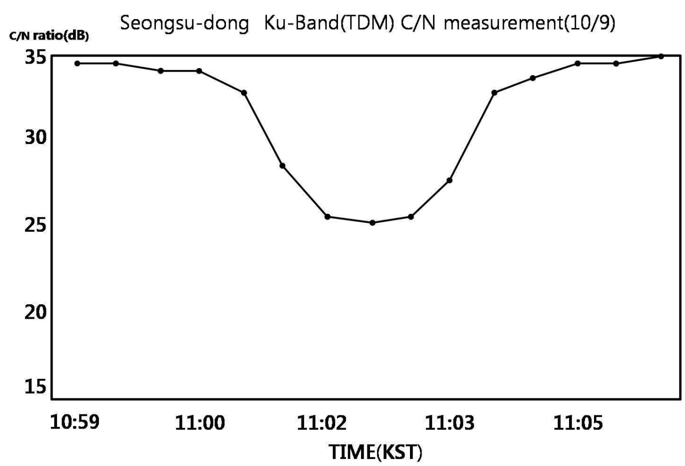

Figure 3. Actual solar interference time observed from TU media ground station in Seongsu-dong (Provided by TU media dated Oct. 09, 2007) (TU media 2007).

In formula (29), T_{sys} is the system noise temperature of an antenna system when there is no solar interference, whilst T_{ant} is the antenna noise temperature calculates via formula (27). While T_{sys} can calculate and measure an actual antenna system, general antenna systems has between roughly 250 $\sim$ 300K values (Lee et al. 1991).

4. Comparison and error analysis of solar interference time

A calculation program is created for solar interference based on the aforementioned formulas. The Visual C++ .Net 2008 was used for programming, and the Origin program was utilized to simulate graphics. In addition, we calculated the solar interference time of TU media ground station in Seongsu-dong displayed in Table 1, to verify the accuracy of the program, and compared with actual observed value.

The actual C/N value and time observed from TU media ground station on Seoungsu-dong on October 9, 2007 is illustrated in Figure 3. As of an observation result, the time of solar interference commenced at about $11^{\rm h}01^{\rm m}$ a.m. on KST, of which reached its maximum at $11^{\rm h}02^{\rm m}30^{\rm s}$ a.m., and over at about $11^{\rm h}04^{\rm m}$ a.m.. $\Delta(C/N)$ value of maximum interference time is 9.8 dB. Figure 4 is a

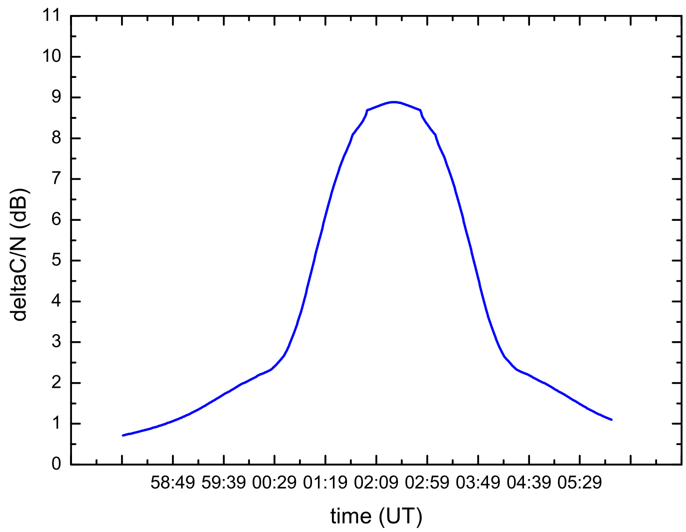

Figure 4. Solar interference time graph from TU media 9.2m antenna calculated through a model (Oct 09, 2007).

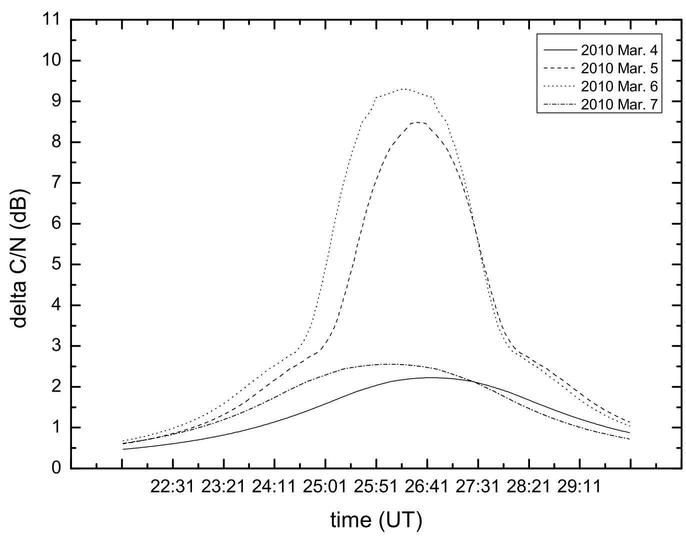

Figure 5. Spring quarter calculation result of 2010 (KST 11:20:00 - 11:30:00).

graph calculated using a model. Where, the calculation is implemented assuming, system noise as 250 K, and efficiency of an antenna system as 65% (Mohamadi & Lyon 1988). The time in Figure 4 displays minute and second units only. As a calculation result, the time of sun interference had

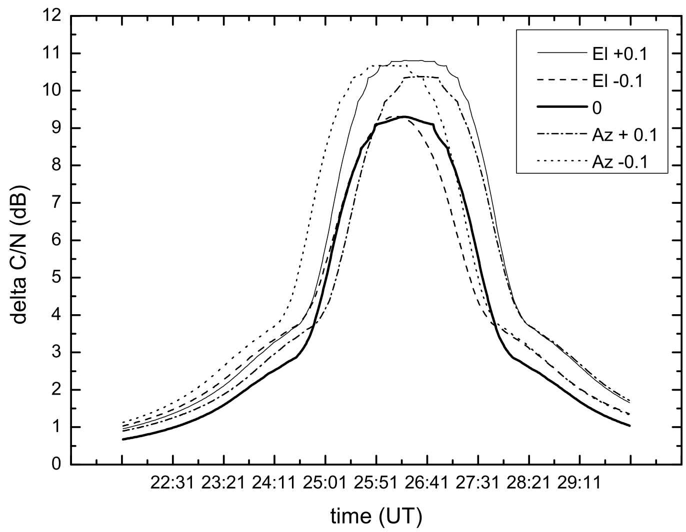

Figure 6. Solar interference time change when the angle of an antenna has $0.1°$ error (KST 11:20:00 - 11:30:00).

commenced at $11^{\mathrm{h}}01^{\mathrm{m}}02^{\mathrm{s}}$ a.m., ended at $11^{\mathrm{h}}03^{\mathrm{m}}50^{\mathrm{s}}$ a.m., showing the maximum interference time as $11^{\mathrm{h}}02^{\mathrm{m}}26^{\mathrm{s}}$ a.m.. Maximum $\Delta(C/N)$ of the maximum interference time is 9.2 dB, which is lower than observation value by 0.6 dB. Through this, we were able to confirm the consistency with a model and actual observation value.

Figure 5 is a graph demonstrates the time of solar interference expected in spring quarter of 2010. According to Figure 5, solar interference starts between 5th and 6th of March, in the case of spring quarter in 2010, and the occurrence time is between $11^{\mathrm{h}}24^{\mathrm{m}}$ a.m. – $11^{\mathrm{h}}28^{\mathrm{m}}$ a.m.. Solar interference occurs the most in March 6, while maximum interference time is at $11^{\mathrm{h}}26^{\mathrm{m}}19^{\mathrm{s}}$ a.m., and the maximum $\Delta(C/N)$ value is 9.29 dB. Solar interference occurs throughout many days, and as days go by, the maximum occurrence time shows a tendency to become faster gradually.

An error analysis is implemented based on March 6, 2010. The date is forecasted as the day, which most solar interference would occur in the spring quarter of 2010. The maximum solar interference occurred time on this day was at $11^{\mathrm{h}}26^{\mathrm{m}}19^{\mathrm{s}}$ a.m., and based on the MBSAT satellite information and earth station antenna illustrated in Table 1, we calculated solar interference occurrence time according to each error, and compared the time, which maximum solar interference occurred, and compared with $\Delta(C/N)$ value. The direction of each earth station antenna shown in Figures 6 and 7 shows the change of $\Delta(C/N)$ value and solar interference time, which would occur in case of error of $0.1°$ and $0.25°$, respectively. The El of Figures 6 and 7 signifies the altitude of the antenna, while Az represents the azimuth angle of the antenna.

Figure 6 represents when the error of direction of an antenna shows $0.1°$. The maximum time of solar interference occurs 9 seconds faster than $11^{\mathrm{h}}26^{\mathrm{m}}19^{\mathrm{s}}$ a.m. when the altitude of an antenna is lower than the standard altitude $0.1°$. When the azimuth angle is as little as $0.1°$, the maximum solar interference occurs 35 seconds faster. When altitude is increased by $0.1°$, the maximum interference occurs 13 seconds faster, and when, azimuth angle is increased by $0.1°$, the interference occurs 16 seconds later. Through this, we are able to confirm that when the altitude of an antenna changes by

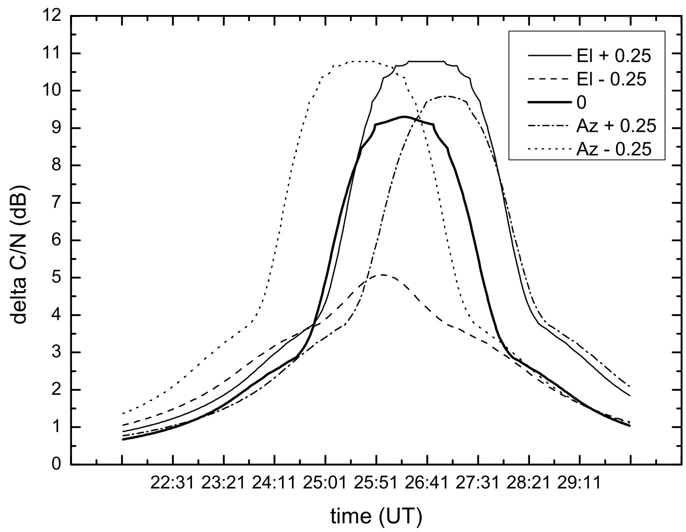

Figure 7. Solar interference time change when the angle of an antenna has $0.25°$ error (KST 11:20:00 - 11:30:00).

$0.1°$, there is an error range with solar interference time at $-35 \sim +16$ seconds. Figure 7 shows the difference when $0.25°$ error is given to an antenna. The time of maximum solar interference when altitude is as little as $0.25°$, it occurs 22 seconds faster than standard time, and when azimuth angle is as big as $0.25°$, it occurs 41 seconds late. Thus, suppose we calculate the rest, when the error of bearing of an antenna is $0.25°$, we are able to confirm an error range of $-27 \sim +41$ seconds.

When we examined Figure 6 and 7, we can see that the intensity of maximum solar interference changes when antenna error occurs, and that changes in the width of $\Delta(C/N)$ is even bigger in $0.25°$ change, compare to $0.1°$ angle change of an antenna, and the error of a solar interference occurrence time increase as much as the antenna pointing angle variance. Through this, we confirmed that the more the accurate measurement is carried on the antennas direction, the higher the accuracy of solar interference time predictions.

Figure 8, illustrates the change in solar interference time when the position of geostationary satellite changes according to perturbation. Suppose we examine Figure 8, when the position of a satellite moves to east by $0.05°$, that is when it is located at the latus rectum $144.05°$, the maximum interference time is $11^{\rm h}26^{\rm m}05^{\rm s}$ a.m., which is faster by 14 seconds compare to when it is positioned at the latus rectum $144.0°$, the standard position. When a satellite moves to west by $0.05°$ and positioned at $143.95°$ east, the time of maximum solar interference is $11^{\rm h}26^{\rm m}32^{\rm s}$ a.m., which is 13 seconds delayed than that of standard position. The change of maximum interference period according to the position of a satellite is $0.05°$, and has error range of $-14 \sim +13$ seconds at the time of change. However, in a case where there is more than $0.1°$ position change, an error occurs with range of one minute or more. In addition, we can also check the change of intensity of solar interference. However, unlike the error occurrence of antennas, we recognized that there is no significant change of in respective cases when a satellite's position changes.

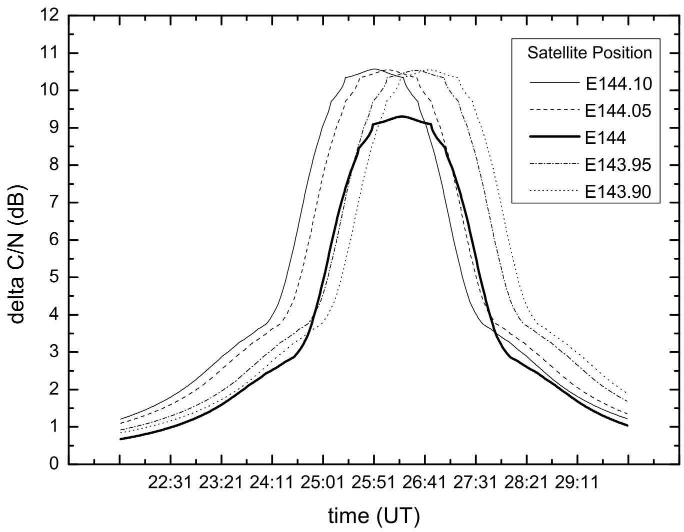

Figure 8. Change of solar interference time according to the change of satellite position (KST 11:20:00-11:30:00).

5. Conclusion

The purpose of this study is to forecast precise prediction of solar interference time. The study calculated the precise position of the Sun, using DE406 and an earth ellipsoid model, and via a solar interference program, we predicted noise temperature and C/N decline of earth station antenna in accordance with solar interference of stationary satellite and earth station. As a result of applying a communication satellite ground station in Seongsu-dong and MBSAT operated by TU media, we confirmed that they are consistent with actual observation, and verified their accuracy through error analysis.

In-depth of consideration is needed for the intensity of solar interference, not only the affect of the Sun, but also on the specific system of each earth station antenna. Specifically, the size of antennas and a wavelength range of radio wave used in antennas affect the most in the time of solar interference, thus it is necessary to have precise information for a better and precise prediction.

An error according to the position change of a geostationary communication satellite will result a time difference within 30 seconds, if position maintenance is implemented within $\pm 0.05°$. Therefore, we expect there will be no significant affect as practical purposes in precise position calculation of satellites. On the other hand, since the direction of antennas can be a significant error factor, precise calculation of the direction of antennas is imperative to the prediction of solar interference time.

In the study, we calculated the time of solar interference between geostationary communication satellite and earth station. In a case of general low orbit satellite, a solar interference time calculation can be conducted using the same method the study employed, if satellite altitude and azimuth angle is obtained from earth station through the orbital elements of satellites.

Moreover, even the precise position of the Moon can be calculated using DE406. It is known that there is noise of about 250K in the Moon, and the interference time according to the Moon can be calculated by taking advantage of this study.

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