Visibility Analysis of Domestic Satellites on Proposed Ground Sites for Optical Surveillance

Jae-Hyuk Kim^{1,2†}, Jung Hyun Jo¹, Jin Choi¹, Hong-Kyu Moon¹, Young-Jun Choi¹,
Hong-Suh Yim¹, Jang-Hyun Park¹, Eun-Seo Park¹, and Jong-Uk Park¹

¹Korea Astronomy and Space Science Institute, Daejeon 305-348, Korea

²Department of Astronomy, Yonsei University, Seoul 120-749, Korea

The objectives of this study are to analyze the satellite visibility at the randomly established ground sites, to determine the five optimal ground sites to perform the optical surveillance and tracking of domestic satellites, and to verify the acquisition of the optical observation time sufficient to maintain the precise ephemeris at optimal ground sites that have been already determined. In order to accomplish these objectives, we analyzed the visibility for sun-synchronous orbit satellites, low earth orbit satellites, middle earth orbit satellites and domestic satellites as well as the continuous visibility along with the fictitious satellite ground track, and calculate the effective visibility. For the analysis, we carried out a series of repetitive process using the satellite tool kit simulation software developed by Analytical Graphics Incorporated. The lighting states of the penumbra and direct sun were set as the key constraints of the optical observation. The minimum of the observation satellite elevation angle was set to be 20 degree, whereas the maximum of the sun elevation angle was set to be -10 degree which is within the range of the nautical twilight. To select the candidates for the optimal optical observation, the entire globe was divided into 84 sectors in a constant interval, the visibility characteristics of the individual sectors were analyzed, and 17 ground sites were arbitrarily selected and analyzed further. Finally, five optimal ground sites (Khurel Togoot Observatory, Assy-Turgen Observatory, Tubitak National Observatory, Bisdee Tier Optical Astronomy Observatory, and South Africa Astronomical Observatory) were determined. The total observation period was decided as one year. To examine the seasonal variation, the simulation was performed for the period of three days or less with respect to spring, summer, fall and winter. In conclusion, we decided the optimal ground sites to perform the optical surveillance and tracking of domestic satellites and verified that optical observation time sufficient to maintain the precise ephemeris could be acquired at the determined observatories.

Keywords: optical surveillance, visibility analysis, dawn-dusk orbit, sun-synchronous orbit, ground track analysis, domestic satellites

1. INTRODUCTION

The attempt to determine satellite orbit and maintain the ephemeris through optical observation has been continuously made since Sputnik I was launched in 1957 (King-Hele 1983). The methods that are generally used for orbit observation such as satellite laser ranging (SLR), radar tracking and global positioning system (GPS)

orbit tracking are superior to the orbit measurement by means of optical observation in terms of precision and accuracy. Among these orbit observation methods, SLR and GPS orbit tracking require the installation of a laser retro-reflector array (LRRR) or a GPS receiver (Pearlman et al. 2002). The orbit of the objects with which mutual communication is impossible, such as space debris or discarded satellites, cannot be determined by these two

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[†]Corresponding Author

E-mail: nasabolt@kasi.re.kr

Tel: +82-42-865-2185 Fax: +82-42-861-5610

methods. However, the orbit determination by optical observation is not dependent on the transmission and reception of specific observation data. Refer to Kim et al. (1987) for detailed information on optical observation. If only the observable optical visibility and sufficient observation time are allowed, the satellite ephemeris can be maintained or improved by estimating the observation position on the celestial sphere in advance on the basis of the orbital elements of a given satellite. The important factors for this process are the effective range and possible frequency of the optical observation with reference to the ground. To explain the efficiency of optical observation to maintain satellite ephemeris, the optimal ground sites with the higher visibility should be determined first, and the effective visibility (EV) of each observatory should be analyzed (Jo 2011).

2. VISIBILITY ANALYSIS OF SUN-SYNCHRONOUS ORBIT SATELLITES ON SECTORIZED FICTITIOUS GROUND SITES

Basically, for all the simulation process, the maximum of the sun elevation angle was set to be -10 degree which is within the range of the nautical twilight. The lighting states of the penumbra and direct sun were set as the key constraints. The minimum of the observation satellite elevation angle was set to be 20 degree, which is the consideration of the light pollution and local sites. To analyze the visibility, 84 fictitious ground sites were set in a 30° interval for the earth's latitude and longitude (Fig. 1). The entire simulation period was one year between Janu-

ary and December, 2010. The subject satellite was Korea multi-purpose satellite-2 (KOMPSAT-2). Table 1 summarizes the specification of KOMPSAT-2. The orbit propagator used for the simulation was the simplified general perturbations propagator (SGP4)¹ that receives the two-line elements (TLE) provided by Analytical Graphics Incorporated (AGI) as the input orbital elements to predict the orbit.

KOMPSAT-2, a domestic sun-synchronous orbit (SSO) satellite, was observationally visible only in the high latitude region (north latitude 34 degrees or higher or south latitude 30 degrees or higher) as shown in Fig. 2. For about 300 astronomical observatories including ground-based astronomical facilities and overseas observatories in the

Table 1. KOMPSAT-2 satellite and orbit specification.*

Satellite information	
Launch date	20060728
Projectile	Rokot rocket
Launch site	Plesetsk, Russia
Mass	800 kg
Diameter	200 cm
Height	280 cm
Orbital elements	
Perigee	656.2999877929688 km
Apogee	680.9000244140625 km
Orbital period	98.5999984741211 min
Inclination	98.0999984741211 deg
Eccentricity	0.0017455226043239236
Orbit	SSO

KOMPSAT-2: Korea multi-purpose satellite-2, SSO: sun-synchronous orbit.
^{*}<http://en.wikipedia.org/wiki/Arirang-2> [cited 2011 Feb 4]

¹http://www.stk.com/resources/help/online/stk/source/stk/vehsat_orbitprop_choose.htm [cited 2011 Feb 2]

Fig. 1. Eighty-four sectorized fictitious ground sites are positioned every 30 deg (30° × 30°), and the text color means same latitude mark, the ground track displayed in the figure is by Korea multi-purpose satellite-2 (KOMPSAT-2).

list of astronomical observatories², we checked out the weather conditions, number of clearly sky days, and provision of the communication and technological support. Excluding the candidate observatories in the countries that are difficult to approach because of international political reasons, 17 candidate observatories were set as in Table 2. The visibility for the SSO satellites that are generally known at the determined observatories was verified as shown in Table 3. The GeoEye satellite (Fig. 3) had the most narrow visibility range which was north latitude 35 degrees or higher or south latitude 40 degrees or higher, whereas the national oceanic and atmospheric adminis-

tration-18 (NOAA-18) satellite (Fig. 4) had the widest visibility range which was north latitude 25 degrees or higher or south latitude 30 degrees or higher.

3. VISIBILITY ANALYSIS OF LOW EARTH ORBIT AND MIDDLE EARTH ORBIT SATELLITES ON PROPOSED 17 GROUND SITES

Before analyzing the visibility of the low earth orbit (LEO) satellites and middle earth orbit (MEO) satellites, we verified if it was possible to categorize currently operating satellites according to orbital elements, and if the categorized groups had the visibility characteristics.

²http://en.wikipedia.org/wiki/List_of_astronomical_observatories [cited 2011 Feb 7]

Fig. 2. Visibility of KOMPSAT-2 on 84 sectorized fictitious ground sites is drawn in topocentric horizon, and the results of same latitude are represented same colors (Kim 2011a).

Table 2. Characteristics of proposed 17 ground sites (Moon 2011).

Proposed ground sites	Latitude (deg)	Longitude (deg)	Elevation (m)	Main telescope
Khurel Togoot Observatory	47.865	107.0536111	1,620	0.4 m
Indian Astronomical Observatory	32.77944444	78.96416667	4,500	2 m
Assy-Turgen Observatory	43.22444444	77.87138889	2,665	1 m RC
Tien-Shan Observatory	43.95	76.95	2,800	1 m RC
Pamir High-Mountain Observatory	38	74	4,350	0.7 m RC
Sanglokh Observatory	38.2	69	2,300	1 m RC
Mount Dushak-Erekdag Observatory	37.95583333	57.90583333	2,020	1 m Wide-field
Maidanak Observatory	38.6725	66.90083333	2,000	1.5 m
Roque de Los Muchachos Observatory	28.76666667	-17.88333333	2,396	11.35 m GTC
Skinakas Observatory	35.21194444	24.89916667	1,750	1.3 m RC
Tubitak National Observatory	36.82416667	30.33555556	2,500	1.5 m
Observatorio Astronómico Nacional en San Pedro Mártir	31.04444444	-115.4666667	2,800	2.1 m
Bisdee Tier Optical Astronomy Observatory	-42.42583333	147.2886111	646	1.3 m
Siding Spring Observatory	-31.27333333	149.0644444	1,165	3.9 m AAT
Vintage Lane Observatory	-41.49333333	173.8391667	37.50	0.6 m RC
South African Astronomical Observatory	-32.378	20.8105	1,759	10 m SALT
Las Campanas Observatory	-29.015	-70.77277778	2,380	6.5 m MT

RC: Ritchey-Chretien, GTC: gran telescopio Canarias (meaning Canaries great telescope), AAT: Anglo-Australian telescope, SALT: southern African large telescope, MT: Magellan telescope.

Fig. 3. Visibility of GeoEye on proposed 17 ground sites is drawn in topocentric horizon, and the different color distinguish between sites. The color was assigned randomly.

Fig. 4. Visibility of national oceanic and atmospheric administration-18 (NOAA-18) on proposed 17 ground sites is drawn in topocentric horizon, and the different color distinguish between sites. The color was assigned randomly.

Table 3. The specifications of several sun-synchronous orbit satellites.*

Satellite	Launch date	Vehicle	Management	Orbit	Altitude(km)	Inclination (deg)	Goal
LANDSAT 5	1984.3.1	Delta 3920	NASA	Sun-synchronous, near-polar orbit	705	98.2	Global archive of satellite photos
LANDSAT 7	1999.4.15	Delta II 7920	NASA	Sun-synchronous, near-polar	705	98.2	Refresh the global archive of satellite photos, providing up-to-date and cloud-free images
NOAA 18	2005.5.20	Delta II 7320	NASA	Sun-synchronous	854	98.74	Weather and climate predictions
NOAA 19	2009.2.6	Delta II 7320	NASA	Sun-synchronous	870	98.7	Weather and climate predictions
SPOT4	1998.3.24	Ariane V 107	CNES	Sun-synchronous	802	98.7	Remote sensing, Earth resources satellite
SPOT5	2002.5.3	Ariane 4	CNES	Sun-synchronous	822	98.7	Remote sensing, Earth resources satellite
GeoEye	2008.9.6	Delta II	OSC	Sun-synchronous	684	98	Earth observation satellite

NASA: national aeronautics and space administration, CNES: centre national d'etudes spatiales, OSC: orbital sciences corporation, LANDSAT: land satellite (originally named earth resources technology satellite), NOAA: national oceanic and atmospheric administration, SPOT: système probatoire d'observation de la terre <http://www.n2yo.com/database/> [cited 2011 Mar 24]

3.1 Categorization of Satellites According to Orbital Elements

We chose 5867 satellites and unidentified flying objects for which TLE were available in the collected data. The horizontal axis in Fig. 5 represents the satellites arranged in order with respect to the orbital elements, while the vertical axis the orbital elements corresponding to the individual satellites. We arranged the satellites according to the orbital eccentricity, orbital inclination, ascending node, perigean declination, and the mean anomaly, and searched the orbital elements with which categorization might be performed. The result showed that the satellites were concentrated within a specific range of orbital

inclination (70-76, 80-91, and 94-100 degree) as shown in Fig. 5.

3.2 Visibility Analysis of the LEO and MEO Satellites

To verify orbital inclination can be a characteristic that may affect the visibility, we categorized the LEO and MEO satellites according to the orbital inclination and analyzed the visibility for the 17 optimal ground site candidates. The total simulation period was one year between January and December, 2010. The specifications of the subject satellites are summarized in Table 4. The SGP4 orbital propagator was used for each satellite.

3.3 The Visibility Analysis Result

The visibility and the observation frequency of the 23 LEO and MEO satellites were independent on the orbital elements, and the difference was less than 1σ among the optimal ground site candidates. The visibility difference was negligible between the orbital communications flight model-2 (ORBCOMM FM-2) satellite (Fig. 6) having the smallest orbital inclination and NOAA-16 (Fig. 7) having the greatest orbital inclination. None of the other satellites was affected by the orbital inclination. Thus, it is difficult to categorize the satellites in view of the orbit and determine the optimal ground site with reference to a general standard. Simulation needs to be performed for domestic satellites and the satellites that are to be launched in the country according to the characteristics and properties of the mission which is the optical surveillance and tracking of the domestic satellites.

Fig. 5. Distribution of the orbital elements of 5867 satellites (Kim 2011b).

Fig. 6. Visibility of orbital communications flight model-2 (ORBCOMM FM-2) on proposed 17 ground sites is drawn in topocentric horizon, and the different color distinguish between sites.

Fig. 7. Visibility of national oceanic and atmospheric administration-16 (NOAA-16) on proposed 17 ground sites is drawn in topocentric horizon, and the different color distinguish between sites.

Table 4. 23 satellites representing typical LEO and MEO orbital characteristics*

Inclination	NORAD ID	Satellite	Perigee (km)	Apogee (km)	Inclination (deg)	Altitude (km)	Period (min)	Information
70~76	23546	ORBCOMM FM 2	689.9	700.1	69.9772	674.99	98.5	Investigate the particle acceleration regions above the auroral region
	31792	COSMOS 2428	851.1	865.8	70.9861	838.14692	102	
	23087	COSMOS 2278	849.4	861	71.0544	834.86388	101.9	
	29047	FORMOSAT 3A	770.6	846.1	71.9783	788.12123	100.9	
	27858	SCISAT 1	646.5	658.5	73.9317	632.62571	97.6	
	26998	TIMED	621.8	624.2	74.0713	603.14358	97	
	19822	EXOS D (AKEBONO)	272.1	5023.4	75.081	2625.0777	142.1	
80~91	13402	COSMOS 1400	476.8	486.7	81.1303	462.20501	94.1	Designed to study Earth's aurora.
	24285	FAST	355.9	3695.3	82.9676	2003.2207	127.6	
	26818	COSMOS 2378	968.7	1017.8	82.9228	972.73001	104.8	
	24872	IRIDIUM 18	783.2	786.4	86.391	764.63005	100.4	
	25039	IRIDIUM 43	783.2	786.3	86.3926	764.62995	100.4	
	24792	IRIDIUM 8	783.2	786.4	86.3939	764.64807	100.4	
	27391	GRACE 1	458.5	475.7	89.0072	447.55374	93.8	
	28382	DOUBLESTAR	242.4	38155.5	88.4161	19150.291	678.2	
	18362	OSCAR 29	1023.6	1181.5	90.3507	1081.7974	107.2	
94~100	27643	CHIPSAT	571.3	591	94.0136	561.36748	96.1	Similar to the equatorial orbiter Navy Navigation Satellite
	26953	QUICKBIRD 2	452.7	454.8	97.0951	434.23216	93.5	
	20439	PACSAT (OSCAR 16)	784.8	800.3	98.3672	772.36822	100.6	
	27845	QUAKESAT	824.9	837.2	98.7168	810.79274	101.4	
	11060	TIROS N	832.5	849.1	99.0041	820.56773	101.6	
	26536	NOAA 16	849.9	865.4	99.1535	837.34856	101.9	
	23711	SURFSAT	940.8	1499.9	100.3324	1199.3774	109.7	

LEO: low earth orbit, MEO: middle earth orbit, NORAD: north American aerospace defense command, ORBCOMM FM-2: orbital communications flight model-2, FORMOSAT-3A(ROCSat-3A): republic of China satellite-3A, SCISAT-1: science satellite-1, TIMED: thermosphere ionosphere mesosphere energetic and dynamics, EXOS D(AKEBONO): exospheric satellite D, FAST: fast, affordable, science and technology satellite , GRACE-1: grace recovery and climate experiment-1, OSCAR: orbiting satellite carrying amateur radio, CHIPSAT: cosmic hot interstellar plasma spectrometer satellite, TIROS N: television infrared observation satellite N, NOAA: national oceanic and atmospheric administration, SURFSAT: summer undergraduate research fellowship satellite.
*<http://www.n2yo.com/database/> [cited 2011 Mar 28]

4. VISIBILITY ANALYSIS OF DOMESTIC SATELLITES ON PROPOSED 17 GROUND SITES

The visibility of ten domestic satellites was analyzed for the 17 optimal ground site candidates. The total simulation period was one year between January and December, 2011, and the simulation was performed for one extra day for each equinox and solstice (the spring equinox, summer solstice, autumnal equinox and winter solstice). The specifications of the subject domestic satellites are shown

in Table 5. To make the final determination of the five optimal ground sites, we fixed ground sites that solely had a local superiority to the surroundings (Las Campanas Observatory, South African Astronomical Observatory, and Observatorio Astronómico Nacional en San Pedro Mártir), made 33 combinations with the observatories concentrated on the southern hemisphere (Bisdee Tier Optical Astronomy Observatory, Siding Spring Observatory, and Vintage Lane Observatory), and compared them as shown in Table 6. The orbits of the domestic satellites

Table 5. Specification of the launched domestic satellites.*

Satellite	NORAD ID	Launch date	Perigee (km)	Apogee (km)	Inclination (deg)	Period (min)	Semi-major axis (km)
COMS-1	36744	2010.06.26	35,787.2	35,798.8	0.0	1,436.1	42,164.0
KITSAT-1	22077	1992.08.10	1,313.9	1,331.6	66.1	111.9	7,693.8
KITSAT-2	22828	1993.09.26	791.6	806.9	98.5	100.7	7,170.3
KITSAT-3	25756	1999.05.26	714.3	734.2	98.6	99.1	7,095.2
KOMPSAT-1	26032	1999.12.21	678.1	685.0	97.8	98.2	7,052.6
KOMPSAT-2	29268	2006.07.28	685.7	706.2	98.3	98.5	7,066.9
KOREASAT-1	23639	1995.08.05	35,939.2	35,985.2	10.4	1,444.7	42,333.2
KOREASAT-2	23768	1996.01.14	35,787.9	35,799.1	3.9	1,436.1	42,164.5
KOREASAT-3	25894	1999.09.04	35,791.1	35,795.1	0.0	1,436.1	42,164.1
KOREASAT-5	29349	2006.08.22	35,785.5	35,803.3	0.0	1,436.1	42,165.4
STSAT-1	27945	2003.09.27	681.3	698.1	97.8	98.4	7,060.7

NORAD: north American aerospace defense command, COMS-1: communication, ocean and meteorological satellite-1, KITSAT: Korean institute of technology satellite, KOMPSAT: Korea multi-purpose satellite, STSAT-1: science and technology satellite-1.

*<http://www.n2yo.com/database/> [cited 2011 Mar 29]

Table 6. The number of 33 cases for the combination of 5 ground sites for best visibility.

Case	Standard ground sites	Candidate ground sites	Fixed ground sites
1	Bisdee Tier Optical Astronomy Observatory	Khurel Togoot Observatory	Observatorio Astronómico Nacional en San Pedro Mártir South African Astronomical Observatory Las Campanas Observatory
2	Bisdee Tier Optical Astronomy Observatory	Indian Astronomical Observatory	
3	Bisdee Tier Optical Astronomy Observatory	Assy-Turgen Observatory	
4	Bisdee Tier Optical Astronomy Observatory	Tien-Shan Observatory	
5	Bisdee Tier Optical Astronomy Observatory	Pamir High-Mountain Observatory	
6	Bisdee Tier Optical Astronomy Observatory	Sanglokh Observatory	
7	Bisdee Tier Optical Astronomy Observatory	Mount Dushak-Erekdag Observatory	
8	Bisdee Tier Optical Astronomy Observatory	Maidanak Observatory	
9	Bisdee Tier Optical Astronomy Observatory	Roque de Los Muchachos Observatory	
10	Bisdee Tier Optical Astronomy Observatory	Skinakas Observatory	
11	Bisdee Tier Optical Astronomy Observatory	Tubitak National Observatory	
12	Siding Spring Observatory	Khurel Togoot Observatory	
13	Siding Spring Observatory	Indian Astronomical Observatory	
14	Siding Spring Observatory	Assy-Turgen Observatory	
15	Siding Spring Observatory	Tien-Shan Observatory	
16	Siding Spring Observatory	Pamir High-Mountain Observatory	
17	Siding Spring Observatory	Sanglokh Observatory	
18	Siding Spring Observatory	Mount Dushak-Erekdag Observatory	
19	Siding Spring Observatory	Maidanak Observatory	
20	Siding Spring Observatory	Roque de Los Muchachos Observatory	
21	Siding Spring Observatory	Skinakas Observatory	
22	Siding Spring Observatory	Tubitak National Observatory	
23	Vintage Lane Observatory	Khurel Togoot Observatory	
24	Vintage Lane Observatory	Indian Astronomical Observatory	
25	Vintage Lane Observatory	Assy-Turgen Observatory	
26	Vintage Lane Observatory	Tien-Shan Observatory	
27	Vintage Lane Observatory	Pamir High-Mountain Observatory	
28	Vintage Lane Observatory	Sanglokh Observatory	
29	Vintage Lane Observatory	Mount Dushak-Erekdag Observatory	
30	Vintage Lane Observatory	Maidanak Observatory	
31	Vintage Lane Observatory	Roque de Los Muchachos Observatory	
32	Vintage Lane Observatory	Skinakas Observatory	
33	Vintage Lane Observatory	Tubitak National Observatory	

were predicted using the SGP4 orbit propagator. The simulation was performed with respect to the ten domestic satellites in connection with the 33 combinatorial cases, resulting in 330 visibility analysis diagrams as shown in Figs. 8-10.

In these figures, the horizontal axis represents the observationally visible time, while the vertical axis the observatories determined for the satellites. All the 33 cases showed the difference less than 1σ , but we found following differences by comparing the observatories having a similar visibility trend. Different from our expectation, a better result was found, not in the observatories that had a local superiority and thus had been included in all the combinatorial cases, but in the observatories that had not been included. Khurel Togoot Observatory showed the observationally visible time 1.2 times longer than that of Observatorio Astronómico Nacional en San Pedro Mártir in summer. Bisdee Tier Optical Astronomy Observatory and South African Astronomical Observatory showed a longer observationally visible time in winter than that of Las Campanas Observatory that was compared together (Fig. 8). In the third case where the communication, ocean and meteorological satellite-1 (COMS-1) was simulated, Assy-Turgen Observatory showed a far longer

observationally visible time than that of other observatories (Fig. 9). In the 11st case, Korean institute of technology satellite-1 (KITSAT-1) seemed to have a similar visibility for the five determined observatories, but Tubitak National Observatory showed the observationally visible time 1.2 times longer than that of Astronómico Nacional en San Pedro Mártir or Las Campanas Observatory (Fig. 10). Hence, we finally determined the five observatories (Khurel Togoot, Assy-Turgen, Tubitak, Bisdee Tier and South Africa) as the optimal ground sites.

5. FEASIBILITY ANALYSIS OF SERIES OBSERVATION BASED ON GROUND TRACK OF FICTITIOUS SATELLITES

Series observation within 24 hours in the process of maintaining the ephemeris through optical observation may greatly help to maintain the ephemeris precision. To analyze the continuous feasibility through the ground track, we set up the Daeduk observatory (DO) and South African astronomical observatory (SAAO) at which series observation may be feasible on the basis of the latitude. Then, we set fictitious sites (FS), considering the series

Fig. 8. Visibility duration of Korea multi-purpose satellite-2 (KOMPSAT-2) on selected 5 ground sites (1st case) is plotted in a chart, and the different color distinguish between sites.

Fig. 9. Visibility duration of the communication, ocean and meteorological satellite-1 (COMS-1) on selected 5 ground sites (3rd case) is plotted in a chart, and the different color distinguish between sites.

Fig. 10. Visibility duration of Korean institute of technology satellite-1 (KITSAT-1) on selected 5 ground sites (11th case) is plotted in a chart, and the different color distinguish between sites.

observation feasibility with the DO to the full (Table 7). The simulation period was for one day and three days on each equinox and solstice (the spring equinox, summer solstice, autumnal equinox and winter solstice). The specifications of the subject satellites, five fictitious satellites for each orbital inclination as well as KOMPSAT-2, are presented in Table 8. KOMPSAT-2 was used as the reference to compare the fictitious satellites with an actual one. In the simulation, the SGP4 orbit propagator of which TLE is updated in real-time was used for KOMPSAT-2. Since the TLE had to be manually put in to the other fictitious satellites, without automatic TLE update, we employed the J4 Perturbation orbit propagator³ that allowed the orbit propagation from the initial input orbital elements. J4 Perturbation (second-order) propagator accounts for secular variations in the orbit elements due

to Earth oblateness, which does not model atmospheric drag or solar or lunar gravitational forces.

The simulation result showed that the maximum number of times for series observation per day was one between DO and SAAO. The mean number of times for series observation per day between DO and the FSs was about one as shown in Table 9, although there was some exceptional cases when the maximum was three times in a day (orbital inclination 98 degree on the winter solstice). Here, 1 point represents the case where series observation was performed for one time, while 0 point represents the case where the observation was possible but not continuously. In the case of three-day interval simulation, the number of times for series observation between DO and FS was relatively greater on the winter solstice, and the number of times for observation was the greatest for the fictitious satellite whose orbit inclination was 99 degree, as shown in Table 10. Therefore, series observation is one factor to increase the precision when maintaining the

³http://www.stk.com/resources/help/online/stk/source/stk/vehsat_orbitprop_choose.htm [cited 2011 Feb 2]

Table 7. Characteristics of chosen 2 ground sites and 1 fictitious ground site.

Proposed ground sites	Latitude (deg)	Longitude (deg)	Elevation (m)	Main telescope
South African Astronomical Observatory	-32.378	20.8105	1,759	10 m SALT
Daeduk Observatory	36.3214	127.42	0	
Fictitious Site Observatory	0	-50	0	

SALT: southern African large telescope.

Table 8. Specification of the 5 fictitious satellites and KOMPSAT-2.*

Satellite	Perigee (km)	Apogee (km)	Inclination (deg)	Period (sec)	Semi-major axis (km)
Inc96	99.9428	99.9428	96	5,188.96	6,478.08
Inc97	390.496	390.496	97	5,541.95	6,768.63
Inc98	652.309	652.309	98	5,866.58	7,030.45
Inc99	891.235	891.235	99	6,168.17	7,269.37
Inc100	1111.42	1111.42	100	6,450.52	7,489.55
KOMPSAT-2	656.3	680.9	98.1	5,916	7,066.9

KOMPSAT-2: Korea multi-purpose satellite-2.

*<http://en.wikipedia.org/wiki/Arirang-2> [cited 2011 Feb 4]

Table 9. Series observation frequency during the day at equinoxes.

Satellite	Vernal equinox	Summer solstice	Autumnal equinox	Winter solstice
Inc100 (DO,FS)	1 point	1 point	1 point	2 points
Inc100 (DO,SAAO)	1 point	0 point	0 point	1 point
Inc99 (DO,FS)	1 point	N/A	2 points	2 points
Inc99 (DO,SAAO)	0 point	N/A	0 point	1 point
Inc98 (DO,FS)	N/A	N/A	1 point	3 points
Inc98 (DO,SAAO)	N/A	N/A	0 point	0 point
Inc97 (DO,FS)	1 point	N/A	1 point	2 points
Inc97 (DO,SAAO)	0 point	N/A	0 point	0 point
Inc96 (DO,FS)	N/A	N/A	N/A	N/A
Inc96 (DO,SAAO)	N/A	N/A	N/A	N/A
KOMPSAT-2 (DO,FS)	N/A	1	N/A	N/A
KOMPSAT-2 (DO,SAAO)	N/A	0	N/A	N/A

KOMPSAT-2: Korea multi-purpose satellite-2, DO: Daeduk observatory, FS: fictitious sites, SAAO: South African astronomical observatory, N/A: not available.

Table 10. Series observation frequency during 3 days at equinoxes.

Satellite	Vernal equinox	Summer solstice	Autumnal equinox	Winter eolstice
Inc96 (DO,FS)	N/A	N/A	N/A	2 points
Inc97 (DO,FS)	3 points	N/A	2 points	6 points
Inc98 (DO,FS)	4 points	N/A	4 points	8 points
Inc99 (DO,FS)	3 points	N/A	6 points	15 points
Inc100 (DO,FS)	6 points	2 points	6 points	10 points
KOMPSAT-2 (DO,FS)	N/A	5 points	N/A	N/A

KOMPSAT-2: Korea multi-purpose satellite-2, DO: Daeduk observatory, FS: fictitious sites, N/A: not available.

ephemeris through optical observation. However, it does greatly affect the determination of the optimal ground sites, and is not appropriate as a requirement for enabling the ephemeris maintenance through optical observation, since its actual frequency is not high.

6. EFFECTIVE VISIBILITY ANALYSIS OF DOMESTIC SATELLITES IN ACTION AND IN PLANNING ON SELECTED 5 GROUND SITES

The EV analysis was performed to verify whether or not the observation data sufficient to maintain the ephemeris could be acquired from the finally determined optimal ground sites.

6.1 Definition of EV

EV is defined as the percentage of the actual observationally visible time, assuming the number of observation points needed for the ephemeris maintenance for two weeks of satellite flying to be 600 and the length of the time when the 600 points are continuously visible to be 100% (Jo 2011). Eq. (1) is the equation to calculate EV. The observationally visible time shorter than 60 seconds is excluded when calculating $0V_{SUM}$.

$$EV[\%] = \frac{0V_{SUM}[\text{sec}]}{600[\text{sec}]} \times 100[\%] \quad (1)$$

where EV denotes effective visibility, EV the Total sum of observationally visible passing time over each site which is longer than 60 second per piece in two weeks.

6.2 Analysis of the Observationally Visible Time During Two Weeks in Each Season for the Domestic Satellites

The observationally visible time during two weeks in each season was analyzed for the five optimal ground

sites (Khurel Togoot Observatory, Assy-Turgen Observatory, Tubitak National Observatory, Bisdée Tier Optical Astronomy Observatory, and South African Astronomical Observatory) among the ground site candidates shown in Table 2. The simulation period was for two weeks from the first day to the 14th day of January, April, July and October in 2010. The subject satellites were nine domestic LEO satellites including KOMPSAT-3, KOMPSAT-3A and KOMPSAT-5 that are to be launched. The specifications of the subject satellites are shown in Table 5. In the cases of the satellites to be launched, the simulation orbit was predicted using the J4 Perturbation orbit propagator to which nominal orbital elements are put in, while the SGP4 orbit propagator was used for other satellites. Fig. 11 shows the result. The horizontal axis in the figure represents the observationally visible time, and the vertical axis the individual satellites determined for each of the optimal ground sites.

With the observationally visible time obtained as the result of the simulation with respect to each satellite, $0V_{SUM}$ was calculated by discarding the observation time shorter than 60 seconds and adding all the remaining time. If the $0V_{SUM}$ resulted from the Eq. (1) is over 100%, the observatory may be considered as the one where the optical observation data minimally required for the maintenance of the ephemeris can be acquired for two weeks.

6.3 The EV Calculation Result

Table 11 shows the EV calculation result for the optimal ground site for each domestic satellite. Firstly, it should be verified whether or not the EV meets the requirements of the optical observation data of the domestic satellites, including the satellites that will be operated in the future, needed for the maintenance of the ephemeris at the five determined optimal ground sites. Excluding KOMPSAT-3, KOMPSAT-3A and KOMPSAT-5 that are to be launched in the future, the observation data needed for the maintenance of the ephemeris are acquired averagely at three out of the five determined optimal ground sites

Fig. 11. Visibility duration of domestic satellites on Khurel Togoot Observatory (April) is plotted in a chart, and the different color distinguish between sites.

over a year. Particularly, Bisdee Tier Optical Astronomy Observatory has a great significance even among the optimal ground sites, since its overall EV is high and the observation is possible even when it is difficult at other ground sites. Among the SSO satellites, the observation in April and October may be difficult with KOMPSAT-3 and KOMPSAT-3A that are supposed to move along the ground track in a similar pattern with that of direct sun as well as KOMPSAT-5 that is supposed to move along the dawn-dusk orbit. Since the accurate orbital elements of the domestic satellites that are to be launched could not be identified, the orbit propagation was performed over an excessively long period of time depending on the nominal orbital elements in the simulation process, and thus the accuracy and reliability of the simulation results regarding the visibility were not high. For this reasons, even the simulation over a year with other candidates in addition to the five optimal ground sites would not enable to make right judgments. Therefore, the optical visibility over 80% could be obtained with respect to the domestic satellites at the selected optimal ground sites. The EV will be increased if the actual orbital elements of the domestic satellites are included in the future.

7. SUMMARY

To perform the optical surveillance and tracking of do-

mestic satellites, we determined five optimal ground sites from 17 candidates, and investigated whether or not the observation data sufficient to maintain the ephemeris could be acquired from the finally determined optimal ground sites. Before determining the optimal ground site candidates, the optical observation limiting factors of the domestic SSO satellites were identified, and the result showed that the candidates on high latitudes (north latitude 25-34 degree or higher, south latitude 30-40 degree of higher) had an advantage for the observation of the SSO satellites. The LEO and MEO satellites were categorized according to the orbit inclination and the visibility was compared with each other. The result showed that the visibility and observation frequency were independent upon the orbital elements including orbit inclination, and the difference was less than 1σ among the optimal ground site candidates. Thus, we found that it is more important to analyze the visibility at the optimal ground sites for the domestic satellites and the satellites to be launched in the country than analyzing any other factors. As a result, five ground sites (Khurel Togoot, Assy-Turgen, Tubitak, Bisdee Tier and South Africa) were finally determined. The series observation feasibility at two or more optimal ground sites, but the actual frequency was low. Thus, the series observation feasibility was not appropriate as a requirement for ephemeris maintenance. The EV was analyzed for the five determined optimal ground sites to verify whether or not the observation data suffi-

Table 11. Effective visibility of observation site candidates for first session of January, April, July, October.

Satellite	SAAO (%)	Tubitak (%)	Assy-Turgen (%)	Khurel Togoot (%)	Bisdee-Tier (%)	Observable sites	Month
STSAT-1	696	N/A	N/A	N/A	303	2	1
	N/A	53	348	639	184	4	4
	N/A	781	617	469	N/A	3	7
	496	N/A	N/A	N/A	889	2	10
KITSAT-1	1373	595	1029	1665	2505	5	1
	1417	1399	2324	3810	1455	5	4
	1182	2147	2580	3292	1612	5	7
	44	1249	1648	1857	1031	5	10
KITSAT-2	394	N/A	N/A	N/A	984	2	1
	N/A	152	538	876	N/A	3	4
	N/A	793	953	705	N/A	3	7
	N/A	N/A	N/E	122	23	2	10
KITSAT-3	N/A	555	520	796	N/A	3	1
	780	667	730	758	636	5	4
	852	339	159	117	1029	5	7
	764	N/A	N/E	52	624	3	10
KOMPSAT-1	729	N/A	N/A	N/A	507	2	1
	N/A	N/E	128	412	12	3	4
	N/A	803	758	594	N/A	3	7
	207	N/A	N/A	N/A	742	2	10
KOMPSAT-2	377	N/A	N/A	N/A	854	2	1
	N/A	N/A	N/E	119	N/A	1	4
	N/A	436	778	996	N/A	3	7
	N/A	N/A	N/A	N/A	165	1	10
KOMPSAT-5	N/A	N/A	N/A	N/A	289	1	1
	N/A	N/A	N/A	N/A	N/A	0	4
	N/A	N/E	261	498	N/A	2	7
	N/A	N/A	N/A	N/A	N/A	0	10
KOMPSAT-3	247	540	657	822	126	5	1
	N/A	N/A	91	353	N/A	2	4
	472	225	99	24	544	5	7
	N/A	N/A	N/A	N/A	10	1	10
KOMPSAT-3A	N/A	513	505	625	N/A	3	1
	N/A	N/A	N/A	N/E	N/A	0	4
	653	N/A	N/A	N/A	651	2	7
	N/A	N/A	N/A	N/A	N/A	0	10

SAAO: South African astronomical observatory, STSAT-1: science and technology satellite-1, KITSAT: Korean institute of technology satellite, KOMPSAT: Korea multi-purpose satellite, N/A: not available, N/E: not enough access time.

cient for the satellites to maintain the ephemeris could be acquired. The result showed that the observation data sufficient to maintain the ephemeris could be acquired at all the five determined optimal ground sites and that the EV was higher than 80% for the domestic satellites. When considering the sites for the optimal ground sites in the process of establishing the optical telescope system for space object surveillance and tracking, the five sites that were found in this study to have high visibility and EV may be selected preferentially, if other conditions are the same including the basic infrastructure. Additionally, the optical observation system could be established on the basis of the assumption that the determined optimal ground sites are located at the most advantageous positions for the optical observation of the domestic satellites and that the data acquired from the observation are sufficient to maintain the ephemeris.

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