Analysis on the Minimization of Contact Overlap Time between KOMPSAT-3 and KOMPSAT-3A

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Abstract: *On March 25, 2015 the KOMPSAT-3A was launched. It is a part of the KOrean Multi-Purpose SATellite (KOMPSAT) Program developed and operated by Korea Aerospace Research Institutes (KARI). KOMPSAT-3A's mission is to acquire satellite images for earth observation. KOMPSAT-3A and KOMPSAT-3 are using an identical satellite bus and similar payload. The mission orbit of KOMPSAT-3A is a sun-synchronous orbit at 528 Kilometers in altitude, inclined 98.513 degrees. Mean local time of ascending node (LTAN) is 13:30. Due to the same LTAN between KOMPSAT-3A and KOMPSAT-3 with different altitude, the close approach of two satellites are foreseen. In this paper, the optimization approach is proposed to operate a KOMPSAT-3 and -3A in more efficient way. For this purpose, we confirmed communication windows, geometrical characteristics, and contact sequences of the KGS with KOMPSAT-3A and KOMPSAT-3 during operation period by using the real orbit data. Also, the mitigation plan is proposed so as to decrease the possibility of KOMPSAT-3 and KOMPSAT-3A flying over the KARI Ground Station (KGS) at the same time. Finally, some issues are removed such as contact overlap time, the interference possibilities and so on. This paper will present more representative analysis result of real satellite operation and could be a reference to setup an operational strategy for the multiple satellite operations in terms of orbit and their communication windows.*

Keywords: *KOMPSAT-3, KOMPSAT-3A, Contact Overlap Time, Minimization of overlap time, Communication Window, Geometric Characteristic, Mitigation Plan, Flight Dynamics Operations*

1. Introduction

Korea Aerospace Research Institute (KARI) is conducting the low earth orbit satellite mission operations for KOrean Multi-Purpose SATellite (KOMPSAT) series, which include KOMPSAT-2, KOMPSAT-3, KOMPSAT-5 and KOMPSAT-3A. Under Korea's space program, KARI had developed and launched satellites shown in Figure 1 [1]. The development status of KOMPSAT series was summarized in Table 1 [2].

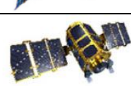
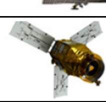
KOMPSAT-1, the first satellites of KOMPSAT series, was launched in December 21, 1999 by a Taurus launch vehicle. It was operated for eight years in a sun-synchronous orbit at an altitude 685 km and 98.13 degree inclination. It carried an optical imager with a ground resolution of 6.6 meters [3], [4], [5]. KOMPSAT-2 was launched in July 2006 and delivered imagery at a 1 meter ground resolution. Its mission orbit is sun-synchronous orbit at 685.13 kilometers in altitude [6]. KOMPSAT-3 was launched in May 2012 using a similar bus architecture as KOMPSAT-2 with an more improved optical payload that reached a resolution of 0.7 meter for panchromatic imagery [7].

In August 2013, a Dnepr rocket launched KOMPSAT-5 that becomes the first radar satellite, outfitted with a Synthetic Aperture Radar (SAR) capable of covering a wide ground swath or operating in a high resolution mode delivering imagery at a 1 meter resolution. Its bus modular design is based on the heritage of KOMPSAT-2, which is parallel integration of the payload, spacecraft bus and propulsion equipment [8]. Mission orbit of KOMPSAT-5 is a sun-synchronous and dawn-dusk orbit which retraces its ground track after 421 revolutions during 28days at 550 kilometers in altitude, inclined 97.65 degrees. In addition, Local time of ascending node (LTAN) is 06:00 [9].

The KOMPSAT-3A was launched on March 25, 2015 at 22:08 universal time coordinate (UTC). Its mission is to acquire satellite images for earth observation. KOMPSAT-3A is a part of the KOMPSAT Program developed and operated by KARI. It is equipped with optical and infrared payloads to deliver the needed data for a variety of purposes [10].

Figure 1. Korea's Space Program

Table 1. Development Status of KOMPSAT Series (As of September, 2015)

	Image	Launch Date	Mission Altitude	Remark
KOMPSAT-1		Dec. 21, 1999	685 kilometers (Sun-synchronous)	End of mission
KOMPSAT-2		Jul. 28, 2006	685 kilometers (Sun-synchronous)	In operation
KOMPSAT-3		May 18, 2012	685 kilometers (Sun-synchronous)	In operation
KOMPSAT-5		Aug. 22, 2013	550 kilometers (Sun-synchronous)	In operation
KOMPSAT-3A		Mar. 25, 2015	528 kilometers (Sun-synchronous)	In operation

2. Mission Overview of KOMPSAT-3A

KOMPSAT-3A is the sister of KOMPSAT-3. These have an identical satellite bus and similar payload. However, KOMPSAT-3A is added the infrared capability and the high quality resolution for an electro-optical image. KOMPSAT-3A provides 0.55 meter Ground Sample Distance (GSD) panchromatic image, 2.2 meter GSD multi-spectral image and 5.5 meter GSD infrared image data for various applications. The main mission of KOMPSAT-3A is to provide the following applications [10]:

- Continuation of earth observation to meet national needs
- Provision of the high-resolution Electro-Optical (EO) images required for Geographic Information Systems (GIS) establishment and the applications for environmental, agriculture and ocean monitoring
- Provision of Infrared (IR) images for GIS application and for monitoring the forest fire, the volcanic activity, the waste heat pollution in lakes and rivers, the flood damage, the urban heat island

The mission orbit of KOMPSAT-3A is a sun-synchronous orbit which retraces its ground track after 423 revolutions during 28 days at 528 kilometers in altitude, inclined 98.513 degrees. Orbit period is about 95.2 minutes and mean local time of ascending node (LTAN) is 13:30. Table 2 shows the mission orbits of KOMPSAT-3A and KOMPSAT-3. Due to the same LTAN between KOMPSAT-3A and KOMPSAT-3 with different altitude, the close approach of two satellites are foreseen. For example, the difference of orbital periods makes two satellites to be close each other every 2 days.

In this paper, the optimization approach is proposed to operate KOMPSAT-3A and -3 in more efficient way. For this purpose, we examine the communication windows, geometrical characteristic between KARI Ground Station (KGS) and two satellites, etc. Also, this paper presents a mitigation plan for the KOMPSAT-3A to minimize the contact overlap time with KOMPSAT-3.

Table 2. Mission Orbits of KOMPSAT-3A and KOMPSAT-3

	KOMPSAT-3A	KOMPSAT-3
Payload	EO, IR	EO
Altitude	528 kilometers	685 kilometers
Inclination	97.513 degrees	98.13 degrees
Mean LTAN	13:30	13:30
Orbit Period	95.2 minutes	98.5 minutes
Number of Revolutions	15.1 revolutions/day	14.6 revolutions/day
Orbit Velocity	7.60 km/second	7.51 km/second
Ground Speed	7.02 km/second	6.78 km/second
Repeated Ground Track	28days/409revolutions	28days/423revolutions

3. Analysis on Communication Windows of KOMPSAT-3A and KOMPSAT-3

To analyze of the close approach influence, we confirmed the contact sequence of KGS with KOMPSAT-3A and KOMPSAT-3 from April 16, 2015 to May 1, 2015 by using the real orbit data. During 15 days, KGS can contact with two satellites about 15 times. From these cases, only 3 cases have interference possibility because the angle between KGS and two satellites is under 2 degrees as Table 3.

Table 3. Pass Information of KOMPSAT-3A and KOMPSAT-3

Case	Satellites	Acquisition of Signal (dd mmm yyyy hh:mm:ss)	Loss of Signal (dd mmm yyyy hh:mm:ss)	Duration (sec)	Min. Angle (deg.)
(1)	K3	16 Apr 2015 05:15:19	16 Apr 2015 05:25:27	607.978	0.339
	K3A	16 Apr 2015 05:15:53	16 Apr 2015 05:24:33	520.216	
(2)	K3	18 Apr 2015 04:53:12	18 Apr 2015 05:04:14	662.668	1.359
	K3A	18 Apr 2015 04:55:01	18 Apr 2015 05:04:26	565.525	
(3)	K3	22 Apr 2015 05:49:46	22 Apr 2015 05:56:54	428.45	1.482
	K3A	22 Apr 2015 05:50:35	22 Apr 2015 05:56:11	335.962	

The Angle of between KGS and two satellites was defined as Figure 2. In this figure, $\overrightarrow{V_{k3a}}$ and $\overrightarrow{V_{k3}}$ are each line of sight vector from KGS to KOMPSAT-3A and KOMPSAT-3. When the angle becomes bigger, relative distance of two satellites is faraway. Correspondingly, when the angle is smaller, relative distance is closer and the interference possibility in communication with same ranges of frequency will be increased. Therefore, the geometry characteristic is the effective element to minimize the contact overlap time with respect to flight dynamics operations.

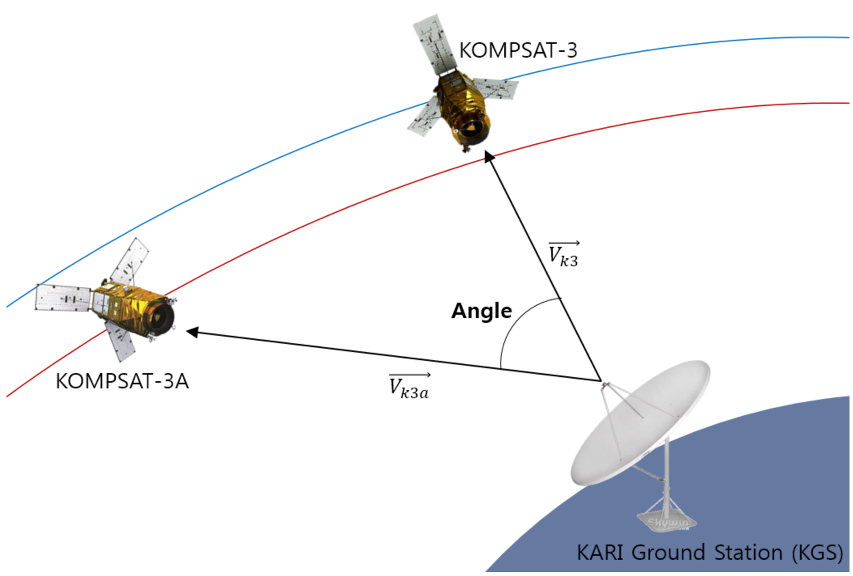


Figure 2. The Definitions of Angle between KGS and two Satellites

Figure 3 is presented on the Geometry Characteristics between KGS and two satellites during pass activities. In these case, the minimum angle between KGS and satellites was expected at April 16, 2015 05:19:39. Consequently, we carried real operational test for X-band interference possibility regarding case (1).

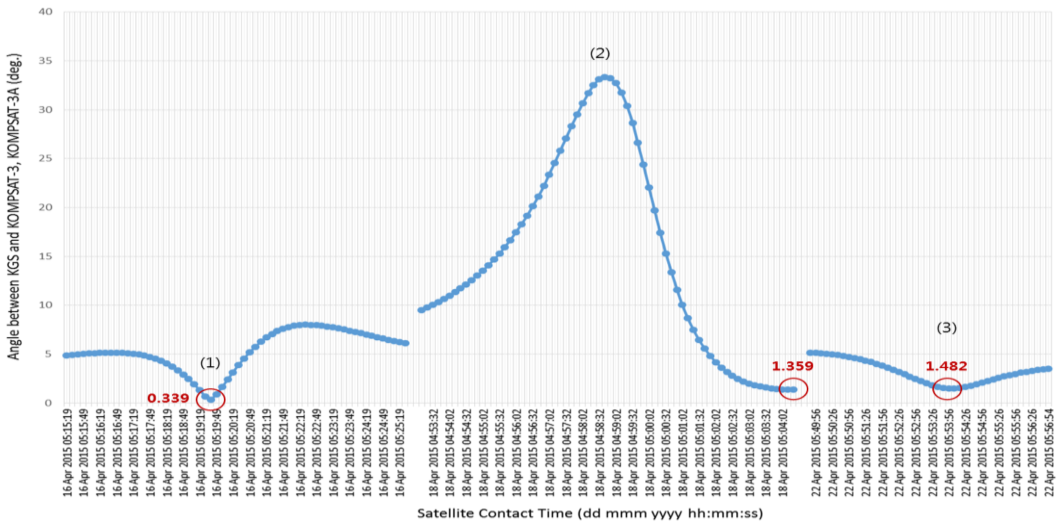


Figure 3. Analysis on the Geometry Characteristics between KGS and two Satellites

We operates two X-band antenna in KGS, which are 7.3 meter and 13 meter parabolic antenna. The lateral distance on ground between two antennas is just about 100 meters. During the passes, KOMPSAT-3 contacts 7.3 meter antenna and KOMPSAT-3A contacts 13 meter antenna. The antennas track the satellites using 3-axis angle generated from real flight orbit data. Figure 4 shows actual azimuth and elevation angle difference between KOMPSAT-3 and KOMPSAT-3A during passes. It shows fewer difference between the actual and predicted values. In this test, the frequency interference is caused between two antennas during 10 second (05:19:29 – 05:19:39). As a result, images of KOMPSAT-3 were a little bit loss of by KOMPSAT-3A.

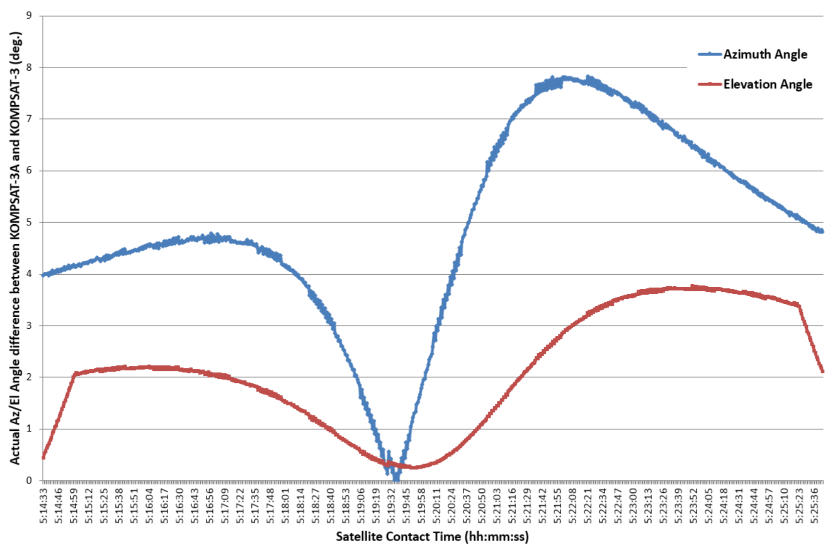


Figure 4. Actual Angle Difference between two Satellites during Passes

4. Mitigation Plan to minimize the contact overlap between KOMPSAT-3A and -3

The phase of two satellites is proposed to decrease the possibility of KOMPSAT-3 and KOMPSAT-3A flying over a KGS at the same time. The orbit is re-designed as follow steps:

- Step 1. Purely numerical simulation for overlapping time check using real orbit data
- Step 2. Re-designing of the orbit for minimizing overlap time
- Step 3. Tuning on the orbit and maneuver simulation
- Step 4. Evaluation of the simulation result

In Step 1, initial orbit elements of KOMPSAT-3 and KOMPSAT-3A are numerically propagated by using the STK's high precision orbit propagation (HPOP) from April 16, 2015 to May 1, 2015 [11]. During 15 days, KGS can contact with satellites about 15 times during 90 minutes 30 second at the same time. Here, only 3 cases have interference possibilities shown Table 3 and Figure 3. Figure 5 is shown contact sequence between two satellites and KGS. In this figure, blue bar is contact sequence and red bar is contact overlap time of two satellites. These information is used to construct a cost function in the next step.

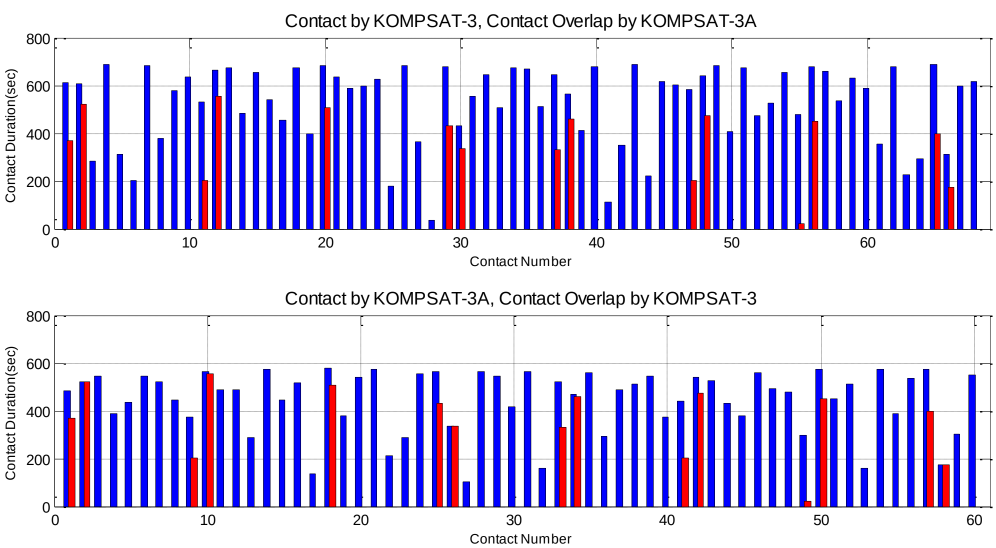


Figure 5. Contact Sequence by Purely Numerical Simulations

In Step 2, only orbit of KOMPSAT-3A is re-designed to minimize overlapping time between KOMPSAT-3 and KOMPSAT-3A by using simulation-based optimization method [12], [13]. The high-fidelity simulation capabilities are provided by commercial off-the-shelf software such as Satellites Tool Kit [11] and MATLAB [14]. Simulation-based optimization can be easily reformulated in the form of a nonlinear optimization problem for designing the sun-synchronous orbit. It can be considered the high-fidelity earth's gravitational model including a full gravitational field model based upon spherical harmonics, third-body's attraction, atmospheric drag, solar radiation pressure and so on.

In this step, semi-major axis is defined as design variable to minimize overlapping time. As a result, KGS contacts with satellites 6 times at the same time during 23 minutes. The contact sequences is shown in Figure 6. Contact overlap time is remarkably minimized about 75 percent in comparison with Step 1. Also, interference possibility is decreased because the minimum angle between KGS and two satellites is not under 20 degrees as shown in Figure 7. Minimum relative distance of two satellites is about 1209.44km. Assumed that the ground speeds of satellites are about 7 kilometer per second, the differences of acquisition of signal (AOS) between satellites and KGS are about 173sec. Re-designed orbit in step 2 is defined as a target orbit for orbit maneuver.

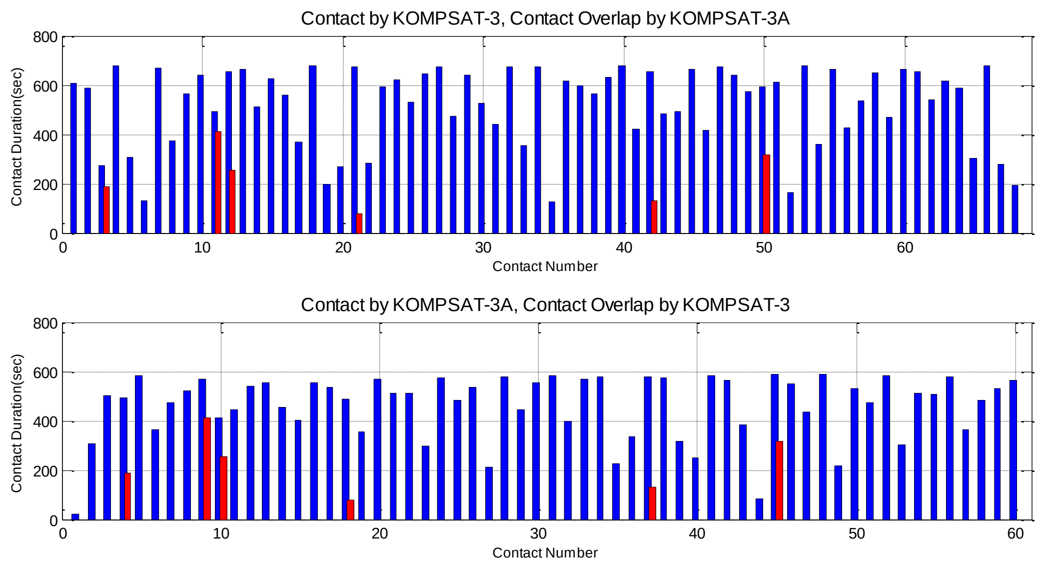


Figure 6. Contact Sequence using Simulation-Based Optimization

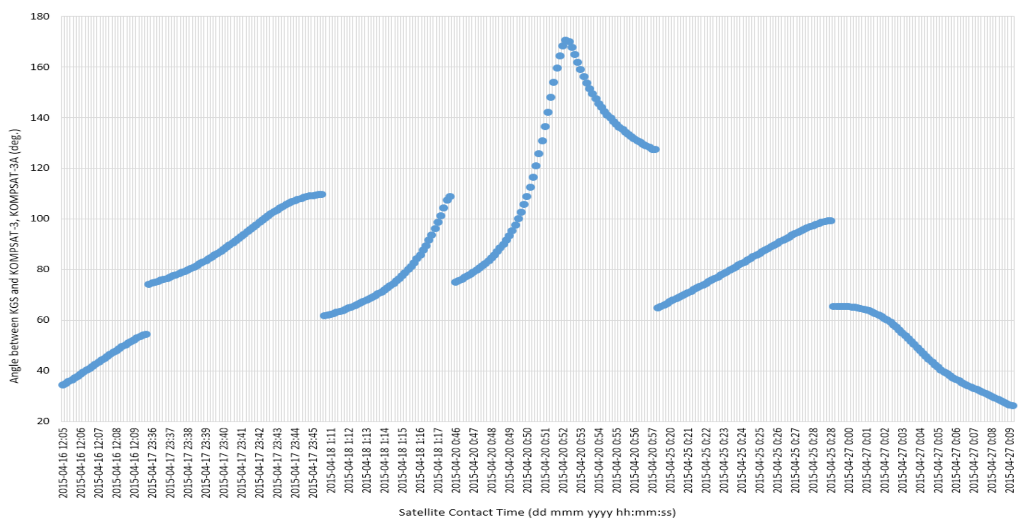


Figure 7. Analysis on the Geometry Characteristics between KGS and two Satellites

In Step 3, just for illustration purpose, we present design examples. To remove the overlapping time between two satellites, target orbit is modified by tuning the altitude of KOMPSAT-3A, phasing of two satellites and so on. For maneuver targeting, initial and target orbit are analyzed with detailed spacecraft model. Orbit maneuvering plan of KOMPSAT-3A was summary as follows:

- Semi-major axis decreased at perigee
- Burn start time: 15 Apr 2015 23:29:00.000
- Burn duration: 148 sec
- Applied Euler angle (LVLH: Roll-Pitch-Yaw): 0.000 -90.000 0.000 (degrees)

Figure 8 show an orbit maneuvers result. During the simulation period, overlap time of two satellites and the interference possibility are perfectly removed. Re-designed orbits of each steps are summarized in Table 4.

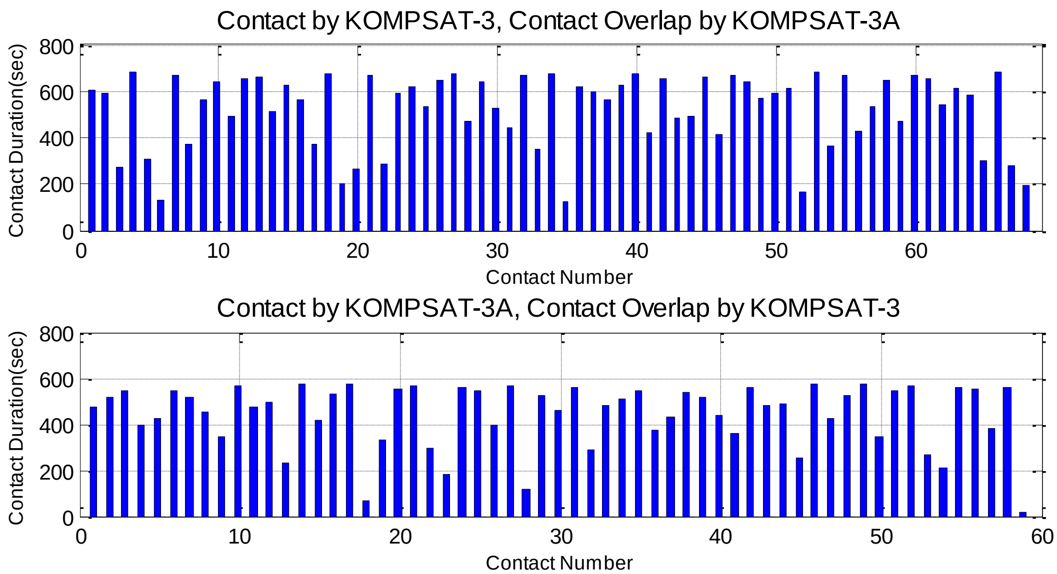


Figure 8. Contact Sequence after Orbit Maneuver using Flight Dynamics Systems

Table 4. Re-design Results of KOMPSAT-3A

	Initial Orbit Elements	Re-designed Orbit	Maneuver Result
Orbit epoch time	15 Apr 2015 15:00:00	15 Apr 2015 15:00:00	15 Apr 2015 23:31:28
SMA (km)	6911.6240	6907.4370	6908.7275
ECC	0.0018228	0.0018228	0.0011684
INC (deg.)	97.5146	97.5146	97.5102
RAAN (deg.)	45.9039	45.9039	46.2630
AOP (deg.)	146.9067	146.9067	141.3310
MA (deg.)	239.5866	239.5866	16.9169
Contact overlap time	about 90min. 30 sec.	about 23min	0 sec

6. Conclusion

In this paper, the optimization approach is proposed to operate KOMPSAT-3 and -3A in more efficient way. For this purpose, we confirmed communication windows, geometrical characteristics, and contact sequences of the KGS with KOMPSAT-3A and KOMPSAT-3 during operation period by using the real orbit data. Also, the mitigation plan is proposed to decrease the possibility of KOMPSAT-3 and KOMPSAT-3A flying over the KARI Ground Station (KGS) at the same time. Finally, some issues are removed such as contact overlap time, the interference possibilities and so on. This paper presented more representative analysis result of real satellite operation and could be a reference to setup an operational strategy for the multiple satellite operations in terms of orbit and their communication windows.

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