Study on Impact of Outdated Two-Line Element Sets in Tracking of LAPAN-A2 and LAPAN-A3 Satellites

Muazam Nugroho
Satellite Technology Center
Indonesia National Institute of Aeronautics and Space
Bogor, Indonesia
muazam.nugroho@lapan.go.id

Nova Maras Nurul Khamsah
Satellite Technology Center
Indonesia National Institute of Aeronautics and Space
Bogor, Indonesia
nova.maras@lapan.go.id

***Abstract*—On satellite tracking, information about orbital elements of the satellite which is contained in North American Aerospace Defense Command Two-Line Element Sets (NORAD TLE) is needed. This paper shows a study of how updating Two-Line Element Sets affecting the position prediction of LAPAN-A2 and LAPAN-A3 satellites. The positions of the satellites observed are determined by their latitude, longitude, and altitude. The results of orbit simulation, and position error calculation demonstrate that in the case of 1-day and 1-week Two-Line Element, compared to the updated Two-Line Element Sets, shows insignificant errors of the satellites position. Nonetheless, for more than 1-week outdated Two-Line Element Sets yields a very high error in predicting the position of the satellites and could affect the satellite tracking results. Furthermore, the mission simulation of LAPAN-A2 satellites illustrates the difference result of the imaging mission of the satellite with roll angle 4.21° between the updated and the outdated Two-Line Element Sets scenario, which makes it convincing that updating Two-Line Element Sets in satellite tracking tools is very important in satellite tracking.**

Keywords*—*orbital elements, Two-Line Element Sets , satellite tracking

I. Introduction

North American Aerospace Defense Command (NORAD) provides two-line element sets (TLE) which contain mean orbital elements for satellites. Orbital elements are a set of six numbers that completely describe satellite orbital plane at a specific time [1]. Two-Line Element Sets is generated using Simplified General Perturbation 4 (SGP4) [2], a mathematical model used to calculate orbital state vector from satellites and space debris, relatives to inertial coordinate of Earth.

On satellite tracking, there are numerous software available, as in [3] tracking tools using NORAD Two-Line Element Sets is developed. In Satellite Technology Center of Indonesia National Institute of Aeronautics and Space (LAPAN), satellite tracking of LAPAN-A2 and LAPAN-A3 satellites is executed with several tracking tools and software such as SatPC, Orbitron, and AGI-STK (System Tool Kit). Then, on regular basis, one of the procedure before tracking is updating TLE in the tracking tools.

LAPAN-A2 is the first Indonesian microsatellite which designed and developed in Indonesia. This satellite carries a mission as a disaster mitigation, take along Automatic Identification System (AIS) for ship identification purposes, and a video camera (space-cam). Other payload aboard in this satellite is Automatic Packet Reporting System (APRS) repeater for communication of ORARI (Indonesian Amateur Radio Organization).

LAPAN-A2 was launched in September 28th, 2015 in Sriharikotta, India. This satellite orbit in Low Earth Orbit (LEO) with altitude 630 km, and 6-degree orbit inclination (equatorial orbit) [8].

LAPAN-A3 is a joint remote sensing microsatellite between Indonesia National Institute of Aeronautics and Space (LAPAN) and Bogor Agricultural University (IPB). It carries mission in monitoring food resources in Indonesia and provides environmental monitoring. The satellite brings two cameras as it's payload. It was launched in June 22nd, 2016, in orbital LEO (Low Earth Orbit) in altitude 505 km with polar sun-synchronous orbit [9].

To support satellite missions, precise orbital satellite predictions are required. Hence, the TLE used in the tracking ought to be accurate. There are several researches on how to improve and minimize TLE errors. [4] analyzed additional optimization and the computational requirements for TLE. [5] and [6] provide analysis of TLE accuracy against GPS precision. Meanwhile in [7] an analysis of TLE consistency has been completed. The analysis of the formation of TLEs has been conducted in [3] and it is concluded that accuracy can be improved through mathematical techniques.

STK, stands for System Tools Kit is an astrodynamics computer program from Analytical Graphics, Inc., used to perform simulation of the satellite orbital, which provides important information needed in satellite tracking and as an assistance in determining satellite missions. Using outdated TLE, to the newest TLE in STK, this paper seeks to investigate the impact of using outdated TLE in satellites position determination.

This paper is organized into three main sections. Section II describes Two-Line Element Sets (TLE) used in the study, the example and TLE's code description. Section III describes material and method used in this paper. Section IV describes the simulations results and analysis.

II. Two-Line Element Sets

Two-Line Element Sets portrays satellite's motion in arranged format contains a reference epoch, satellite information such as launch date and year, and drag coefficient. TLE catalog is released publicly through NASA, www.space-track.org website, and http://www.celestrak.com/ and updated daily. The exact process of updating the TLEs is unknown, but in the essence, Joint Space Operation Center (JSPOC) operated by the US Air Force Space Command (AFSPC) performed the observations several times a day.

For better understanding of TLE, the example of LAPAN-A2 and LAPAN-A3 satellite's Two-Line Element Sets is presented in the appendix, and the description of each number in each line is disclosed in Table 4. A TLE set might include a title line prior to the element data in Line 1 and Line 2, thus each listing takes up three lines in the file.

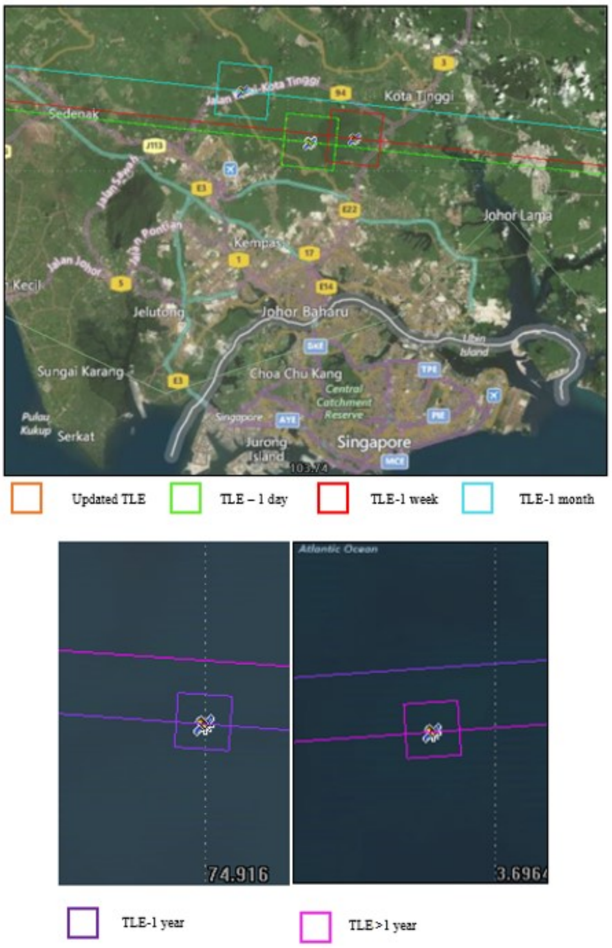


Fig. 1 LAPAN-A2 with 6 TLEs

III. Material and Method

In this paper, a simulation using Systems Tool Kit (STK) has been conducted. For the initialization, first, several TLE scenarios are set, starting from the newest TLE scenario, to the most outdated TLE scenario in the software. The newest TLE scenario for this study dated to May 21st, 2018. The outdated TLE scenarios set to 1-day TLE, 1-week TLE, 1-month TLE, 1-year TLE, and more than 1-year TLE scenario. Next, the parameters of satellites are arranged corresponding to LAPAN-A2 and LAPAN-A3 satellite's parameters. Then, the simulation time is scheduled from 0.00 to 06.00 UTC on May 21st, 2018.

A. Simulation on STK

In simulation, each satellite with six different age of TLE is observed. Then, orbital planes and positions of the satellite is being measured. Figure 1 and 2 demonstrate the simulation for LAPAN-A2 satellite and LAPAN-A3 satellite respectively.

From the figures, it is displayed that there are position errors for satellite with outdated TLE scenario. Later, LLA (Longitude, Latitude, and Altitude) report of the satellites with six TLE scenarios is generated. With reference point is set to the updated TLE scenario, the distance of each outdated TLE scenario, later stated as the position error is calculated.

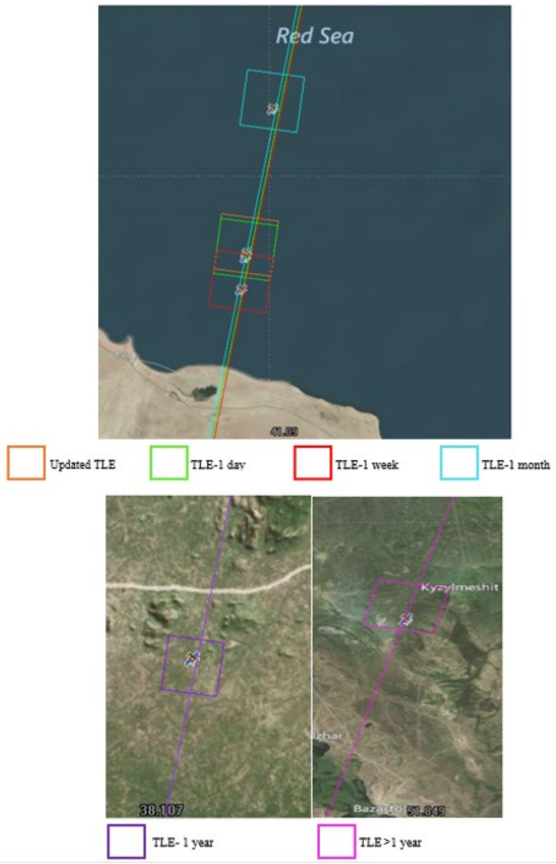


Fig. 2 LAPAN-A3 with 6 TLEs

B. Satellite's Position Error Calculation

Mathematically, the distance between satellite position with updated TLE scenario and each outdated scenario or as we called position error can be computed using Spherical Law of Cosines as shows in [9] - [11]. To apprehend this, assume there is point A and B with great circle distance as shown in figure 3.

978-1-5386-6031-7/18/$31.00 ©2018 IEEE

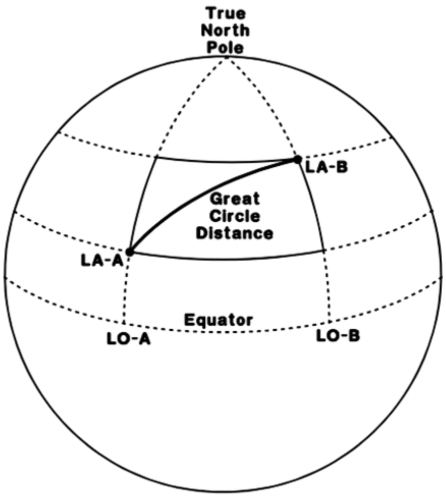


Fig. 3 Nomenclature for Great Circle Path Computation [12]

The difference in longitude between points A and B can be calculated with

$$\Delta\lambda = LO_A - LO_B \tag{1}$$

where $\Delta\lambda$ is difference longitude in degrees or radian, LO_A and LO_B is longitude of point A and B respectively. Next, the true bearing from point A to B and true bearing from point B to A can be calculated as in (2) and (3).

$$\theta_{A\rightarrow B} = \arctan\left[\frac{\sin(\Delta\lambda)}{\cos(\Phi_A).\tan(\Phi_B) - \sin(\Phi_A).\cos(\Delta\lambda)}\right], \tag{2}$$

$$\theta_{B\rightarrow A} = \arctan\left[\frac{\sin(\Delta\lambda)}{\cos(\Phi_A).\tan(\Phi_A) - \sin(\Phi_B).\cos(-\Delta\lambda)}\right], \tag{3}$$

with Φ_A as LA-A or latitude point of A and Φ_B as LA-B or latitude of point B. Suppose $\zeta = \sin\Phi_A.\sin\Phi_B$, and $\xi = \cos\Phi_1.\cos\Phi_2.\cos\Delta\lambda$, then we can determine the position error d as

$$d = \arccos[\zeta + \xi].\mathrm{R} \tag{4}$$

stating R as earth radius in km, with 111.19 for formula in degree and 6370 for formula is in radian.

C. Satellite Mission Simulation

This subsection illustrates the effect of error-position satellite to satellite mission. As mentioned before, LAPAN-A2 satellite's mission is for disaster mitigation and ship identification. With space-cam as its payload, the satellite has a very distinct requirement about the distance of mission's target to capture images needed. Even one degree of error could affect kilometres of shifting in capturing the images.

The mission simulation scenario is conducted to capture south coast of Singapore for 10 second along the ground track. If the mission's target is not aligned with satellite's ground track, it is required to do attitude control to turn the camera facing the designated target. Equation in figure 4 is used to calculate satellite's roll angle.

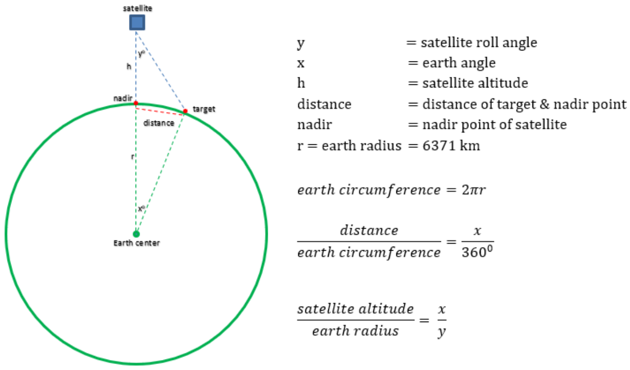


Fig. 4 Roll Angle Satellite calculation

Satellite with updated TLE and satellite with TLE 1-month, with average error position 3.551 km or 3.19 degree from satellite perspective are observed in the simulation. In both scenarios, the attitude control is set the same to face the target which fixed to roll angle 4.21°. Satellite's camera turned on for

Fig. 5 Satellite with updated TLE

Fig. 6 Satellite with 1-month TLE

10 second to capture area along the south coast of Singapore. Figure 5 and 6 shows the mission accomplishment between satellite with updated TLE and satellite with TLE 1-month old respectively. Satellite with TLE 1-month demonstrates significance shifting of the target mission track compared to satellite with updated TLE. Therefore, the satellite mission to observe ship identification and movement in south coast of Singapore will not be met in the case of outdated TLE satellite. This simulation shows the importance of updating TLE to the newest data before conducting missions.

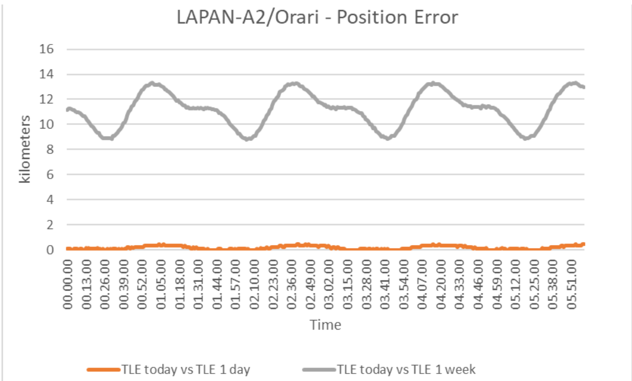
IV. Results and Analysis

Distance calculation performed with latitude-longitude values from generated STK LLA report from 00.00.00 to 06.00.00 with interval every 1 minute. Position error as a comparison between newest TLE and each outdated TLE scenario calculated separately. Comparison result then projected into a graph to show error difference between each outdated TLE scenario.

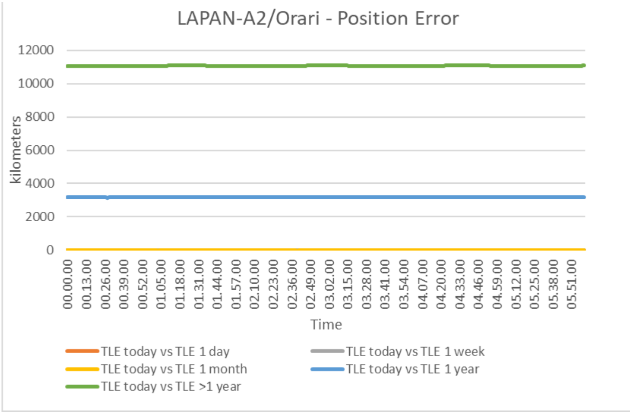
In graph 1, position error of TLE 1-day and TLE 1-week scenarios compared to updated TLE is presented. It does not show significant number where the average errors are 0.172 km and 11.179 km respectively. In comparison, graph 2 observes all positions error of outdated TLE scenarios. From the graph, it is clearly shown that TLE >1-year scenario gives massive number of error position with average error on 11059.055km, compared to 1-day TLE scenario. For more details, table 1 shows data sample of calculated error position every hour for LAPAN-A2 satellite.

Table 1 : LAPAN-A2 samples of error values per hour :

Time	Updated TLE vs TLE 1 day (km)	Updated TLE vs TLE 1 week (km)	Updated TLE vs TLE 1 month (km)	Updated TLE vs TLE 1 year (km)	Updated TLE vs TLE >1 year (km)
01.00.00	0.351	13.258	3.947	3179.752	11059.589
02.00.00	0.111	9.2736	5.648	3165.193	11043.239
03.00.00	0.332	11.555	4.877	3182.255	11087.098
04.00.00	0.222	11.483	4.473	3172.393	11039.635
05.00.00	0	11.119	6.131	3173.261	11068.208
06.00.00	0.443	12.964	4.108	3185.825	11078.081
average	0.172	11.179	5.041	3174.323	11059.055



Graph 1 Position error LAPAN-A2: Updated TLE vs TLE 1 day & 1 week



Graph 2 Position error LAPAN-A2: Updated TLE vs 5 outdated TLEs

In the case of LAPAN-A3/ IPB satelite, As we can see in graph 3, it shows some similarities in the results. Position error of 1-day TLE scenario and 1-week TLE scenario compared to updated TLE scenario does not show significant number where the average errors are 0.364 km and 12.892 km respectively. Nevertheless, if all outdated TLE combined in 1 graph, we can see in graph 4 that the comparison between position error of 1-day TLE scenario and TLE >1-year shows massive number of error position, about 10866 times (average error of TLE> 1-year scenario is 3955.272 km). Table 2 shows details of data sample from error position calculation in every hour for LAPAN-A3 satellite.

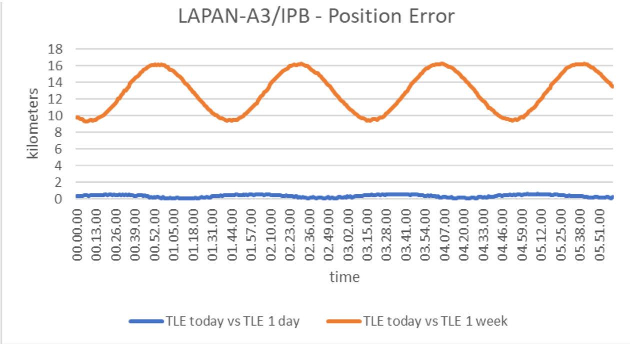
Table 2 : LAPAN-A3 samples of error values per hour :

Time	Updated TLE vs TLE 1 day (km)	Updated TLE vs TLE 1 week (km)	Updated TLE vs TLE 1 month (km)	Updated TLE vs TLE 1 year (km)	Updated TLE vs TLE >1 year (km)
01.00.00	0.129	15.916	2.877	3293.121	3938.564
02.00.00	0.533	11.435	4.041	3298.083	3916.755
03.00.00	0.242	11.463	3.259	3343.356	3954.289
04.00.00	0.350	16.086	3.377	3316.304	3991.243
05.00.00	0.588	9.829	4.223	3299.999	3977.295
06.00.00	0.239	13.476	3.146	3318.865	3943.328
average	0.364	12.892	3.551	3314.210	3955.272

In addition to the previous results, the comparison of average position error values from both satellites, is observed and presented in Table 3.

Table 3 : Comparison of average position error of LAPAN-A2 and LAPAN-A3

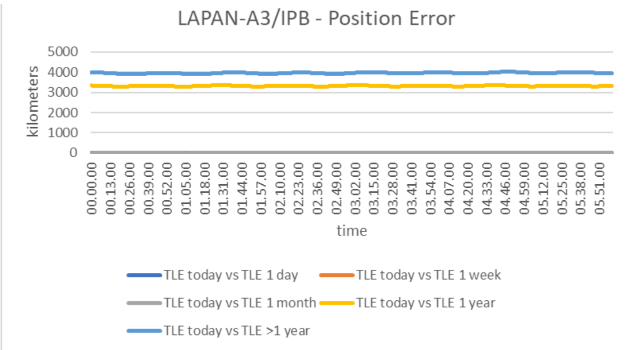
Satellite Name	Updated TLE vs TLE 1 day (km)	Updated TLE vs TLE 1 week (km)	Updated TLE vs TLE 1 month (km)	Updated TLE vs TLE 1 year (km)	Updated TLE vs TLE >1 year (km)
LAPAN-A2	0.172	11.179	5.041	3174.323	11059.055
LAPAN-A3	0.364	12.892	3.551	3314.210	3955.272



Graph 3 Position error LAPAN-A3 : Updated TLE vs TLE 1 day & 1 week

From Table 3, it is shown that average position error comparison of both satellites display various results. At one time, LAPAN-A2 have greater error number, and at another time, LAPAN-A3 have greater error number. This is occur because of differences in orbital plane of both satellites. LAPAN-A2 uses equatorial orbit with 6 degrees of inclination, while LAPAN-A3 uses polar sun-synchronous orbit.

From these results, it can be deduced that the more outdated the TLE is used, the greater the satellite position error occurred. With the significance of this error, the need for satellite prediction with high precision cannot be met. Hence, satellite's mission could not be accomplished accurately.



Graph 4 Position error LAPAN-A3 : Updated TLE vs 5 outdated TLEs

In addition to the requirements to maintain the satellite's attitudes in satellite tracking, the importance of updated TLE became very urgent for the need to download the necessary data from the satellite, such as image data, AIS, and so on. The time needed by the satellite to pass the coverage of the ground station is only around 11 minutes, whereas if the tracking software does not have an updated TLE, then there will be errors in determining the start of the download time. However, for the sake of downloading activity, it is possible to set a limit of the age of TLE in tracking software by observing the satellite position inside the ground station coverage.

Figure 7 and figure 8 shows the LAPAN-A2 and LAPAN-A3 satellites with various TLE scenarios inside a ground station coverage. The simulation on both satellites giving a similar result, and it can be concluded that for download activity, the age limit of TLE is until 1-month TLE. For 1-year TLE and more, the download activity is not possible to be executed,

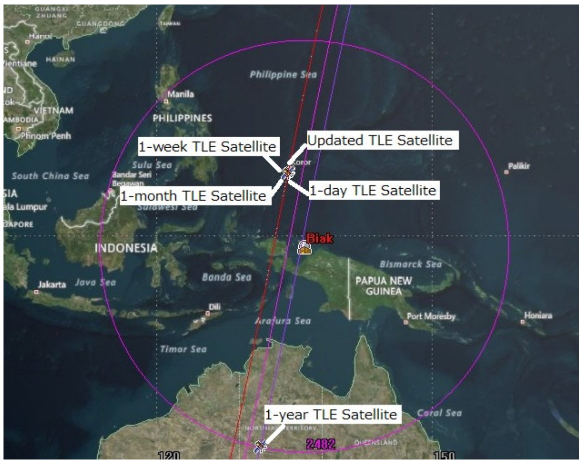


Fig. 8 Position of LAPAN-A3 Satellite in various TLE scenarios inside Biak ground station coverage

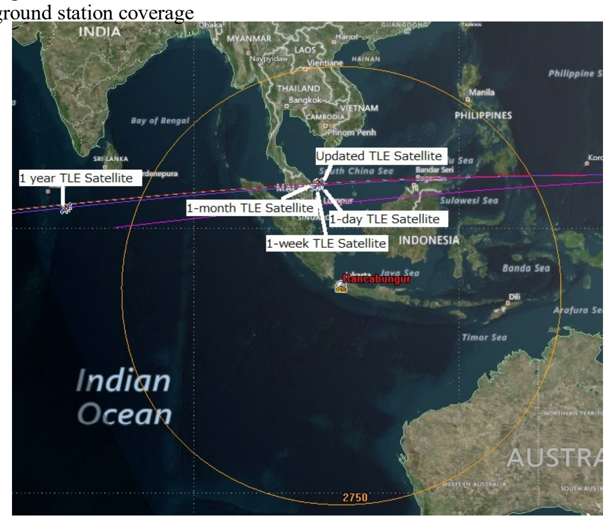


Fig. 7 Position of LAPAN-A2 Satellite in various TLE scenarios inside Rancabungur ground station coverage

because the satellite position is already out of the coverage of the ground station.

V. Conclusion

This paper has conducted visual simulation, calculations, and mission simulation for various TLE scenario in satellite tracking tools of LAPAN-A2 and LAPAN-A3 satellites. From simulation results, it can be concluded that outdated TLE affect position error in satellite tracking, and after calculation, the position error of the satellites is worsening along with outdated TLE. This results in inaccuracy of prediction on satellite position, that can lead to disturbance in satellite missions as demonstrated in satellite mission simulation. Thus, daily TLE update in satellite tracking activity is crucial to support satellite in conducting its missions and reaching its maximum performance. Another importance of updated TLE is displayed in the download activity, because the satellite position in some outdated TLE is already out of the coverage of the ground station. However, after observing the distance of each TLE scenario to the updated TLE scenario, there is a possibility to perform download activity with outdated TLE scenario limited to 1-month TLE.

APPENDIX

TLE of LAPAN-A2:

LAPAN-A2

1 40931U 15052B 18146.02593750 .00000721 00000-0 11407-4 0 9998

2 40931 5.9979 308.1657 0013399 51.3065 240.0850 14.76576768143715

TLE of LAPAN-A3:

LAPAN-A3

1 41603U 16040E 18146.80913697 .00000118 00000-0 87393-5 0 9993

2 41603 97.4124 208.7182 0012659 321.4085 148.2551 15.19560064106838

Table 4 : Line description of Two-Line Element Sets

Line 1	
Column	Description
01	Line Number of Element Data
03-07	Satellite Number
08	Classification (U=Unclassified)
10-11	Last two digit of launch year
12-14	Launch number of the year
15-17	Piece of the launch
19-20	Epoch year
21-32	Epoch (Day of the year)
34-43	First Time Derivative of the Mean Motion
45-52	Second Time derivative of the Mean Motion
54-61	Drag term
63	Ephemeris type
65-68	Element number
69	Checksum (modulo 10)
Line 2	
Column	Description
01	Line Number of Element Data
03-07	Satellite Number
09-16	Inclination
18-25	Right Ascension of the Ascending Node
27-33	Eccentricity
35-42	Argument of Perigee
44-51	Mean Anomaly
53-63	Mean Motion
64-68	Revolution number at epoch
69	Checksum

Ref: https://www.celestrak.com/NORAD/documentation/tle-fmt.asp

REFERENCES

[1] M. Davidoff, K2UBC, The Radio Amateur's Satellite Handbook. Connecticut: The American Radio Relay League, Inc., 1997.

[2] E. Kahr, O. Montenbruck, K. P. G. O'Keefe, "Estimation and Analysis of Two-Line Elements for Small Satellites", Journal of Spacecraft and Rockets, Vol. 50, No. 2 (2013), pp. 433-439.

[3] E.I Croitoru, G. Oancea, "Satellite Tracking Using NORAD Two Line Element Set Format," Scientific Research and Education in The Air Force-AFASES, 2016.

[4] C. Levit, "Improved Orbit Predictions Using Two-Line Elements," Advances in Space Research 47. 1107-1115. 2011.

[5] T. S. Kelso, "Validation of SGP4 and IS-GPS-200D Against GPS precission," 17th AAS/AIAA Space Flight Mechanics Conferene, AAS Paper 07-127, Jan. 2007.

[6] S. Aida, M. Kirschner, "Collision Risk Assessment and Operational Experiences for LEO Satellites at GSOC," Proceedings of the 21st International Symposium on Space Flight Dynamics, Sao Jose dos Campos, Brazil, 2011.

[7] P. Legendre, R. Garmier, B. Revelin, and S. Delavault, "Improvement of the TLE Accuracy Model Based on a Gaussian Mixture Depending on the Propagation Duration," AIAA/AAS Astrodynamics Specialist Conference and Exhibit, AIAA Paper 2008-6772, Aug. 2008.

[8] A. Wahyudiono, "Opportunity for Maritime surveilance based on LAPAN-A2/ORARI AIS and Spacecam Performance," Advance in Aerospace Science and Technology in Indonesia, Vol. I, 2016.

[9] C. T. Judianto, E. N. Nasser, "The Analysis of LAPAN-A3/IPB Satellite Image Data Simulation using High Data Rate Modem," The 1st International Symposium on LAPAN-IPB Satellite for Food Security and Environmental Monitoring, Procedia Environmental Sciences 24 pp. 285-296, 2015.

[10] J. J. Mwemezi, Y. Huang, "Optimal Facility Location on Spherical Surfaces: Algorithm and Application," New York Science Journal, 4(7), 2011.

[11] F. Ivis, "Calculating Geographic Distance: Concepts and Methods," Northeast SAS Users Group, 2006.

[12] W.D. Reeve, "Position, Distance, Bearing Calculations," 2014.

[13] A. Julzarika, "Utilization of LAPAN Satellite (TUBSAT, A2, and A3) in Supporting Indonesia's Potential as Maritime Center of the World," IOP Conference Series: Earth and Environmental Science, 2017.

[14] S.D. Harsono, "Tracking Satelit LAPAN-A2 Menggunakan Program Open Source," Seminar Nasional IPTEK Penerbangan dan Antariksa XX, 2016.

[15] Z. Zylshal, N. M. Sari, J. T. Nugroho, D. Kushardono, "Comparison of Spectral Characteristic between LAPAN-A3 and Sentinel-2A," IOP Conference Series: Earth and Environmental Science, 2017.

978-1-5386-6031-7/18/$31.00 ©2018 IEEE